VOLUME 2

INTERIM REPORT OF THE ASTRONOMY SPACELAB PAYLOADS STUDY

VOLUME 2
ULTRAVIOLET AND OPTICAL ASTRONOMY

PREPARED BY THE
ASTRONOMY SPACELAB PAYLOADS PROJECT

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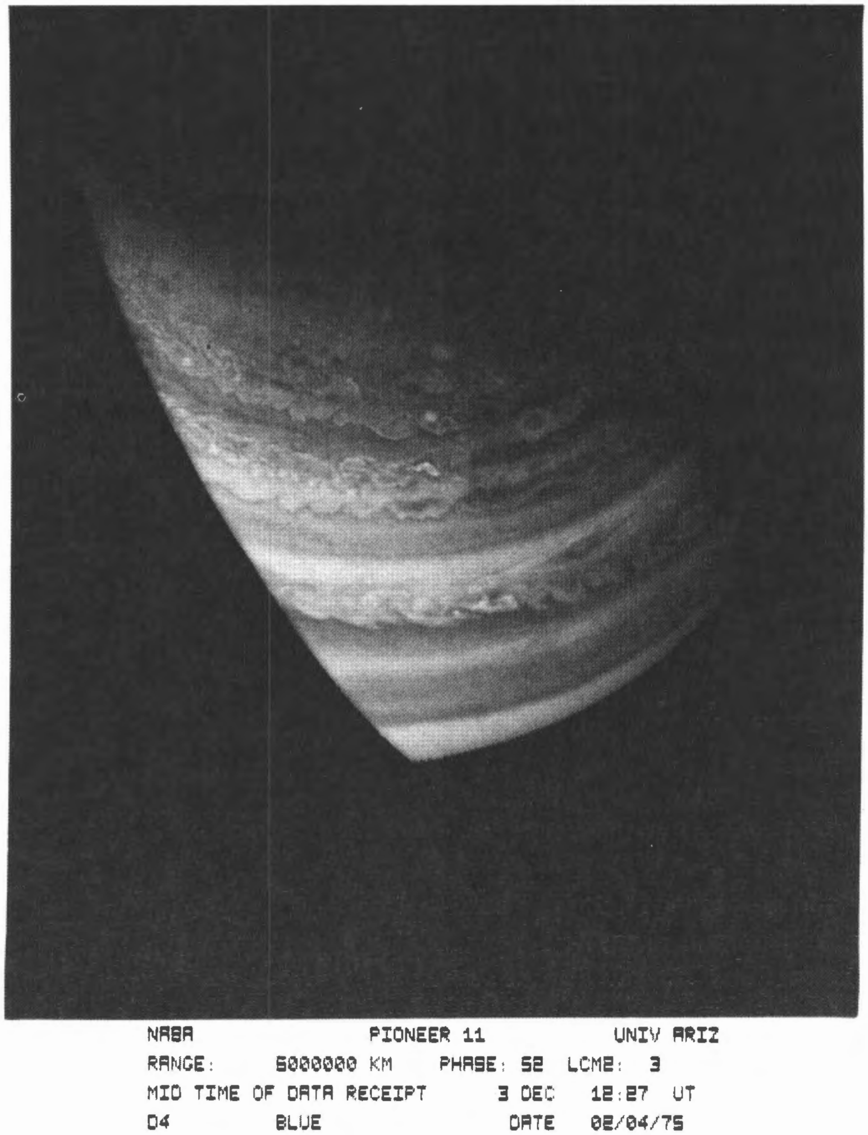

Frontispiece — Jupiter in blue light as observed by Pioneer 11 at a distance of 609,000 km on 3 December 1974 (photograph courtesy of Dr. Tom Gehrels, University of Arizona). The limiting linear resolution in this view is somewhat greater than 300 km. The excellent image quality provided by SUOT will allow spatial resolution on Jupiter from earth orbit equaling or exceeding that achieved by Pioneer 10 and 11. The flexibility of Spacelab operations will allow the use of instrumentation designed for specific research goals — e.g., narrow band interference filters to isolate and map specific spectral features. The FDT recommends that a planetary camera be carried on each flight of the SUOT to provide regular synoptic coverage.

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SECTION I.

SPACELAB UV-OPTICAL ASTRONOMY PAYLOADS STUDY OVERVIEW AND SUMMARY

A. Introduction

The Space Shuttle will comprise NASA's primary transportation system into near-earth orbit during the 1980s. The Shuttle will provide the astronomical community with a major new capability to send a wide variety of instrumentation into orbit, to utilize it there under manned or automatic control for periods from seven to thirty days, and to return it to the ground. To this end the European Space Research Organization (ESRO) is developing Spacelab, an array of interchangeable components - pressurized manned modules, unpressurized pallets and related support systems - to be mounted in the Shuttle payload bay.

Spacelab will offer important opportunities to carry out astronomical research with instruments optimized for specific objectives. With a high flight frequency and with the ability to modify or interchange telescopes and instruments between flights, one will not need to make rigid long-term commitments to specific and compromised telescope/instrument/detector combinations as is the case for automated satellites. Observational techniques demanding the physical return of data and equipment - in particular the use of photographic film, instruments requiring tight calibration controls, cryogens, high-risk detectors and degradeable optical coatings - will open research areas not readily addressed by automated satellites. Although Shuttle flight duration will be limited to periods from seven to thirty days, substantial data can be obtained with a single instrument on short missions, if targets are carefully selected and prioritized, and a large number of instruments can be accommodated on a single flight. Important astronomical data are regularly obtained on sounding rocket flights of five minutes duration. Spacelab will provide far longer observing periods for large and small telescopes, with resources greatly exceeding those of sounding rockets, while retaining much of the sounding rocket philosophy in terms of instrument flexibility, simplicity, reliability assurance and development costs.

The Ultraviolet and Optical Astronomy Program on Spacelab is being planned to provide optical astronomers with relatively simple and regular access to the extended wavelength coverage, the superior image quality and the darkness of the night sky available above the earth's atmosphere. In a rapidly evolving science one cannot predict what problems will be timely in the 1980s. Extrapolating from the current epoch, however, one can envision a continuing interest in such areas as the structure, composition and phenomenology of planetary surfaces and atmospheres; the composition and physical nature of the interstellar medium; the composition, structure and life history of stars, especially those in advanced stages of evolution; the stellar population of other galaxies; such enigmatic phenomena as X-ray binary black holes, pulsars, active galactic nuclei and quasars; large scale interactions between galaxies and the nature of the intergalactic medium; precise calibration of the Hubble law for the expansion of the universe; the average density of the universe; and the existence of extra-terrestrial life.

To begin the exploitation of the Shuttle-Spacelab potential for UV-Optical Stellar Astronomy in the era starting with the Orbiter flight tests in 1979-80 and continuing with Spacelab missions in the early 1980s, two facilities for the accommodation of scientific instruments are being defined by the Astronomy Spacelab Payloads (ASP) study at the Goddard Space Flight Center:

1. A general-purpose, one-meter class Spacelab UV-Optical Telescope (SUOT) facility, to be mounted on an ESRO-provided instrument pointing system (IPS), which will provide wavelength coverage from 90 to 4000 nm and images of excellent quality (0.2-0.3 arc sec) over a wide angular field (0.5°) to interchangeable focal plane instruments carried in groups of two to four on each flight, and

2. small instrument pointing systems (such as the SIPS or TIPS systems described elsewhere) which will provide three-axis stabilization, standard instrument canisters for thermal control and contamination protection, and command, data and power interfaces for relatively small, autonomous instruments analogous to those currently flown on sounding rockets, balloons and Explorer class satellites.

The feasibility of both facilities has been preliminarily established by current ASP studies.

The scientific requirements for the SUOT have been defined by a Facility Definition Team (FDT) of astronomers, formed by NASA AO #3. This team has established the potential of the SUOT to obtain unique astronomical data at the frontiers of research, and its ability to return from missions as short as seven days with significant quantities of data obtained with instruments optimized for specific research objectives. As now defined the SUOT's performance capabilities exceed those of any previous or planned space telescope except the LST, and it will excellently complement the capabilities of the LST. As a Spacelab payload, the SUOT's cost can be kept relatively low and its instrumentation flexibility over a ten year lifetime will be high. The SUOT can be available for flight by mid-1981 and can be reflown at least twice per year for ten years or longer. Some of its focal plane instruments, such as a wide-field direct imaging camera, a planetary camera, and a precise spectrophotometer-polarimeter will be of very broad interest and should become a part of the facility, whether developed by Principal Investigators or by NASA. A list of members of the FDT is included in their interim report, section II.A. of this volume, which outlines the FDT's preliminary concept for the SUOT facility, based on four months of team activities, December 1974, to March 1975. A brief interim report on the concurrent optical design study of the SUOT facility is given in section II.B. The FDT study and the optical design study provide the basis for the engineering systems analysis and facility conceptual design to be completed by August 1975. An interim report on this engineering study is available from Goddard Space Flight Center.

Small payloads of the sounding rocket or Explorer-satellite class can precede the first SUOT flight and will continue to fly as autonomous instruments for obtaining specialized data in parallel with SUOT and other facility telescopes developed later in the program. Candidate payloads of this type were identified by astronomers participating in the first Spacelab Astronomy Small Payloads Workshop, held at GSFC on February 13-14, 1975. Representatives from all currently identifiable United States groups with hardware experience in sounding rockets, balloons and airplanes in EUV, UV, Optical and IR astronomy were invited, as well as a representative from ESRO and GSFC engineers responsible for Spacelab astronomy subsystems development. Summary proceedings of the Workshop are given in section III.A. of this volume. We plan to reconvene this Workshop yearly to review Spacelab "small payloads" accommodations planning. In addition detailed engineering studies in this area will involve a continuing dialogue with individual experimenters. A detailed "small payloads" adaptation analysis, sponsored by the SAP study, is now underway at the University of Wisconsin. This study will identify problem areas and estimate costs in the modification of a currently existing sounding rocket payload design for use with Spacelab and SAP support subsystems and in the implementation of payload testing, integration, safety assurance and other procedures. An interim report on the Wisconsin study is given in Section III.B.

Sections I.B. and I.C. below summarize preliminary study results for the SUOT facility and for the "small payloads" support requirements definition, respectively. The SUOT facility and the representative payloads described at the Small Payloads Workshop form the basis for a model dedicated UV-Optical Astronomy mission, described in the Mission Analysis volume of this report and summarized in section I.D. below. The goals of this mission analysis include an evaluation of the adequacy of proposed Spacelab and ASP payload accommodations and the development of a realistic scenario for the efficient use of a large number (14 in this case) of instruments on a flight of limited duration.

Section I.E. discusses payload development schedules and costs and the major study conclusions are given in Section I.F.

B. Spacelab UV-Optical Telescope (SUOT) Facility Preliminary Study Summary

The SUOT Facility Definition Team has evaluated an extensive list of potential scientific applications of a one meter class, general purpose astronomical telescope for Spacelab on the basis of three criteria: (1) scientific merit, (2) complementarity to other proposed space observatories (especially the LST) and (3) major impact on the telescope facility design. Four illustrative areas of research which satisfied all three criteria were selected by the FDT for detailed investigation. These are:

1. high angular resolution or faint light imagery over wide fields,

2. far ultraviolet spectroscopy,

3. precisely calibrated spectrophotometry and spectropolarimetry,

4. solar system studies.

Specific research programs were identified in each area and illustrative focal plane instrument concepts for each area were suggested. Of particular importance, a preliminary estimate was made of the potential quality and quantity of data that might be returned in each area from a single Shuttle flight as short as 7 days. That potential is impressive.

The f/15 SUOT with a fully corrected 0.5° field, when carrying a large format electrograph or image tube camera, will have great impact on astronomical problems requiring high resolution or faint light imagery over fields significantly larger than the 2.5 arcmin field of the LST f/24 camera. These include stellar evolution in globular clusters (10-60 arcmin diameter), the history of star formation in nearby galaxies (12° for the Large Magellanic Cloud, 4° for M31, 34 arcmin for M81, 10 arcmin for the Virgo galaxies) and studies of intergalactic matter in clusters of galaxies (10 arcmin to several degrees). For many such problems, involving resolution of faint point sources on bright backgrounds or in crowded fields, SUOT will have a major advantage over any ground-based instrument. We anticipate a limiting magnitude for point sources near $V=25$ with a 30 min. exposure. With SUOT a definitive investigation of the properties of distance indicators in nearby galaxies and the identification of candidate distance indicators in galaxies as distant as 100 Mpc will strongly support the LST's program to precisely evaluate the Hubble law. For the first time the main sequence turnoff in nearby galaxies (e.g. surveys to $M_V \sim +6$ in the LMC) will be accessible with SUOT. Many globular clusters can be sampled for color and luminosity data to $M_V \sim 10$ with their central regions resolved, and galactic clusters can be searched for faint members, especially white dwarfs. In surveys for faint objects to a fixed limiting magnitude, SUOT will be more efficient than LST by a factor $\geqslant 7$, by virtue of its 100 times larger field area. The SUOT will be faster than LST by a factor of at least 2.6 for the study of faint extended objects, by virtue of its smaller f/ratio. The faint extended regions surrounding or interconnecting galaxies, important in studies of galaxy dynamics and evolution, will be accessible to SUOT to about 26 mag/arcsec^2 at reduced angular resolution, and SUOT may realize an important gain in such studies over ground-based telescopes, especially in the near-infrared, because of the darkness of the sky above the airglow.

The SUOT is the only space telescope currently envisioned which will be capable of continuing and significantly extending the important spectroscopic investigations in the 900-1150Å wavelength range begun by the Copernicus satellite. This will be possible because the SUOT can periodically fly with LiF overcoated primary optics on missions optimized for the far-UV, the rather large on-axis Rowland spectrograph required can be accommodated in the SUOT instrument bay, and the relatively high risk detectors required, developed in a constantly evolving detector technology, can be incorporated into the flight program on a short lead time basis. The SUOT will be much more efficient in collecting data in this difficult region than is Copernicus, and hence, will reach to significantly fainter magnitude limits. The far-UV spectral range is of great interest for studies of the interstellar gas, of the atmospheres of stars and, for two problems, of solar system objects. Detection of the higher Lyman series members of atomic deuterium (972Å, 950Å, 938Å, etc.) at high galactic latitudes, in interstellar matter somewhat isolated from the material processed through stars in the galactic disc, may provide the best estimate yet of the primordial D/H ratio and hence, of the present average density of the universe. Measurements of the Lyman system ($\lambda \leqslant 1106$Å) of molecular HD, when compared to measurements of H_2 ($\lambda \leqslant 1108$Å) and to the interstellar D/H ratio will provide insights into the rates of ion-molecule exchange reactions in interstellar clouds. The O VI lines at 1032-1038Å may be the only conspicuous tracer of the tenuous, high-temperature ($T > 10^5$°K) component of the interstellar medium and, with SUOT, they could be used to probe the galactic halo at great distances from the plane of the galaxy. The 1084Å line of N II and the 977Å line of C III are ideally suited as probes of the extent of zones of ionized hydrogen and helium around stars. The region shortward of 1150Å will be of great importance in the study of very hot stars such as white dwarfs or the central stars of planetary nebulae. The SUOT will be used to study X-ray binaries wherein the fainter but hotter companion may be observed at wavelengths shortward of the primary's blackbody cutoff.

Absolutely calibrated spectrophotometry is of fundamental interest to most areas of astrophysics. Space telescopes have unique advantages in making such measurements not only because they have access to the entire electromagnetic spectrum but also because they avoid the time-variable and wavelength-dependent absorption of the earth's atmosphere. The SUOT will be the first space telescope with adequate aperture and adequate calibration control to extend such measures to moderately faint stars, stars faint enough for use as reference standards by LST. This is facilitated in part by the capability to return SUOT to earth for post-flight calibration checks. A single flight would suffice for the establishment of an internally consistent system of 30 spectrophotometric standards well distributed over the sky, representing a dynamic range of more than 100 and calibrated from the Lyman limit to the redmost capability of photomultipliers - a most worthy project. On other flights the same instrumentation on SUOT would provide 10 Å bandpass UV spectrophotometry with one percent precision or better to limiting magnitudes $V \gtrsim 16$ for a variety of important targets. Such observations would:

- extend knowledge of the interstellar extinction law into the far ultraviolet,
- provide UV spectral energy distribution data for X-ray sources, faint blue stars, nuclei of planetary nebulae, Wolf-Rayet stars, dwarf novae, old novae, galactic nuclei, etc.
- establish empirical bolometric luminosities for individually resolved globular and galactic cluster stars,
- establish circumstellar and interstellar extinction properties for complexes of stars within H II regions,
- help discriminate among various models for Seyfert galaxy nuclei and serve to define more accurately the physical conditions in QSOs.

Moreover, the same instrumentation may be used for spectropolarimetry, with high angular resolution, of planetary surfaces, nebulae and the interstellar dust.

The high angular resolution, the accessibility to the IR and UV spectral regions and the ability to observe at small solar elongation angles will make SUOT a valuable tool for the study of planets, satellites and comets. A diffraction-limited planetary camera on SUOT will achieve spatial resolution on Jupiter, for example, equaling or exceeding that obtained by Pioneers 10 and 11. It could include a polarimeter and narrow-band filters to isolate and map individual spectral features over a planetary disc (e.g. bands of methane and ammonia, the sodium D lines, absorption features of minerals such as pyroxene). The FDT recommends that such a camera be carried on each SUOT flight to accommodate synoptic planetary studies. In addition, solar system investigations will profitably use spectrographs, a spectrophotometer and other instruments developed for other programs. Individual solar system objectives will include:

- mapping of distinct geological provinces on Mercury;
- observations of the 100m/s UV clouds on Venus, giving better understanding of zonal and meridional motions in its atmosphere; positive identification of the composition and size distribution of Venus' cloud particles;
- studies of initial stages of Martian dust storms, and of the relation between Martian water ice clouds and the large Martian volcanos;
- establishment of the zonal and meridional components of Jupiter's wind field to 0.2m/s precison and high resolution cloud morphology leading to a better understanding of Jupiter's general circulation; establishment of cloud heights and the planet-wide distribution of ammonia in the Jovian upper atmosphere; determination of the temporal and spatial distribution of ultraviolet absorbing aerosols on Jupiter; similar studies of the Saturnian atmosphere;
- a search for cloud structure on Uranus, providing the first accurate value of the planet's rotation period;
- a UV spectroscopic search in the atmospheres of Jupiter, Saturn and Titan for biologically important organic molecules;
- UV spectroscopy yielding the distribution of hydrogen and the isotopic abundances H/D around Jupiter, Saturn, Io and Titan; establishment of the argon abundance in the Martian atmosphere;
- High angular resolution IR spectroscopy yielding better localization and quantitative measure of H_2O vapor in the Jovian atmosphere.

Details of the scientific objectives, instrumentation and illustrative observing programs in these and other research areas may be found in the FDT preliminary report included in this volume.

The potential data return from relatively short Shuttle flights may be illustrated by assuming a flight of SUOT, carrying a wide field direct imaging camera, a far-UV spectrograph and the planetary camera. On the assumption of 96 orbits of data collection, with the direct imaging camera observing primarily in the earth's shadow, the far -UV spectrograph observing primarily in daylight and the planetary camera occupying short observing periods each day, the FDT found it possible, for example, to

- conduct a high angular resolution study of the stellar populations of M31, M32 and M33 to $M_v = +1$ - 42 exposures,
- explore at high resolution the structure of two supernova remnants (Crab, S 147) in the light of two ions sensitive to small changes in excitation and ionization - 12 exposures,
- search for very faint extensions in one radio galaxy (Fornax A) and one group of interacting galaxies (Stephen's Quartet) - 8 exposures,
- explore two clusters of galaxies (Perseus and Pegasus) for improved distance indicators, intergalactic matter and faint members - 18 exposures,
- survey three fields near the south galactic poles for faint blue members of the galactic halo, for QSOs and for faint clusters of galaxies - 15 exposures,
- obtain far-UV spectra (with a photometric precision of 1% in most cases) of 19 distant OB stars, 6 heavily reddened OB stars associated with dark interstellar dust clouds, 8 sub-dwarf O-type stars, 11 planetary nebula nuclei, 4 binary X-ray sources and 4 planets.
- obtain high angular resolution imaging of the bright planets in 6 photometric bandpasses and in one bandpass with four polarizers once each day for about six days.

Thus, although Shuttle flights as long as 30 days are highly desirable, substantial and important scientific data will be returned from flights as short as seven days, if one carefully selects and prioritizes observing targets.

The current concept of the SUOT facility is based upon a one-meter, f/15, Ritchey-Chretien telescope which, with a Gascoigne corrector and a field flattener, will provide a flat field 0.5 degrees in diameter with image diameters in the range 0.2-0.3 arcseconds (70% encircled energy) at wavelengths $> 2000\text{Å}$. Without refractive correctors it will provide similar image quality in a 0.1 degree flat field or a 0.2 degree curved field over the wavelength range determined by its optical coatings. The choice of f/15 is the best compromise between desired field size and the dimensions and linear resolution of currently envisioned electrographic or intensified photographic detectors. It is also dictated by the desire to provide full-field baffling, while still maintaining an obscuration ratio below 0.40, and by the difficultues of flattening the strongly curved field of a system as slow as f/30. The currently accepted optical parameters of the telescope are summarized in Table 1.

Table 1
Preliminary Optical Parameters for the
Spacelab UV-Optical Telescope Facility

Primary focal length	- 2.0m
Mirror separation	- 1.64m
Secondary focal length	- 0.42m
Image distance from secondary	- 2.73m
Back-focal distance	- 1.09m
Secondary magnification	- 7.5
Back-focal ratio	- 0.547
Pupil ratio	- 0.204
Exit pupil radius	- 0.1021m
Petzval radius	- 0.532m
Data field, 220-520 nm angular diameter	- $0\overset{\circ}{.}5$, corrected to 0.3 arcsec - $0\overset{\circ}{.}4$, corrected to 0.2 arcsec
linear diameter	- 0.130m
Data field, uncorrected and flat angular diameter	- $0\overset{\circ}{.}1$, image blur 0.2 arcsec
Data field, uncorrected and curved angular diameter	- $0\overset{\circ}{.}2$, image blur 0.2 arcsec
Image Motion Compensation field	
O.D	- $0\overset{\circ}{.}8$, 0.210m
I.D.	- $0\overset{\circ}{.}7$, 0.180m
Obscuration ratio	- 0.37

To preserve image quality in the 0.2-0.3 arcsec range, the telescope facility will provide internal image motion compensation to 0.02 arcsec (1 σ) or better by articulation of the secondary mirror. Error signals in pitch and yaw will be generated by focal plane startrackers, imaging stars brighter than V = 13 in an annular tracking field surrounding the data field. Roll control will be provided by the telescope's gimballed mount, which is currently assumed to be a standard Instrument Pointing System (IPS) developed by ESRO as a Spacelab subsystem. The telescope facility thermal control system will maintain a room temperature environment (= 21°C) within the telescope and within the instrument bay throughout a mission.

Figures 1 and 2 illustrate a preliminary SUOT layout and Table 2 summarizes the basic system parameters. The FDT desires that at least four focal plane devices (not including startrackers) be carried on each flight. These are:

- at least two major scientific instruments, interchangeable with other instruments between flights,
- a planetary camera for synoptic coverage,
- a field acquisition and verification TV camera (with a 1000 line TV monitor at the Payload Specialist Station).

The minimum number of two major instruments per flight is dictated both by requirements for redundancy (if one instrument fails, as some will in a low-cost program, scientific data may continue to be taken with the other) and by the desire to make full use of the time in orbit. For the latter, faint light instruments requiring observations in the earth's shadow may be paired with other instruments amenable to use in sunlight. Some focal plane instruments, such as a wide-field direct imaging camera, a planetary camera, and a precisely calibrated spectrophotometer, are of very broad interest and should become part of the facility, whether developed by P.I.'s or by NASA. A variety of more specialized instruments can also be accommodated.

The instrument bay layout illustrated in Figures 1 and 2 provides a very flexible arrangement for mounting a wide variety of instrument types. Relay mirrors coupled to a rotatable instrument selector turret feed the f/15 beam to the radial instrument area, to the acquisition camera and to the planetary camera. The axial instrument area receives the telescope beam directly. The possibility of "serendipity" observing modes with both radial and axial instruments in simultaneous use is being considered. The axial instrument area will hold one or more relatively narrow field instruments that require minimal reflective light losses or polarization, such as a far-UV spectrograph or a spectrophotometer/polarimeter. It will accommodate instruments up to 1.5m in length. The radial instrument area will hold instruments utilizing the full 0.5° corrected field of view - a variety of cameras or perhaps an astrometric instrument. It is being sized to hold the rather large and bulky magnetically focussed, image intensifier cameras of the kind now used in Air Force photo-reconnaissance and should provide adequate volume for a variety of instruments. Simple access to the radial instrument area during flight will facilitate the interchange of film packs on extended missions. Doors will also be provided to allow emergency access to the instrument selector turret and to the axial instrument area.

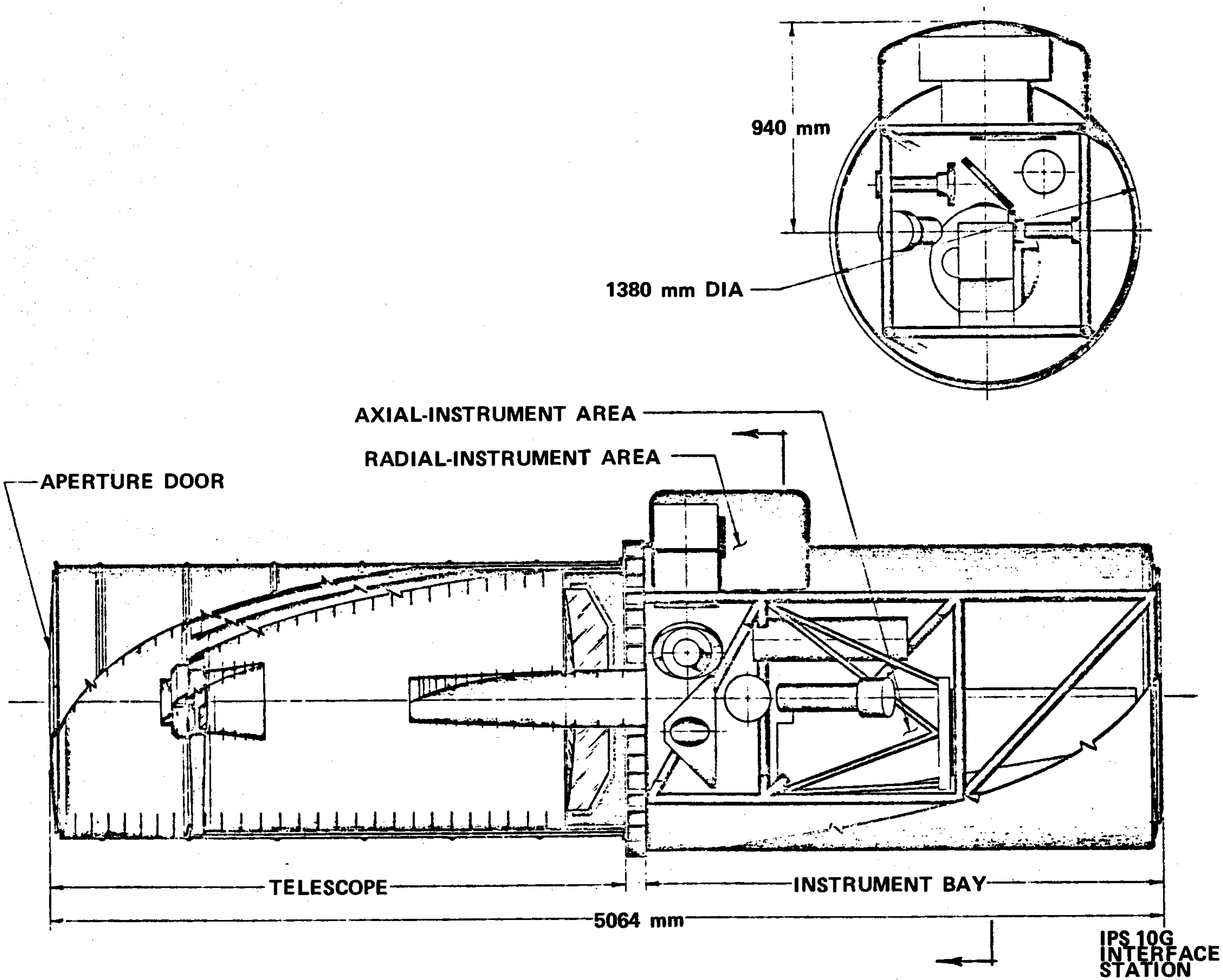

Figure 1. Preliminary Concept for the One-Meter Spacelab UV-Optical Telescope Facility

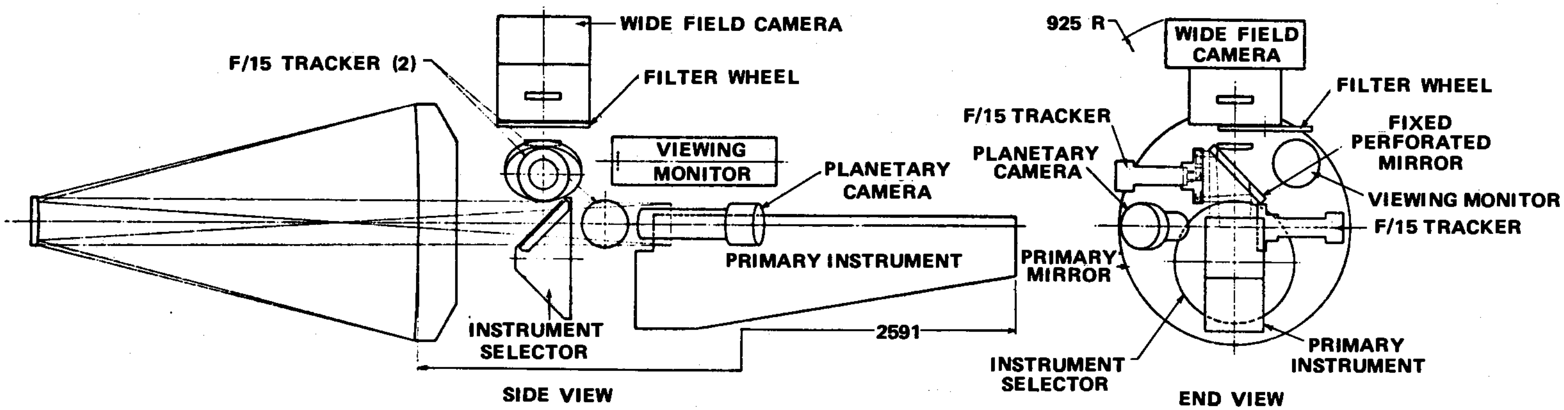

Figure 2. Preliminary Instrument Accommodation Concept for Spacelab UV-Optical Telescope Facility

Table 2
Physical Parameters for Spacelab
UV-Optical Telescope Facility

Telescope dimensions (m)		
length	-	5.064
diameter	-	1.380
radial instrument extension	-	0.940
Instrument bay volume (mxmxm) accommodations for single flight		
radial instrument location	-	0.50 × 0.50 × 0.50
axial instrument location	-	1.50 × 1.00 × 0.50
TV field monitor	-	0.75 × 0.25 × 0.25
planetary camera	-	0.50 × 0.25 × 0.25
additional small instrument	-	0.50 × 0.25 × 0.25
plus two star-trackers for pointing and IMC control		
Resonant frequencies (Hz)	-	23.6, launch
(graphite epoxy shell structure, honeycomb instrument bay structure)	-	13.4, orbital
Telescope mass (kg)		
telescope optical structure	-	34
secondary structure	-	104.3
optics (primary mirror)	-	349 (252)
instrument bay structure	-	549
star-trackers, TV monitor	-	63.5
electronics	-	31.8
cabling, bracketing and hardware	-	170
telescope facility subtotal	-	1301.6
representative instruments		442.7
total		1744.3 [1]
Telescope heater power (watts)		
inner baffle (lm length)	-	175
primary mirror	-	5
secondary mirror	-	30
metering structure	-	12
heater power subtotal		222

Table 2 (continued)

Telescoping operating power (watts)		
star-trackers	-	20
TV-monitor	-	80
secondary mirror	-	6
instrument selector	-	2
command data interface unit	-	10
operating power subtotal	-	118
Representative instrument power (watts)		
spectrograph	-	140
planetary camera	-	70
direct imaging camera	-	162
instrument subtotal	-	372
Total system power (watts)	-	712
Remote Acquisition Units (command and data requirements)		
discrete commands	-	100
serial command bits	-	300
serial digital channels	-	7 channels at 2kbps
analog channels	-	200 channels at 10 bits resolution
single bits	-	420
Pointing accuracy (arcsec)		
pitch and yaw (1 σ)	-	±1
roll (1 σ)	-	±50
Pointing stability (arcsec)		
gimbal mount p and y (1σ)	-	±2
gimbal mount roll (1 σ)	-	±4
image motion compensation, p and y (1 σ)	-	±0.02
Pointing special requirements[2]		
raster scan rates	-	1.3 arcsec/sec maximum
	-	0.001 arcsec/ sec minimum
free-drift tracking	-	0.064 degree/sec, 20-30 minutes
slew rate	-	30 degrees/min

Table 2 (continued)

Thermal environment (internal)	
operating range, primary optics	- 21°C ± TBD
operating range, instrument bay	- 21°C ± 5°C
longitudinal gradient	- TBD
transverse gradient	- TBD

(1) Note 113kg of the total is due to structural stiffening for compatability with ESRO inside-out gimbal IPS.
(2) Unanticipated image displacements in IPS $>$ 0.02 arcsec must not occur in time interval $<$ 0.2 sec.

Two sets of primary optics are currently envisioned for the SUOT facility. One set will be overcoated with MgF_2 for routine use on the majority of flights. The other set will be LiF overcoated and carefully maintained for use on missions optimized for the far-UV. The telescope structure will be adequately sealable to maintain an internal dry nitrogen atmosphere during integration, to allow a dry N_2 purge during launch, ascent and descent and to protect the system from contamination in orbit (by RCS thruster exhaust for example). The possibility of interchanging both primary and secondary mirrors to convert SUOT to a very fast Bowen-Vaughn camera for wide-field photographic work was also considered and rejected. The same objectives might be accomplished by use of a simple focal reducing lens in a focal plane camera.

Figure 3 provides a schematic view of the deployed SUOT facility mounted on the Spacelab Instrument Pointing System, attached to Spacelab pallets. The 5m long SUOT will occupy two 3m pallet elements when stowed for launch and landing and hence, will occupy 40% of the payload volume in a 5 pallet Spacelab flight configuration. The tie-down hardware for stowage is illustrated. The total estimated weight of the SUOT facility, a representative set of focal plane instruments, the IPS and other payload-chargeable hardware is approximately 2900 kg.

The SUOT is being defined to provide a benign environment and relatively simple interfaces for a variety of user-provided focal plane instruments. It will, therefore, be a rather sophisticated facility. By virture of this sophistication, it will relieve the astronomical community of a substantial design burden with respect to the focal plane instruments and will hopefully permit the development of such instruments at low cost, on a best-effort engineering model basis, by groups at universities and at private or government institutions.

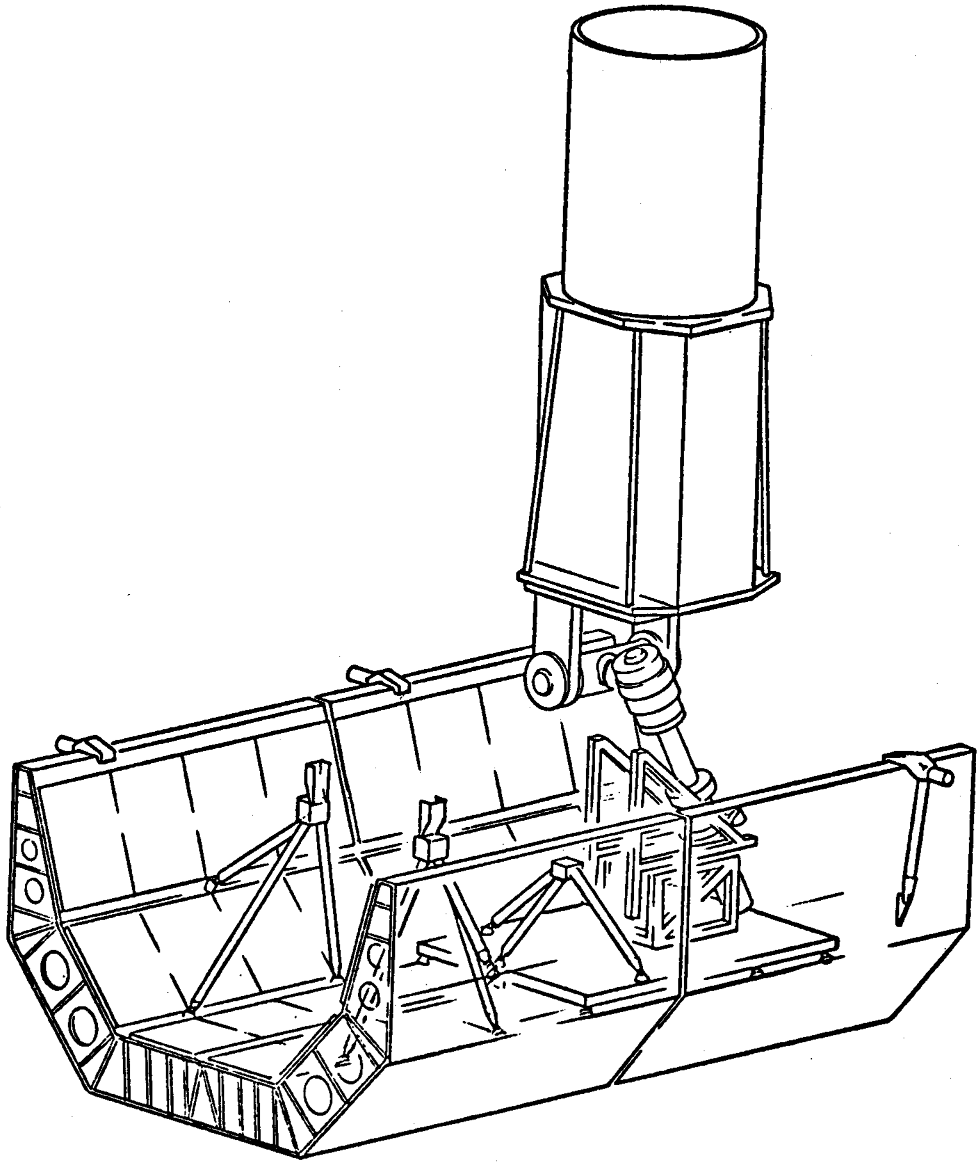

Figure 3. Spacelab UV-Optical Telescope Facility
Pallet-Mounted and Deployed

C. Small Astronomy Payloads Accommodations Preliminary Study Summary

Shuttle Spacelab flights of seven days duration or longer will offer astronomers the opportunity to utilize special purpose instruments, comparable to those currently flown on sounding rockets, with observing times, spacecraft support facilities and operational flexibility far exceeding that now available in rocket astronomy. The ASP study is now defining feasible concepts for the use of such payloads in the Shuttle orbiter test flights and in Spacelab. For the purposes of the GSFC Small Payloads Workshop, a "small payload" was loosely defined as one with a minor impact on the complete Spacelab system, a short lead time for development and a relatively low cost. It should weigh 450 kg or less and be smaller than one Spacelab pallet element (3m length). Pointing and stabilization requirements should be in the arc second range. Some payloads discussed at the Workshop exceed these guidelines but will nevertheless remain under consideration.

Participants at the Workshop were asked primarily to describe currently existing payloads of this type, or payloads currently in the planning stage, so as to provide a realistic set of subsystems requirements. It was not expected that the scientific programs described would necessarily be the same as those of greatest interest in the early 1980s. Nevertheless, a number of very interesting projects were outlined and these serve to illustrate the kinds of tasks one might undertake.

A sample of these is given below:

- Very high resolution ($\lambda / \Delta \lambda = 3 \times 10^5$) far ultraviolet spectroscopy for interstellar matter research, including measurement of the temperature of the tenuous un-ionized intercloud medium; studies of the physical differences between H I and H II regions by velocity separation of their absorption lines; studies of the rates of formation, destruction and rotational excitation of H_2 by velocity separation of high and low rotation temperature components; precise determination of interstellar gas densities in the vicinity of the Sun. The required spectrograph is novel, requiring the full length of the payload bay but being only about 15 cm in cross-sectional diameter (a long stovepipe). It is of "sounding rocket class" in that it is lightweight (< 50 kg), inexpensive, conceptually simple and designed to accomplish a special class of observations outside the capability of a general telescope facility.

- A far-ultraviolet (1050-2000Å) direct imaging and spectroscopic sky survey by use of a pair of small electrographic Schmidt camera/

spectrograph units, flown routinely on many Spacelab missions. The system would reach in 20 min exposures V = 18 (equivalent unreddened B0 stars) in direct imagery, V = 11 for 2Å resolution spectroscopy and V = 9.5 for 0.5Å resolution spectroscopy to provide a wealth of data on stars, nebulae, galaxies and quasars.

- Narrow-band, infrared photometry in the 4 to 30 μm wavelength range of small discrete sources and of diffuse sources of large angular extent. Objectives include spectral and spatial mapping of the zodiacal cloud to identify compositional classes of the emitting particles; definition of the spectrum of the cosmic background in the middle IR for use in cosmological studies; survey of the galactic plane for extended regions of non-thermal emission; extension of present surveys for IR point sources to faint limiting magnitudes; a detailed IR survey of the Virgo cluster of galaxies. The observations would be made with a small, cryogenically cooled (LHe) telescope.

- A coarse angular resolution (10 arcmin) survey for extreme ultraviolet (100-1000Å) sources. Radiation at these wavelengths is extremely important in the investigation of the atmospheres of the hottest stars and of other energetic sources. However, it is heavily absorbed in the interstellar medium. A relatively small, inexpensive, grazing incidence imaging telescope, flown on Spacelab, would establish whether such sources are detectable in advance of the development of more elaborate facilities for their study.

- Establishment of a precise absolute energy calibration for a network of about 40 early-type stars brighter than V = 6 in the spectral interval 925-3400Å. Any member of this group of carefully measured stars would serve as a secondary standard of absolute flux for other UV telescopes in orbit. This program is facilitated by the capability for in orbit calibration checks and post-flight calibration provided by Spacelab. Two flights spaced at seasons six months apart would be required to assure uniformity of the network around the sky.

- Imaging of faint surface brightness objects, such as supernova remnants, planetary nebulae, emission and reflection nebulae, and galaxies in the ultraviolet light of high excitation forbidden lines of O II, O III, Ne III, Ne IV and Ne V to determine temperature and density structure as a function of spatial position. The program uses a Schwarzschild camera, either with broad-band filters or an objective grating, which can record 19th visual magnitudes per square arcsec in a 20 minute exposure.

- Polarization measurements of stars and other galactic sources, the zodiacal cloud and the earth's airglow in the spectral range 1500 to 4100Å. The required instrument, consisting of seven UV polarimeters, is very small (20 cm × 35 cm) and could readily share payload accommodations with another instrument. A V = 10 A0 V star can be observed with a one percent precision in about 100 seconds integration time.

- Near ultraviolet (2000-3400Å) spectroscopic investigations of stellar chromospheres, dynamics of extended atmospheres of supergiants and Wolf-Rayet stars, mass transfer in close binaries including X-ray binaries, chemical abundances in stellar atmospheres and chemical abundances and electron temperatures in the interstellar medium. The instrument is a currently existing balloon payload, a telescope and high-resolution echelle spectrograph, which includes a complete pointing system, possibly adaptable to Shuttle use even for early test flights when standard pointing systems may not yet be available.

Table 3 summarizes support requirements data for a sample of the payloads discussed at the Small Payloads Workshop. Additional information may be found in the Workshop proceedings, section III.A. of this volume.

The primary support subsystem currently envisioned for the accommodation of small payloads is a pointing system containing one or two rather large canisters to provide thermal control, acoustic noise protection, purge capability and contamination protection. This Small Instrument Pointing System (SIPS) was originally conceived as a two-axis system, based on OSO-H pointing controls, to point solar physics instruments as large as the ATM class with 1 arcsec accuracy and stability. Its adaptation for use with stellar payloads by the addition of an optional roll axis and a star-tracker/rate integrating gyro package has been established as feasible and effective.

The SIPS is described in detail in the Engineering Volume of this report. In summary it consists of a central deployable pedestal to which may be mounted two semi-independent fine altitude and azimuth controls. The pedestal itself provides coarse azimuth control. Each fine control system can hold a canister containing one or more scientific instruments and each provides about 20° of angular freedom in azimuth and about 120° freedom in altitude. The SIPS configuration on a Spacelab pallet and the current canister concept are illustrated in Figures 4 and 5, respectively. The canister frame will be the primary interface for the user and may be kept at his home institution during the assembly, mounting and checkout of his instrument. Observers willing to time-share in orbit - e.g. those with limited target lists or those whose instruments can be used in sunlight or in darkness - may share a canister. The largest canister for use in the two-axis SIPS will accommodate instruments weighing $\leqslant$ 340 kg

Table 3
Sample Small Payloads Support Requirements

Experiment	Weight	Size	Shape	Orbit: Alt.	Orbit: Inclin.	Minimum Observation Time: /Orbit	Minimum Observation Time: /Flight	Pointing/Viewing Requirements	Power Requirements Unless noted: Does not Include Thermal Control
Schmidt Cameras	60 kg each	115 cm x 55 cm x 30 cm	Cylinder	Any	–	30 min.	4200 orbits over many flights	$\pm 1°$ accuracy; ± 20 arc sec stability for 20 minutes	5W continuous 20W for monitor pulsed 6W/ .5 sec for film advance
Schwarzschild Camera	161.5 kg	.38m dia. x 1.9mL	Cylinder	200 km to 630 km	0 to 57°	–	7-28 days	$>90°$ from sun., $>15°$ from earth 360 arc sec accuracy, 1 sec. stability	16W 28V 80W 32V 130W 20V
Cryo-cooled I.R. Telescope	171 kg	.508m dia. x 1.38mL	Cylinder	400 km	$\approx 28°$ depends on observation		7 day Mission	1 arc min. accuracy; 20 arc sec stabil. $>30°$ from any structure, sun, moon, or earth	150W 28V
EUV Imaging Telescope	150 kg	43.8 cm dia. x 250 cm L	Cylinder	≥ 100 km	-	1 min to 90 min.	>5 days reqrd.	$\pm 15°$ clear field of view reqrd. $\pm 1°$ pointing – not closer than 30° to sun	12 watts
Microchannel Spectrometer	17 kg	16.5 cm W 26.8 cm H 167 cm L	Rect.	160 km	-	10 sec to 1 hour	Nominal Mission Time	$\pm 10°$ field of view, ± 1 arc min accuracy, avoid sunlight in aperture	42 watts @ 28V
UV Polarimeter	2.7 kg	19.7 cm dia. x 34.4 cm L	Cylinder	200 km	-	-	Nominal Mission Time	4° FOV full angle ± 1 arc min.	2 watts
EUV Spectrometer	15.8 kg	17.8 cm x 65 cm x 26.8 cm	Rect.	260 km	-	-	>5 days	$\pm 30°$ clear field of view various programmed scans	10 watts
UV Photometer	90 kg	38 cm dia. 196 cm L	Cylinder	300 km	-	20 min per single pointing	7 days	Two 1 week flights separated by 6 months, accuracy ± 15 arc sec; ± 5 arc sec stabil; FOV $\pm .50$ degrees	100 watts
IUE Spectrograph	107 kg	60 cm dia. 300 cm L	Cylinder	≥ 200 km	$\approx 28°$	10 min.	5 days	1 arc min accuracy in P&Y, 1° in Roll; 1° Roll, .25 arc sec P&Y Stability	185 watts avg.

Table 3 (Continued)

Experiment	Data Requirements				Mechanical Systems	Special Requirements	Special Safety Considerations	Source of Information
	Rate	Real* Time	Cmd's	Stored Data Vol.				
Schmidt Camera	Analog 30 bps		Min. 2	Film	SIPS Cannister Mount	Operate dark portions of orbit Protect film from heat	Dry Nitrogen or dry air RH $<$ 10% until launch, operating pressure $< 10^{-5}$ Torr	SP Workshops
Schwarzschild Camera	Analog 30 bps		Min. 2	Film	SIPS Cannister Mount	Observe during orbital night	Pressurize Camera (N_2)	SP Workshop
Cryo-Cooled I.R. Telescope	10^6 bit/Day	-	-	60 K 16 bit Mem.	SIPS Cannister Mount	Sun Shade	18 kg liquid Helium	SP Workshop
EUV Imaging Telescope	20 Kbps	–	4 analog output	Record of aspect angle	SIPS Cannister Mount	Door Access to Electronics	None	SP Workshop
Micro Channel Spectrometer	5×10^5 bps	-	TBD Required	PDP-11 or equivalent 1024, 16 bit words	SIPS Canister Mount	Manned Support desired	None	SP Workshop
UV Polarimeter	1 Kbps	60 bps		Required	SIPS Cannister Mount	Manned Support desired	None	SP Workshop
EUV Spectrometer	up to 10 Kbs contin. 40 Kbps 5 min.	-	10 lines	Record of aspect angle	SIPS Cannister Mount	Purge with dry N_2 until before launch	None	SP Workshop
UV Photometer	2.7×10^7 bits per day	500 bps	30 command lines	Required	SIPS Cannister Mount	N_2 purge, Cal. check during int. and test	None	SP Workshop
IUE	40 Kbps	-			SIPS Cannister Mount	Quicklook spectra and acquisition TV at GSFC	None	I.U.E. Tech Note IUE-701-73-015

Table 3 (Continued)

Experiment	Initial Prep. Time	Turn Around Time Bet. Miss.	Preflight Support Requirements	Ground Support Equipment	Integration Support		Testing (Test Plans, Rept's & Review)	Inflight Support Requirements	Postflight Support Requirements
					Hardware	Software			
Schmidt Cameras	4-8 wks	2 wks	Payload kept at < 10% RH	Minimal for film type payload	√	None	TBD	Command capability	Access for film retrieval
Schwarzschild Camera	20 wks	6 wks	Dry N_2 flush	Darkroom	√	None	TBD	Command cap.; retrieval of film (EVA 2) or keep cool	No req. except for film
Cyro-cooled I.R. Telescope	3 years	8 wks	Electronic check out & LHe fill	Capability of filling LHe	√	√	TBD	Manned support reqrd. to operate tel. / gimbals	Provide aspect to 30′ in 3 axes
EUV Imaging Telescope	Will be complete by 1978	4 wks	Monitor of 4 analog outputs	Electronic access to exp readouts	√	√	TBD	None	Provide aspect to 30′ in 3 axes
Microchannel Spectrometer		4 wks	Determine proper operation of exp. & processing electronics	Computer onboard or ground & displays test facilities	√	√	TBD	Prefer manned support but not required	None
UV Polarimeter	18 mos	5 wks	Adequate time to ensure proper operation of experiment	Compatible computer for onboard mini computer	√	√	TBD	Manned support desired	None
EUV Spectrometer	Complete by 1979	4 wks	Purge with dry N_2 until launch @1 cu. ft./hr	Provide minimal support to produce data for preflight checks	√	√	TBD	None	Provide aspect to 30′ in 3 axes
UV Photometer	Initiate + 12 mos	6 mos	Dry N_2 purge	Test & cal. equipment	√	√	TBD	None	Would like to repurge
IUE Spectrograph	24 mos	TBD	Elec. or hdwire access to exp.	Computers TV displays	√	√	TBD	Access to spectra in some form and T.V. acq. picts.	None

Table 3 (Continued)

Experiment	Thermal		Vibration*		Acoustic*		Electromagnetic Radiation		Chemical Contamination		Magnetic Fields		Trapped/ Nuclear Radiation	
	Accept.	Gener.	Accept.	Gener.	Accept.	Gener.	Accept.	Gener.	Accept.	Gener.	Accept.	Gener.	Accept.	Gener.
Schmidt Camera	10°C to 35°C operating, 10°C non. op.	TBD	TBD	TBD	TBD	TBD	TBD	TBD	8 hrs. out-gassing before turnon	TBD	TBD	TBD	TBD	TBD
Schwarzschild Camera	20°C ± 15°C	Remove 100 W From Focus Coil	TBD	TBD	70 db operating 130 db non-operating	TBD	TBD	TBD	TBD	TBD	TBD	TBD	2.78×10^{-11} J/Kg/s	TBD
Cyro-Cooled I.R. Telescope	10°C ± 30°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
EUV Imaging Telescope	5°C to 45°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Microchannel Spectrometer	-40°C to +50°	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
UV Polarimeter	±40°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
EUV Spectrometer	-40°C + 55°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
UV Photometer	-40°C to +100°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD
IUE	10 ± 10°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD

*All except IUE can withstand Aerobee 170 protoflight environment.

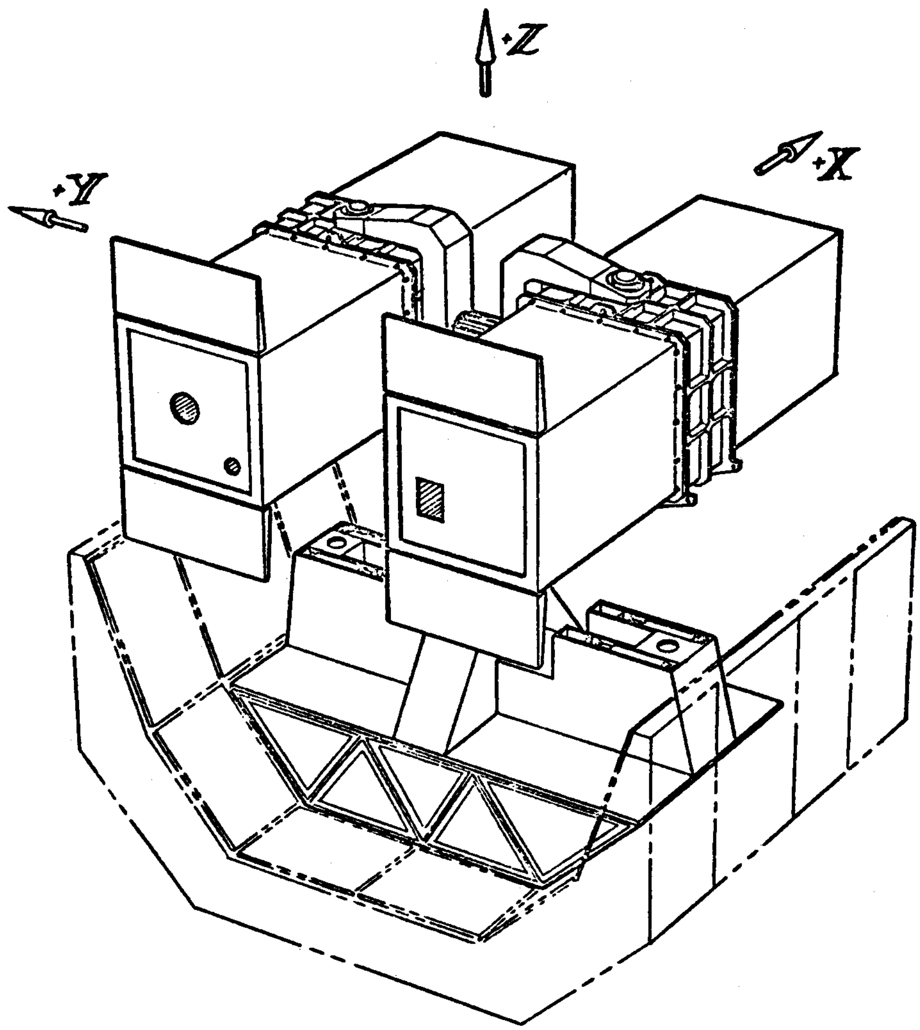

Figure 4. SIPS Nominal-Instrument Configuration

in an envelope 0.9 × 0.9 × 3.1m. An optional inner roll gimbal, providing fine roll stabilization as well as ±90° roll orientation, will limit instrument diameters to sizes no less than 0.6m. Further investigations will consider the accommodation of side-looking and cryogenically cooled payloads. In addition a Tiny Instrument Pointing System (TIPS) for the accommodation of instruments in the 100 kg weight class, independently pointed and stabilized to about 10 arcsec, is being considered. The TIPS system will be based on current Aerobee sounding rocket pointing controls.

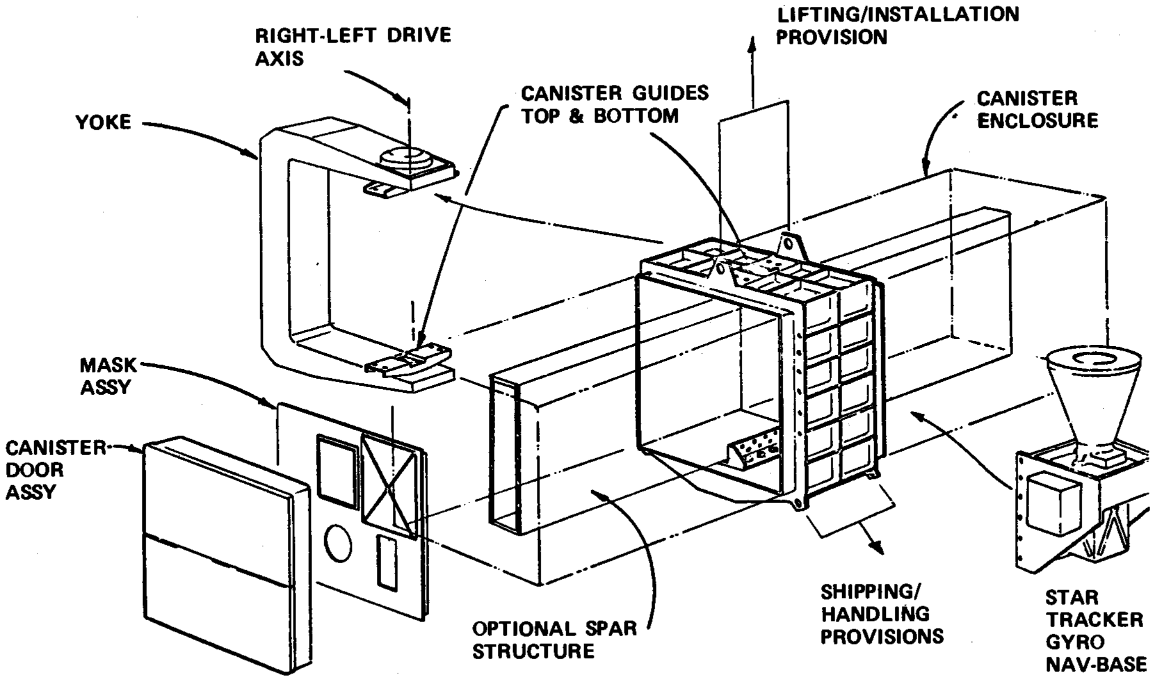

Figure 5. Preliminary SIPS Cannister Concept

The current philosophy of the sounding rocket program for small payload accommodation should be followed in the Spacelab program if scientific viability and instrument costs per observing second are to be maintained at an attractive level. To this end the experimenter must be able to easily integrate and deintegrate his payload, have access to it at specified times during the integration process and operate it (or even have it fail) during a flight without interfering with other payloads. Interface simplicity was a recurring theme at the Small Payloads Workshop and remains an ASP study goal.

D. An Illustrative Dedicated UV-Optical-IR Astronomy Mission

A technically feasible concept for the accommodation of a large number of UV-Optical-IR instruments, based on the Spacelab and ASP support subsystems described throughout this report, is schematically illustrated in Figure 6. The Spacelab mode is a five-pallet configuration which would occupy the full shuttle payload bay, as shown in Figure 7. Two pallets are used for the one meter SUOT facility. Each of the remaining three pallets contains one SIPS pedestal with two semi-independent gimballed mounts attached. No attempt has been made here to illustrate a realistic configuration for the optional inner roll gimbal in the SIPS mounts, although the requirement for roll fine stabilization

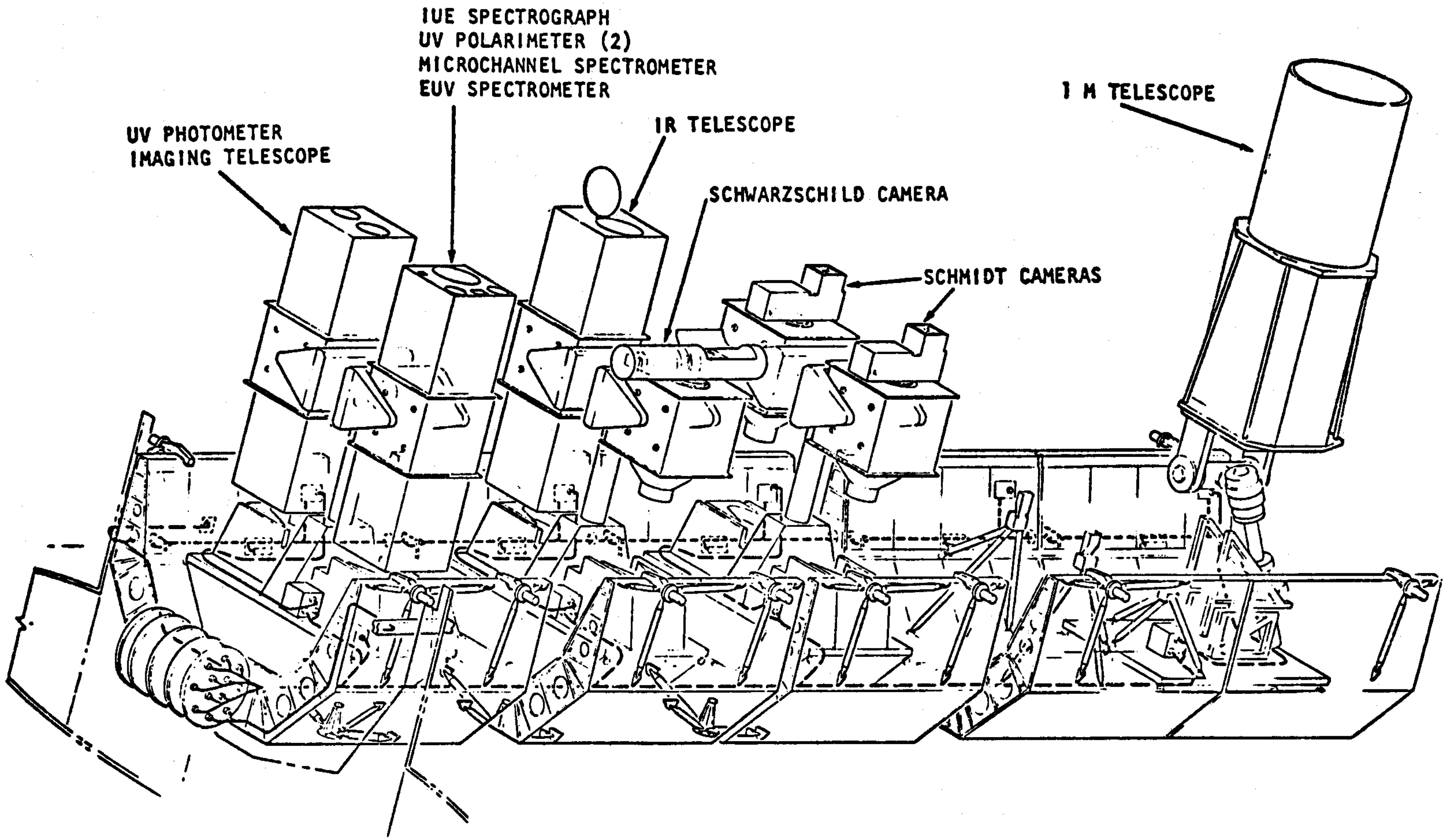

Figure 6. Illustrative Dedicated UV-Optical-IR Payload

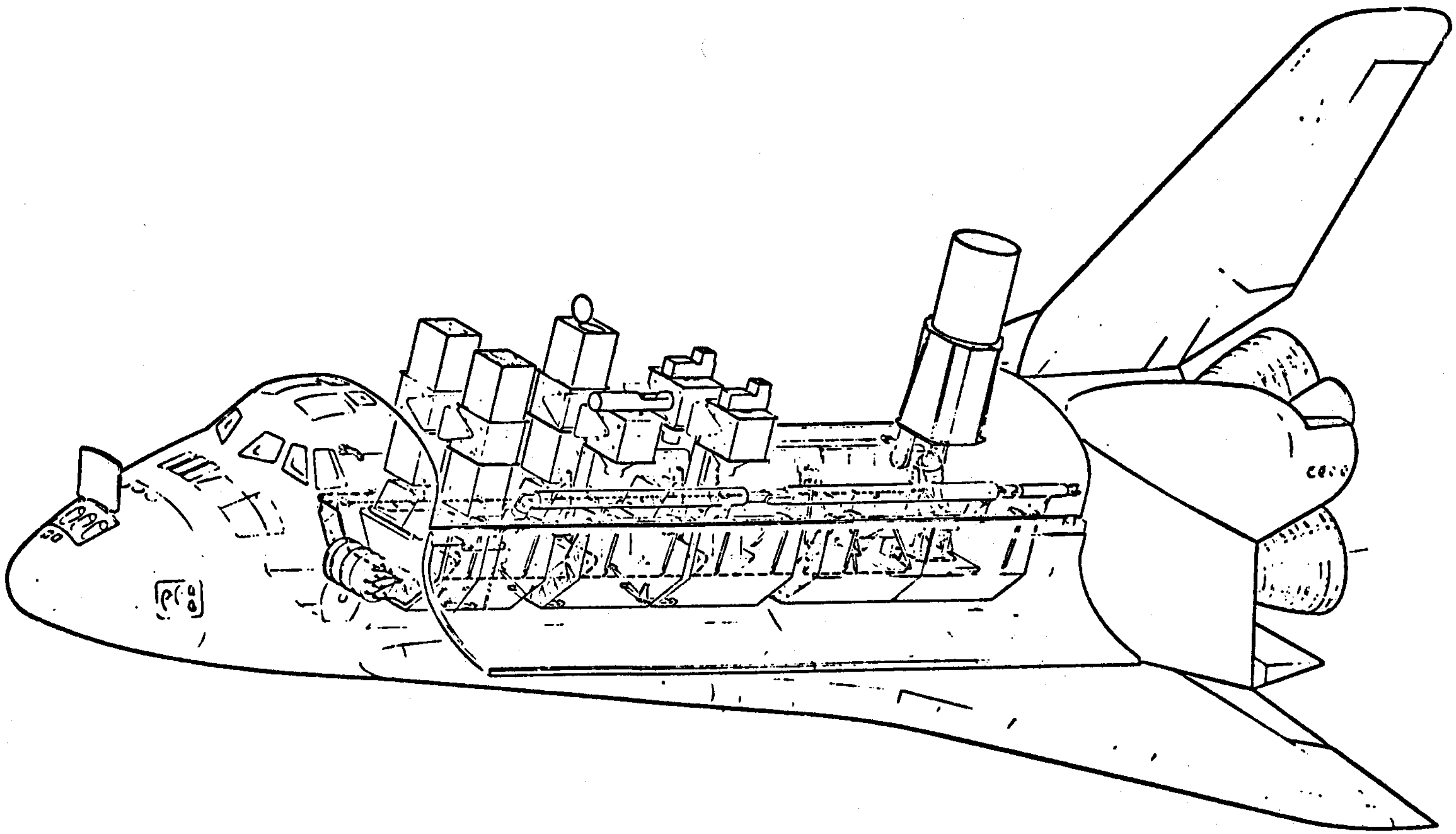

Figure 7. Shuttle Stellar Observatory

for the imaging Schwarzschild and Schmidt cameras is acknowledged in the sketches of those instruments. Although not illustrated here, a small thermal canister to house the side-looking cameras would be provided.

The modular nature of this configuration must be emphasized. Each pallet/SIPS combination could be flown separately, as could the two-pallet train carrying SUOT, in conjunction with a free-flier launch or in a mixed mission with payloads from other disciplines. The interchange of SIPS-mounted instruments between flights is facilitated by a simple exchange of thermal canisters. A standard mounting plate provides the mechanical interface between the gimballed IPS and the SUOT facility, so that the telescope may be quickly interchanged with another large instrument requiring the IPS after a flight.

In this example a total of fourteen scientific instruments are accommodated - three at the focal plane of the SUOT and eleven on the SIPS mounts. Some of these are very specialized instruments for limited observing objectives, some might be amenable to use by a number of observers with different objectives. Clearly, regular flights of a dedicated astronomy payload of this sort, say twice per year, would offer dependable and routine access to space to a large number of observational astronomers on a basis of simple interfaces, relaxed testing and reliability requirements and low instrumentation costs. For a detailed discussion of the accommodations and costs of one illustrative instrument, see the Wisconsin preliminary report, Section III.B.

The illustrative payload shown in Figure 6 is being used for a detailed UV-Optical mission analysis, preliminary results of which are discussed in the Mission Analyses volume of this report. For the purposes of this analysis the following were specified:

- 38 target regions around the sky, weighted by number toward the anti-solar hemisphere but with one region in the ecliptic plane within 20° of the sun, (Regions were specified in instantaneous ecliptic coordinates with origin at the anti-solar point.)

- launch time and orbital parameters chosen to maximize orbital night duration and to minimize exposure to the South Atlantic Anomaly at night,

- instruments grouped so that pointing capabilities would be shared by instruments requiring night observing and those capable of observing in daylight (no pointing system should be idle during orbital day),

- orbiter orientation schemes to be investigated which seek to minimize line of sight column densities produced by VCS thruster firings - e.g. orbiter free drift modes,

- orbiter orientation schemes to be investigated which allow short periods of near-Sun observing with maximum protection of instrument apertures from direct sunlight - e.g. shadowing by the orbiter body.

In summary, the mission timeline allowed a total of 285 Shuttle pointings of 20-30 minute duration at the 38 target regions over 95 orbits. Each independently gimballed instrument could acquire a target within the viewing cone of its pointing system during each of the 285 orbiter pointings. If both sides of the SIPS mounts could be used simultaneously for all regions, a total of 1995 integration periods, distributed among the 14 instruments, would result. This is an optimistic upper limit, however, because night viewing instruments may require SIPS canister closure in the sunlight and because of the semi-independent nature of the two gimballed mounts on each SIPS pedestal - i.e. it is not clear that both sides of a SIPS will always simultaneously acquire targets within their gimbal ranges. A conservative lower limit, assuming the use of one side of a SIPS at each orbiter pointing and the use of SUOT at all pointings, would be 1140 integration periods, distributed among the 14 instruments, in a seven day mission.

In this mode of operation a maximum 2496 kg of RCS fuel would be required, less than the total 2740 kg available in the baseline orbiter system. Use of free drift or semi-stabilized orbiter orientation schemes would not cut this usage markedly. Total payload landing weight in this example is 12,278 kg, including Spacelab and payload-charged orbiter hardware. This is well below the 14,515 kg landing weight limit. The payload falls slightly outside the required lift-off longitudinal center-of-gravity envelope, but this is easily compensated by the inclusion of 680 kg of added OMS propellant in the orbiter fuel tanks as ballast (a common aircraft method of weight distribution). Further subsystems details of the mission analysis are given elsewhere in this report.

E. Preliminary Payload Development Schedule and Estimated Costs

SUOT FACILITY

Figure 8 illustrates a feasible and timely development schedule for the SUOT facility and its initial set of focal plane instruments. The SUOT could be ready for its first flight as early as middle 1981. Development of the first group of three or four focal plane instruments should be followed by the regular introduction of additional instruments, say at the rate of one new development per year starting in 1979-1980, accompanied by an ongoing program of maintenance and refurbishment of previously flown instruments. With major interchange of focal plane instruments, SUOT could be ready for re-flight in approximately six months. It might fly more frequently with a less frequent interchange of instruments.

The currently estimated definition, design, fabrication, testing and initial integration costs of the SUOT facility, excluding focal plane instruments, is $\$13 \times 10^6$ (1975) based on a detailed work breakdown analysis. These costs can be kept relatively low because only one protoflight version will be built (one end item) at a level of reliability assurance and documentation lower than that required for automated satellites. Design costs are reduced because the design parameters involving weight and volume are not tightly constrained. Substantial use will be made of Spacelab and ASP-provided subsystems, including the Instrument Pointing System. A portion of the first flight will be devoted to a full system test in orbit and ground testing will be somewhat reduced from the norm. Finally, SUOT is being designed to facilitate emergency repair of simple failures by EVA in orbit.

The cost of focal plane instruments could range from a few hundred thousand dollars each or less (as in sounding rocket astronomy) to values approaching ten million dollars each (as in the LST program). If SUOT focal plane instruments can be made simpler or more specialized than in the LST program, if they can be developed on a best-effort engineering model basis with strong in-house participation at universities and government agencies, and if they take full advantage of the simple interfaces and benign environment provided by the SUOT facility, it is hoped that their individual costs can be constrained to an average $\$1 - 2 \times 10^6$ (1975) or less. It is clear that primary assurance of reliable instrument performance should derive from the astronomer's desire to continue participation in the program and not from costly NASA-imposed test and documentation requirements.

The activities illustrated in Figure 8, concluding with flight #1 of SUOT, are estimated to cost approximately $\$20 \times 10^6$ (1975). This value includes an initial set of three focal plane instruments, instrument integration into the telescope, facility and instrument related engineering support during flight operations, post flight de-integration and data processing. It does not include the launch tariff (approximately $\$4 \times 10^6$), training costs for Payload Specialists, prorated costs for the use of Spacelab-provided subsystems, an on-going SRT program (for example for detector development), or government IMS charges.

Subsequent reflights of SUOT will involve facility maintenance, re-integration, operations support, de-integration and data processing and analysis averaging approximately $\$1.3 \times 10^6$ (1975) per flight. Maintenance or refurbishment of old instruments and the periodic development of new ones will probably entail costs of approximately $\$3 \times 10^6$ (1975) per year. A major overhaul of SUOT is assumed after every 10 flights at a cost of approximately $\$7.5 \times 10^5$ (1975). Table 4 illustrates the cumulative SUOT funding requirements for two flights per year after an initial flight in CY 1981 with a new focal plane instrument being provided annually.

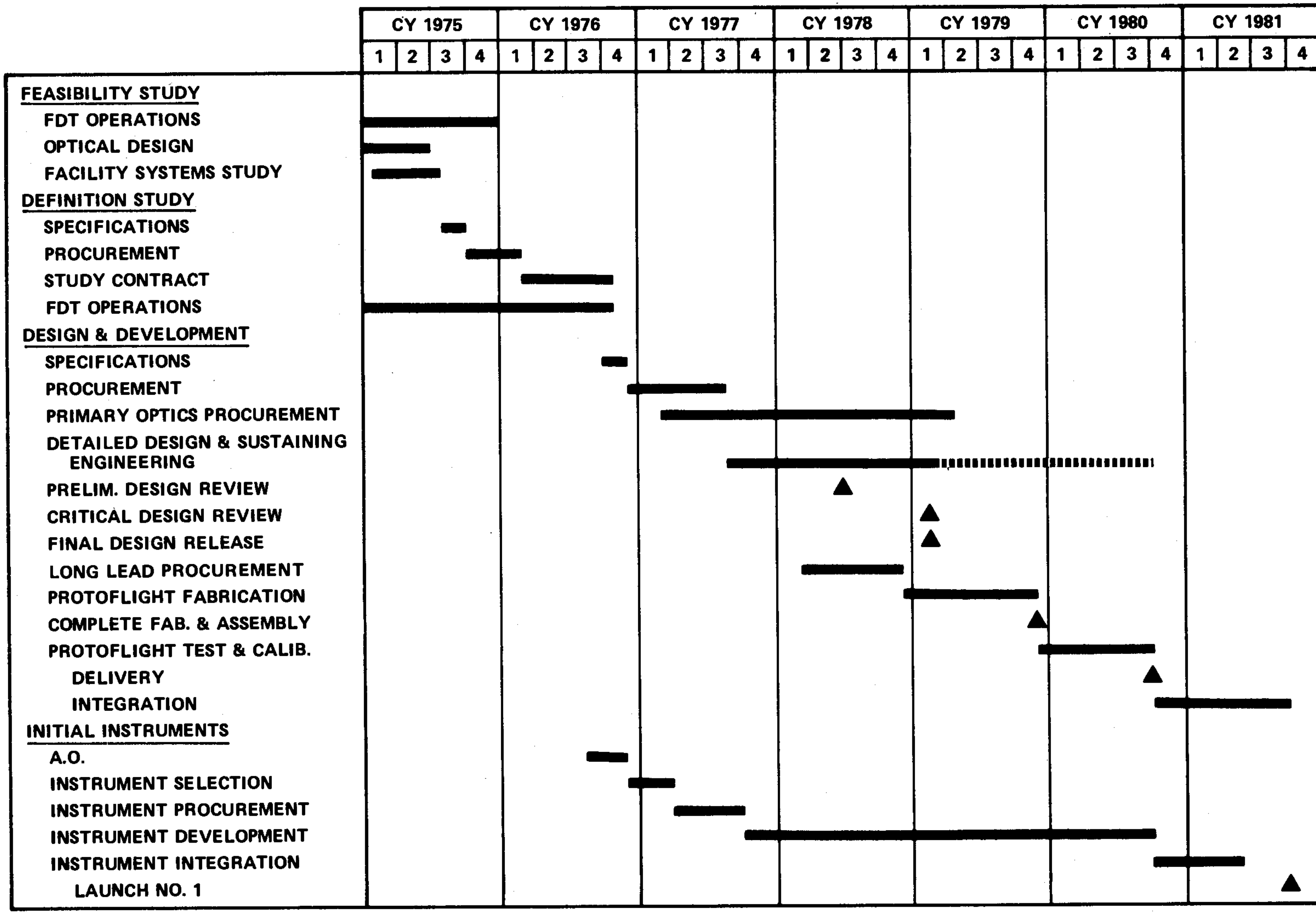

Figure 8. SUOT Development Schedule

Table 4

Facility Class Cumulative Payload Costs

UV-Optical SUOT Costs	CY 1981	CY 1982		CY 1983		CY 1984		CY 1985	
	Initial Flt (000)	1st Flt (000)	2nd Flt (000)	1st Flt (000)	2nd Flt (000)	1st Flt (000)	2nd Flt (000)	1st Flt (000)	2nd Flt (000
SUOT	13,000	700	700	700	700	700	700	700	700
Focal Plane Instrument:									
No. 1	2,000								
No. 2	2,000	250	250						
No. 3	2,000	250	250	250	250				
No. 4		2,000	250	250	250	250	250		
No. 5				2,000	250	250	250	250	250
No. 6						2,000	250	250	250
No. 7								2,000	250
Facility Support & Flight Analysis	750	650	650	650	650	650	650	650	650
	19,750	3,850	2,100	3,850	2,100	3,850	2,100	3,850	2,100
CY Totals	19,750	5,950		5,950		5,950		5,950	

Small Payloads

Some of the autonomous instruments described at the Small Payloads Workshop and others identified since will be suitable for use on the Shuttle orbiter test flights beginning in 1979. Other payloads in this class can easily be available for use on the earliest Spacelab flights, given the availability of a standard small pointing system such as SIPS or TIPS. A feasible program goal would be to provide about 10-20 flight slots per year on a regular basis with accommodations of the sort described in sections I.C. and I.D. above. The growth of this capability would follow the growth of Spacelab flight opportunities generally.

To identify viable small payload candidates for the orbiter test flights and for early Spacelab missions, we suggest an Announcement of Opportunity concurrent with that for the initial SUOT focal plane instruments in calendar year 1976. Lead time for development of small payloads is 1-3 years with reflight capability typically in less than six months. Both AOs should be on-going, allowing payload proposals to be submitted by astronomers at any time.

Estimates of instrument development costs, based on the past experience of experimenters with payloads described at the Small Payloads Workshop, are given in Table 5. These costs were developed independently by each experimenter and are intended to indicate the expected range of costs rather than being specifically accurate in each case. One would expect such payloads each to be reflown several times with recurring costs on the order of 25% of the initial development cost.

The University of Wisconsin Small Payload Adaptation Study, Section III.B., has estimated the detailed cost breakdown shown in Table 6 for the adaptation of a current payload design to Spacelab use. Such adaptation of current payloads offers a very low cost approach to obtaining important data on the earliest flights.

In addition to payload development costs, the "small payloads" would be charged a "pointing cost" for use of the ASP-developed SIPS. Each SIPS flown will involve a tariff of about $\$2.5 \times 10^5$ (1975), to be distributed among the instruments sharing the SIPS.

UV-Optical Astronomy Mission Cost

The costs summarized above may be combined to illustrate the total cost of a dedicated UV-Optical Astronomy mission of the kind described in section I.D. This result is given in Table 7. Table 8 summarizes a plausible cost evolution for the UV-Optical Astronomy program for Spacelab, whether or not the various building blocks of that program - the SUOT and SIPS-mounted autonomous instrument - are flown together on dedicated flights.

Table 5

Estimated Costs for the UV Science - ASP Portion

Small Astronomy Payloads	Non-Recurring (000)	Recurring (000)
UV Photometer	225	56
Imaging Telescope	40	15
IUE Spectrometer	600	50
UV Polarimeter (2)	200	50
Microchannel Spectrometer	150	37
EUV Spectrometer	85	21
IR Telescope	1,900	250
Schwarzschild Camera	200	50
Schmidt Camera (2)	100	10
Far UV Hi Resol. Spectrom.	300	75
UV Telescope Spectrom.	320	80
30" Schmidt Telescope	2,000	500

Table 6
University of Wisconsin Small Payload Adaptation Study
Cost Breakdown (Overhead and Fringe Benefits Lumped with Salaries) 1975 Dollars

A. Optical-mechanical effort to modify the payload and calibrate it once before delivery to GSFC:		Cost in Thousands
Construction		
Materials		4
Instrument Maker (10 MM)		20
Physicist (3 MM)		8
Calibration (up to delivery)		
Instrument Maker (1 MM)		2
Physicist (4 MM)		11
B. Electronic effort required to modify and integrate the instrument for delivery to GSFC:		
Design and Construction		
Materials		8
Engineer (5 MM)		13
Electronic Technician (7 MM)		15
Programmer (3 MM)		6
Integration at Wisconsin		
Engineer (1 MM)		3
Electronic Technician (1 MM)		2
Programmer (1 MM)		2
Administrative Cost		
Travel - 2 trips (1 MM)		4
Project manager (4 MM)		15
Astronomer (planning) (3 MM)		7
Total cost to delivery to GSFC without optional equipment	120	

C. Additional calibration and support of 2 flights		Cost in Thousands
Calibration		
Physicist (9 MM)		24
Testing and Integration		
Engineer (2 MM)		5
Programmer (2 MM)		4
Operations		
Programmer (1 MM)		3
Astronomer (1 MM)		2
Project Manager (2 MM)		7
Travel		
14 Man Trips		4
4 Man Months		8
Data Analysis		
Programmer (1 MM)		3
Astronomer (3 MM)		10
Total estimated testing and flight	70	
D. Options		
Prototype		15
Electronic simulator		3
Onboard vacuum system		19
	37	
Total estimated cost w/o options		190
with options		227

Table 6

Estimated Cost for UV Mission - ASP Portion

UV Mission Costs	Non-Recurring (000)	Recurring (000)	Pallet Req.	Pointing Provided By	Pointing Cost (000)
Facility Instruments:					
SUOT	13,000	1,400		IPS	
Focal Plane Instrument					
No. 1	2,000	250	2		
No. 2	2,000	250			
No. 3	2,000	250			
Small Astronomy Payloads					
UV Photometer	225	56		SIPS (1)	250
Imaging Telescope	40	15			
IUE Spectrometer	600	50			
UV Polarimeter (2)	200	50	1		
Microchannel Spectrometer	150	37			
EUV Spectrometer	85	21			
IR Telescope	1,900	250	1	SIPS (1)	250
Schwarzschild Camera	200	50			
Schmidt Camera (2)	100	10	1	SIPS (1)	250
Pointing Costs	750	750			
Total ASP Mission Costs	23,250	3,439			

Table 7

Estimated Cost for UV Mission — Science Portion

C.Y.	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Facility Telescope	0.5	1.0	4.0	5.0	3.0	2.0	1.5	1.5	1.5	2.5	1.5
Focal Plane Instruments	0.1	1.0	2.0	2.0	1.0	1.5	3.5	3.5	3.5	3.5	3.5
Small Astron. Payloads	0.1	2.0	3.0	5.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
Totals	0.7	4.0	9.0	12.0	14.0	13.5	15.0	15.0	15.0	16.0	15.0

F. Major Study Conclusions

1. A general purpose, one meter class Spacelab UV-Optical Telescope (SUOT), providing wide wavelength coverage and images of excellent quality to interchangeable focal plane instruments carried in groups of two to four on each flight, is technically feasible and can be developed at relatively low cost for a 1981 launch. The SUOT will have strong scientific capabilities in its own right and will excellently complement the LST.

2. The standard Small Instrument Pointing System (SIPS) defined for use with Solar Physics payloads, can be readily adapted for use with stellar astronomy payloads as well. It will meet or exceed the performance requirements of most autonomous instruments of the kind described at the Spacelab Astronomy Small Payloads Workshop and will obviate the need for the separate design and development of a standard pointing system for stellar payloads in the 100-400 kg class.

3. A standard pointing system for very small astronomy payloads ($\leqslant$ 100 kg pointed to $\sim$ 10 arcsec) is desirable and should be developed on a low cost basis.

4. Autonomous instruments analogous to those currently flown on sounding rockets, balloons and Explorer satellites can be available for flight as early as the Orbiter Flight Tests of 1979-1980. A few of these can utilize baseline Orbiter pointing and stabilization but most will require finer pointing control. It is imperative that immediate development of the SIPS begin.

5. The basic building blocks of UV-Optical Astronomy Spacelab payloads (the SUOT occupying two pallets and SIPS - mounted autonomous instruments occupying one pallet per SIPS) can share flights with payloads from other disciplines or with automated satellite launches and retrievals or they can be combined into full Shuttle payloads dedicated to UV-Optical Astronomy.

6. Spacelab flights as short as seven days will yield substantial quantities of data and an excellent scientific return, if observing targets are carefully selected and if full advantage is taken of the unique Spacelab capability to fly instrumentation optimized for specific research objectives. Full use will be made of time in orbit, both in sunlight and in darkness, and the accommodation of multiple instruments, both at the SUOT focal plane and in SIPS mounts, will be routine.

7. Selection of SUOT focal plane instruments and of SIPS-mounted autonomous instruments should be implemented by an open-ended announcement of opportunity to which astronomers may respond at any time. Many instruments will be of broad usefulness to astronomers and should be available to the general community, whether developed by PIs or by NASA.

8. Continued study in several problem areas with major impact on Spacelab astronomy will be required. These include the following:

   a. methods of circumventing contamination and data degradation by the orbiter VCS system, including optional CMG or cold gas stabilization kits, orbiter free-drift or semi-stable modes to minimize thruster firings and signals provided to payloads by the orbiter prior to each thruster firing;

   b. detailed verification of the ESRO-developed Instrument Pointing System's ability to accommodate the requirements of the SUOT facility;

   c. final, detailed definition of the Spacelab Command and Data Management system and development of a viable concept for the control and data handling of a complex, multi-instrument astronomy payload which makes optimum use of the Payload Specialist, the Payload Operations Control Center and the Spacelab Computers and which retains relatively simple interfaces for individual experimenters;

   d. development of a reasonable testing, quality assurance and documentation program for payloads which will fully assure payload safety and will also assure a reasonably high frequency of mission success, while allowing a low-cost payload philosophy to be pursued (of special concern is the degree to which pallet-only payloads will require man-rating, if EVA is to be used occasionally for simple emergency repairs or film pack interchange).

SECTION II.

SPACELAB UV-OPTICAL TELESCOPE (SUOT) FACILITY

SECTION II. A.

INTERIM REPORT OF THE SUOT FACILITY DEFINITION TEAM - MAY, 1975

I. INTRODUCTION

NASA through the Astronomy Spacelab Payloads study at Goddard Space Flight Center is conducting a study of the feasibility, preliminary design and scientific potential of a general purpose, one-meter class, telescope facility to be used for astronomical (non-solar) observations in the UV-optical wavelength range. This telescope will be operated on the NASA Space Shuttle with the support of Spacelab systems. The present Facility Definition Team (FDT), selected by NASA Headquarters through AO#3, is responsible for the definition of scientific requirements for this Spacelab UV-Optical Telescope (SUOT) facility and for the scientific review of related engineering design studies. The membership of this team is:

Team Members:

C. M. Anderson, University of Wisconsin
K. G. Henize, NASA, Johnson Space Center, Team Leader
E. B. Jenkins, Princeton University
R. W. O'Connell, University of Virginia
A. M. Smith, NASA, Goddard Space Flight Center

Special Advisors:

H. Arp, Hale Observatories
W. G. Fastie, The Johns Hopkins University
A. B. Underhill, NASA, Goddard Space Flight Center

Ex-Officio Team Members:

D. S. Leckrone, NASA Goddard Space Flight Center, Study Scientist
J. D. Rosendhal, NASA Headquarters, Program Scientist
B. A. Smith, University of Arizona, Advisor for Solar System Studies.

The major objective of the FDT and supporting engineering studies is to develop a detailed concept for the SUOT facility which is scientifically meritorious, technically feasible and relatively low in cost. The guidelines developed by NASA to define the scope of these studies are listed in Appendix A.

The FDT has met four times from December 1974 through March 1975 and will continue its studies until December 1975 at which time a final report will be written. This interim report contains the consensus so far reached by the FDT concerning their concept of the SUOT optical and mechanical specifications and of the more compelling scientific programs for which SUOT will be useful. It is prepared at this time so as to be available for National Academy of Sciences review in the summer of 1975.

II. UNIQUE CAPABILITIES AND HIGH PRIORITY PROGRAMS FOR SUOT

The Spacelab UV-Optical Telescope is envisioned to be a very flexible, general purpose facility capable of accommodating a wide variety of focal plane instrumentation in the 1981-1990 timeframe. We do not presume to be able to predict the full range of applications it will engender. For the purposes of this study, however, it is necessary to identify potential observing programs for SUOT which will serve to illustrate the scientific merit of the facility, to delineate the complementary role of this telescope relative to other space telescopes, and to provide a basis for decisions concerning telescope design. The SUOT facility will be defined so as to readily accommodate these easily foreseen programs, but careful consideration will also be given to avoiding constraints which may preclude its use for other purposes as well. We have assumed that SUOT will operate in the same timeframe as the Large Space Telescope and primary consideration has been given to scientific programs which complement the expected capabilities of the LST. However, we firmly believe that the SUOT will have strong scientific merit in its own right and should be optimized for those capabilities rather than for use as a test bed for LST instrumentation. If the LST should slip markedly in schedule, SUOT could provide a rather powerful interim capability, carrying out exploratory programs in high resolution field imagery, spectroscopy and photometry in preparation for more detailed LST observations. The SUOT will, of course, not be able to compete with a "full-up" LST in terms of ultimate angular resolution or light gathering power.

Based on the above considerations, four general observational programs have been given high priority and will be discussed in detail in Section III. These are:

- high angular resolution imagery over wide fields;
- far ultraviolet spectroscopy;
- precisely calibrated spectrophotometry and spectropolarimetry over a wide wavelength range,
- solar system studies, including high resolution synoptic imagery.

Other programs considered interesting but not discussed in detail here are stellar spectroscopy over 1200-3000Å, nebular spectroscopy, broad band photometry including high time resolution studies, near infrared (1-4 μm) imagery and spectroscopy, very high resolution (Fabry-Perot) spectroscopy and Michelson interferometry.

Each of the four high priority programs is made feasible by, or at least substantially profits from, the unique flexibility offered by Spacelab. The SUOT will use field correctors to provide a flat field 0.5 degrees in diameter with image diameters in the range 0.2 - 0.3 arc seconds (70% encircled energy) at wavelengths >2000Å. Without refractive correctors it will provide similar image quality over a 0.1 degree flat field within the full wavelength range determined by its optical coatings. The full potential of this imaging capability may be exploited by large format electrographs using nuclear track emulsions or by magnetically focused image intensifiers coupled to photographic emulsions. Hypersensitized photographic emulsions without intensification may also be useful for relatively bright targets. This performance is to be compared to the LST f/24 camera which will provide 0.1 to 0.2 arcsec images over a detector-limited 0.04 degree field. The capability to carry large intensifiers or electrographs, to interchange film cassettes by EVA on extended flights and to return film to the ground for immediate processing is a unique Spacelab capability which will yield valuable returns in a number of astrophysically important areas. In this capacity SUOT will be able to survey selected fields to in 30 min. exposures $V \sim 25$ mag for point sources, or to $V \sim 26$ mag/arcsec^2 at degraded resolution for extended sources, to serve as a finder instrument for LST.

Neither the International Ultraviolet Explorer nor, as currently envisioned, the LST will carry out spectroscopy over the wavelength interval 900-1150Å. The primary LST optics will be MgF_2 overcoated and will not be well suited to applications at these wavelengths. Instrument packaging problems and deficiencies in currently available detectors also mitigate against far UV spectroscopy with LST. We recommend that SUOT be capable of periodically flying in a configuration optimized for far-UV observations. The primary and secondary mirrors, which routinely fly with MgF_2 coatings, could be interchanged with carefully protected LiF overcoated optics or they could be recoated between missions depending on which is the more economical. The SUOT facility should be designed for the quick interchange and realignment of optics. With a reasonably high flight frequency and the ability to modify the facility between flights made possible by Spacelab, one need not make a long term commitment to a single telescope/instrument/detector configuration. Relatively high risk detectors, developed in a constantly evolving detector technology, can be used thus ensuring the greatest possible scientific access to the difficult far-UV region.

The ability to carry onboard calibration sources and to return the SUOT to Earth for postflight calibration will help to ensure high photometric precision in the establishment of spectrophotometric standard reference stars sufficiently faint to be of use to LST (bridging the gap between V = 6 to 11 mag.). The same instrumentation will yield high precision (one percent statistics, 30 min. integration, 10Å bandpass) ultraviolet spectrophotometry on a variety of important targets to V~16 mag or fainter (equivalent unreddened O7 star). Otherwise unobtainable spectrophotometry at wavelengths shortward of 1200Å will be obtained on flights of SUOT carrying LiF overcoated optics.

The opportunities offered by Spacelab for innovative research are well illustrated by SUOT solar system objectives. The SUOT will achieve spatial resolution on Jupiter, for example, equaling or exceeding the best images obtained by Pioneers 10 and 11 (see frontispiece). While LST will be better suited to long term synoptic coverage, SUOT will be able to utilize highly specialized instrumentation, suited to specific research objectives – e.g., narrow bandpass interference filters for isolating and mapping particular spectral features over the planetary disc. The SUOT may be the only space telescope useable for near-Sun observations of Mercury, Venus and comets, taking advantage of shadowing by the body of Shuttle or by a special purpose Sun shield. The SUOT can respond to targets of opportunity — e.g., Martian dust storms, comets of special interest — with instrumentation carefully chosen for specific objectives. We envision that SUOT will carry a high resolution planetary camera on each flight to accommodate synoptic coverage of planets.

In summary, the SUOT facility will be capable of accommodating a wide variety of specific instrumentation which is tailored to the goals of individual research programs. It will possess a capability for growth and improvement by virtue of interchangeable optics, coatings, focal plane instruments and detectors. It will be amenable to the exploratory use of newly developed detectors. Finally, although Shuttle flights as long as 30 days are highly desirable, we will show that substantial and important scientific data will be returned from flights as short as seven days, if one carefully selects and prioritizes observing targets. Instrumentation both for use in daylight and for use in the dark portions of an orbit can be carried on each flight so as to maximize the data return.

III. SCIENTIFIC PROGRAMS

The FDT, as noted above, has chosen the following research programs as the primary areas for exphasis with SUOT:

- high angular resolution imagery over wide fields (star clusters, nebulae, galaxies, clusters of galaxies, interacting galaxies);
- far ultraviolet spectroscopy (interstellar matter, stellar and planetary atmospheres, X-ray binaries);
- precisely calibrated spectrophotometry and spectropolarimetry over a wide wavelength range (early-type stars, QSO's, galactic nuclei, X-ray binaries, etc.);
- solar system studies, including high resolution synoptic imagery of the planets.

In this section we will examine in detail the scientific programs expected to be of special interest and will give a representative observing program for a seven-day mission in each area in order to illustrate the degree to which significant advances in areas of primary scientific importance can be achieved by even such short missions. In actual practice it is hoped that most missions will have durations considerably longer than the basic seven-day mission and, in any case, it is expected that a mission will usually blend together observations in two or three of these areas.

To insure that the representative observing programs are consistent with one another the following conventions were adopted:

- A seven-day mission will allow six days of round-the-clock observing. Approximately 96 orbits were assumed available for data collection, and inefficiencies due to South Atlantic Anomaly passages, housekeeping operations, etc., were neglected.
- Maximum exposure time is 30 minutes. (Actually in a 450 km orbit any object will be above the horizon for at least 55 minutes each orbit, but the maximum observing time in the earth's shadow is 35 minutes.)
- Sky brightness (V) –

ground based sky	22 mag arcsec^{-2}
night sky in orbit	23 mag arcsec^{-2}
day sky in orbit	20 mag arcsec^{-2}

- Limiting magnitudes are to be expressed in terms of the visual magnitude of the B0 star which can be observed at the wavelength in question. The B0 flux is that defined by Gingerich and Carbon. Assume reddening to be defined by the Bless and Savage reddening curve.

A. High Angular Resolution Imagery Over Wide Fields

For direct imagery SUOT's impact will be greatest on problems requiring high resolution over fields significantly larger than the 2.5 arcmin field of the LST f/24 camera. A great many important astrophysical problems fall in this category — ranging from stellar evolution in globular clusters (10-60 arcmin diameter), to the history of star formation in nearby galaxies (12° for the Large Magellanic Cloud, 4° for M31, 34 arcmin for M81, 10 arcmin for the Virgo galaxies), to studies of intergalactic matter in clusters of galaxies (10 arcmin to several degrees for intermediate distance clusters [$z \lesssim 0.1$]). In these areas SUOT can be expected to function not only as a survey instrument for other space facilities but also as a primary research tool which will supply definitive information.

A number of programs suitable for SUOT imagery are discussed below. These are based on the expectation (details are given in Appendix B) that in a 30 minute exposure, SUOT will reach V = 25 with S/N = 10 for point sources and V = 26 mag/arcsec^2 with S/N = 10 for extended sources (with reduced angular resolution). These values assume a bandwidth of 1000Å, an overall detection efficiency of 0.1, an image diameter of 0.2 arcsec, and a sky background of V = 23 mag/arcsec^2 in the Earth's shadow. The limiting magnitude for point sources is V = 26 with a 5000Å bandpass.

For many extragalactic problems involving observations in the near infrared or resolution of faint point sources on bright backgrounds, SUOT will have a distinct advantage over any ground-based instrument.

It is also worth noting that in surveys for very faint objects not observable from the ground, SUOT will be much more efficient than LST. For point sources at V = 27, SUOT will reach the same S/N as the presently-envisaged LST with roughly 14 times the exposure. However, since the SUOT data field is 100 times the area of the LST, SUOT has an advantage by a factor of about 7 in a survey to fixed limiting magnitude. For a given pixel size and detector efficiency, SUOT is also faster than LST by a factor of 2.6 for detection of faint extended objects by virtue of its smaller f ratio.

The Extragalactic Distance Scale

A limiting magnitude of V = 25 and image diameters of 0.2 arcsec would allow SUOT to provide a more definitive value of the Hubble constant based on accurate distances to giant galaxies within 100 Mpc. The primary distance indicators and the respective distances to which they could be employed are: RR Lyrae stars (600 kpc); Cepheids, brightest Pop II stars and main sequence OB stars (3-10 Mpc); brightest supergiants in spiral and irregular galaxies (60 Mpc); sizes of HII regions (70 Mpc for 3 pixel coverage); and globular clusters (100 Mpc). Three major clusters of galaxies (Virgo, Pegasus and Perseus) lie within the 100 Mpc limit and the Coma cluster could be reached with a 1 mag increase in limiting magnitude. For the first time a truly representative sample of objects with accurate distances will be available to study the nature of the local Hubble flow and to calibrate secondary distance indicators (such as elliptical galaxy core diameters) for use at even greater moduli.

Stellar Content of Nearby Galaxies

In addition to the distance criteria cited above, an unprecedented amount of information on the stellar content of nearby galaxies will be available to SUOT. For the first time, the main sequence turnoff in other galaxies will be accessible. Systems nearer than 100 kpc (such as the Magellanic Clouds and the Sculptor dwarf system) can be sampled to $M_v \sim +6$. $M_v \sim +1$ can be reached in M31 and its companions; thus, the horizontal branch in all metal poor dwarf galaxies in the local group can be studied. The distribution of metal content and positional variation of star formation may be studied in detail via individual variable stars and the morphology of field and cluster HR diagrams. Of special interest are star formation rates in the vicinity of spiral shocks derived from observations of hot main sequence stars in spiral galaxies up to 4 Mpc distant. Only the Magellanic Clouds and M31 are significantly larger than the SUOT data field. All smaller galaxies may be surveyed to V = 25 with a single exposure in each color in a total of only about two hours of observing time per object.

Deep Sky Imagery

a. Extended regions of galaxies: Very low luminosity extended areas are known to surround (and in some cases interconnect) a number of galaxies. These will undoubtedly shed light on galaxy dynamics and evolution. These extensions may represent a significant fraction of the total galactic mass, and thus may be of interest for cosmology as well. The ultimate limit of 27-28 mag/ $arcsec^2$ obtainable with multiple exposures on SUOT represents a considerable advance in detectability over ground-based techniques. Targets of special interest include halos of edge-on spiral galaxies, rings around Seyfert galaxies, external HI spiral arms without known optical emission, HI "dark companions," interacting galaxies, and elliptical galaxies.

b. Search in selected fields for very distant clusters of galaxies for cosmography. A limiting distance modulus of ~47 is possible for giant ellipticals.

c. Survey selected areas for QSO's for LST study and for statistical purposes. Ultraviolet or near infrared identification criteria could be used to advantage. At V = 22.5, approximately 40 QSO's should be contained in a single SUOT field.

d. Search in blank radio fields for optical counterparts and in radio lobes (typically 5 arcmin) of relatively nearby radio galaxies for luminous matter.

e. Search for luminous intergalactic matter within clusters of galaxies. Near infrared capability is important to detect low mass stars. Hot gas may be visible in red-shifted Lyman lines. The cores of most clusters of interest are larger than 20 arcmin.

f. Surveys for very low surface brightness dwarf galaxies (thought to be very numerous) in order to determine the faint end of the galaxian luminosity function.

g. Study of spatial fluctuations in the cosmic light — indicative of object population (including primordial galaxies) at very high redshift. Scales of interest are several arcsec to ~1 arcmin.

Structure of Nearby Galaxies

a. High resolution surface photometry of galaxies — especially ultraviolet photometry (including selected emission lines) of late-type objects with spiral structure and objects with conspicuous dust lanes.

b. Surveys of nuclear structure, especially for active galaxies (Seyferts, M82, M87, etc.), objects with complex (hot-spot) nuclei, and compact galaxies, studies of dust lane structure near nuclei. SUOT could extend probable LST coverage here but will offer no particular advantage.

Stellar Surveys of Our Galaxy

a. Resolution of the nuclear bulge of our galaxy through gaps in the absorption.

b. Population at galactic poles — especially hot subluminous stars. Color statistics will be useful to the limiting magnitude in determining the structure of the galactic halo.

c. Slitless spectra of selected fields using a prism or grating in the converging beam to derive low resolution (primarily ultraviolet) spectroscopic information for large numbers of objects in the same field.

Star Clusters

a. Search for faint members of galactic clusters — especially white dwarfs (in order to test supernova models) and lower main sequence stars.

b. Globular clusters: resolution of central regions; large sample color-magnitude diagrams (including ultraviolet colors); luminosity functions below turnoff; population of very hot stars. Many globulars can be sampled to $M_v \geqslant 10$.

Interstellar Medium

a. Fine structure in nebulae (e.g. condensations and filaments in planetaries); structure of supernova shock waves, especially through narrow band imagery of ultraviolet emission lines. Wide field imagery will serve in part as survey for subsequent SUOT (or LST) spectrometry.

b. Fine structure in dust clouds — especially globules. Background star counts in direction of clouds. Fine structure in dust/gas interaction regions (elephant trunks, etc.). Ultraviolet photometry of reflection nebulae.

Special Applications

a. Highest resolution imaging: Since resolution at the f/15 focus will be affected by pixel size of the detector even for pixel diameters of 10 μm, the smallest expected in the near future, one can improve SUOT's angular resolution by using transfer optics to expand the plate scale in order to allow several pixels per angular resolution element at a sacrifice in field of view. Several of the programs listed above, such as (4b), (6b) and (7) could benefit from the increased resolution without being severely compromised by the reduction in field. Even though many such problems are high priority programs for the LST, which offers both higher speed and angular resolution, it is anticipated that special aspects of these problems might be more effectively pursued by SUOT. One area in particular is that of planetary imaging where SUOT may take advantage of special filters, may follow planets closer to the Sun, etc.

b. Ultraviolet polarimetry: Given a nearly linear and highly stable detector, this will be a very interesting application for SUOT imagery. Objects of interest include planets, reflection nebulae, circumstellar clouds, galactic non-thermal sources (such as the Crab Nebula), and dust lanes in galaxies. It is possible that polarization would be a useful identification criterion for faint QSO's.

In formulating a typical observing program we have assumed a launch time near new moon near the autumnal equinox. All exposures are made in the Earth's shadow. Since one such exposure can be made on each orbit, the total number of exposures which may be made in the six operating days of a seven-day mission is 96. We assume an S-20 photocathode operated with 10 filter positions: five broad band filters centered approximately at 0.25 μm; 0.35 μm, 0.45 μm, 0.55 μm, 0.75 μm; two narrow band filters isolating the C III λ 1908 and C II λ 2326 features; two intermediate band filters isolating regions in the 0.2–0.4 μm range free of common nebular emission lines; and one unfiltered position.

a. M31 region: stellar populations and distance criteria. Two fields: one centered on M32 (including a large fraction of the M31 southern minor axis) and an adjacent M31 field to the southwest including several spiral arms. One exposure each in the five broad-band filters. Series repeated twice at one to two day intervals for variable stars. Total: 30 exposures.

b. M33: spiral structure and stellar populations. Broad band series, emission line filters, one exposure each. Broad band series repeated several days later. Total: 12 exposures.

c. Supernova remnants: Ionization/excitation structure in C II, C III ions; ultraviolet non-thermal radiation in Crab Nebula. Two objects are included: S147 and the Crab Nebula. Only part of S147 can be included in the SUOT field. For each object, two exposures in each of the two emission line filters. For the Crab Nebula, two exposures each in the line-free filters. Total: 12 exposures.

d. Interacting and/or radio galaxies: for each object, four exposures without filtration to reach faintest limiting magnitudes on surface areas. Fornax A (main body and one radio lobe) and Stephan's Quartet are appropriate targets. Total: 8 exposures.

e. Clusters of galaxies: For Hubble problem and search for intergalactic matter. For each object, four unfiltered photographs of cluster core for surface photometry, and five broad band exposures for distance criteria. Targets here might be the Perseus cluster (100 Mpc) and the Pegasus cluster (75 Mpc). Total: 18 exposures.

f. South galactic polar survey: three selected fields for stellar population in the halo, QSO's and distance clusters of galaxies. Broad band series for each. Total: 15 exposures.

Thus with 95 exposures made in the course of six days it will be possible to conduct a high resolution study of the stellar populations of M31, M32 and M33 to $M_v = +1$, to explore at high resolution the structure of two supernova remnants in the light of two ions sensitive to small changes in excitation and ionization, to search for very faint extensions in one radio galaxy and one group of interacting galaxies, to explore two clusters of galaxies for improved distance indicators, intergalactic matter and faint members, and to survey several fields near the south galactic pole for faint blue members of the galactic halo, for QSO's and for new and very distant clusters of galaxies. Since these exposures were confined to the night portions of orbits, at least an equal amount of time is available during the same mission for spectroscopic or planetary studies.

B. Far Ultraviolet Spectroscopy

Due to instrumentation difficulties, few space telescopes are able to gather data in the astrophysically important 912-1150Å region. In this region it is necessary to avoid all transmission elements, to employ LiF overcoated mirrors, to minimize the number of reflective surfaces and to use only open faced detectors with no transmission elements. The only telescope so far designed to reach this region is OAO-C (Copernicus). Neither LST nor IUE will have this capability. Therefore it is highly desirable to use the flexibility of SUOT to conduct further studies in this region on one or more missions. In addition to a moderate gain in light-gathering area over that of Copernicus, SUOT can make use of imaging detectors instead of scanning phototubes, which will offer an enormous advantage in the rate of data accumulation.

The scientific programs appropriate to this wavelength region relate primarily to the study of interstellar matter. However, important data on stellar atmospheres also lie in this region as do two problems in solar system spectroscopy. These are discussed below.

Interstellar Matter

The ultraviolet region of the spectrum contains most of the important resonance lines from the ground states of common elements, especially for the more predominant levels of ionization expected in space. Also, at low densities, molecular hydrogen can most easily be detected by observing absorptions by the electronic transitions in the far ultraviolet. These were the primary objectives of the Princeton UV telescope-spectrometer which is operating on OAO-C, and we can best illustrate the important features which lie in the spectral region between 900 and 1150Å by summarizing important data which were derived exclusively from Copernicus observations in this wavelength range:

a. Molecular hydrogen Lyman (and Werner) band systems; relative populations in various stages of rotational excitation may be observed. The longest wavelength for a transition from the lowest rotation and vibration level in the Lyman system is 1108Å.

b. HD molecules principal lines of the Lyman system start at 1106Å and go shortward.

c. Atomic deuterium; the Lyman-α (and frequently Lyman-β) interstellar hydrogen lines swamp the accompanying deuterium lines. Hence the higher members of the Lyman series (at 972Å, 950Å, 938Å, etc.) must be observed.

d. O VI (1032Å, 1038Å)

e. N II (1084Å)

f. C III (977Å)

The importance of molecular hydrogen is almost self evident, in view of its high abundance in dense accumulations of gas and the unexpectedly high degree of rotational excitation which has been found. When compared with the amount of H_2 present and evaluations for the interstellar D/H ratio, measurements of HD give us insight on the rates of ion-molecule exchange reactions in clouds, which in turn are governed by the atomic hydrogen ionization rates.

The ratio of deuterium to hydrogen in the interstellar gas, which reflects upon a universal deuterium abundance, is especially relevant to our estimating the present average density of the universe, if one makes use of the theories of nucleogenesis in the early stages of the primordial explosion. Although there are many other astronomical situations where abundances of deuterium atoms may be sensed, determinations of interstellar atomic D/H ratios provide what is probably the most straightforward measure of the universal ratio. In establishing whether the interstellar ratio is not significantly altered from the primordial value, it would be useful to reach beyond the initial Copernicus results and detect gas at high galactic latitudes which may be somewhat isolated from the material processed through stars (and supernovae) in the disc of the galaxy.

Observations of weak and broad absorption features due to interstellar O VI have established the existence of a tenuous, high-temperature component of the interstellar medium. Absorptions by other highly ionized species, such as S IV, N V and Si IV do not seem to appear, and this is probably a consequence of the gas being at a temperature in excess of a few times 10^5 °K. Hence, although limited success in registering this gas might result from a very careful search (above 1150Å) for absorptions by N V, Si IV and perhaps C IV, experience up to now suggest O VI may be the only conspicuous tracer. This is an especially important consideration for research by satellites more sensitive than Copernicus, since we could expect to register spectra of stars very distant from the plane of the galaxy and probe the conditions in the galactic halo regions. Our present knowledge of the density, composition, temperature and dynamics of high-temperature gas in the halo is indeed sparse, and additional information here should be valuable in our understanding of galactic structure and evolution. An insight on the distribution of galactic material at large distances is also relevant to a possible explanation for intermediate red-shift lines (from intervening galaxies) appearing in QSO spectra.

Neutral nitrogen atoms have an ionization potential just slightly greater than that of hydrogen. Hence, except for ionization by cosmic rays and x-rays, there should be virtually no production of N II in H I regions. Practically all of the observed N II must arise from H II regions, and this ion serves as an ideal probe not only for the extent of the ionized zones, but also representative electron densities since absorptions from excited fine-structure levels may be observed.

Another near coincidence of ionization potentials may be found for neutral helium and singly ionized carbon. It follows that C III should be a good indicator for the amount of helium ionization around the stars. Observations of C III by the Copernicus instrument have been somewhat hampered by the relatively low signal and high background levels near 977Å.

Additional benefits for analyzing the interstellar material may result from observations below 1150Å. There are several weak transitions from such abundant species as Si II (1021Å), N I (964Å) and O I (989Å) which allow us to circumvent difficulties in the interpretation of stronger lines (at longer wavelengths) which are strongly saturated, even for nearby stars.

Stellar Atmospheres

It is usually possible to learn much about the structure and composition of the atmospheres of stars by analyzing spectra taken at wavelengths longward of 1150Å. Nonetheless the shorter wavelengths may often play a significant role in providing data on particular ions whose lines at longer wavelengths may be weak weak or blended. The peak of the black-body curve occurs near or below 1150Å for the very hot stars, and a study of the spectral behavior near this maximum is crucial since it is here that the effects of line blanketing are most important in altering the emergent flux. Also, weak lines show their greatest contrast over wavelengths on or shortward of the Planck maximum, since relatively large changes in flux occur for the small temperature differences between the atmospheric levels responsible for the line cores and the adjacent continuum. In the ultraviolet, the wealth of strong resonance lines for highly ionized atoms also contributes some advantage. The discovery of mass loss from the very luminous early-type stars using rather primitive rocket-borne spectrographs exemplifies well the new insights which may result from examining short wavelengths. Using a space observatory one would like to continue studies of P-Cygni type profiles from such ions as C III (977Å), N III (990Å), O VI (1032, 1038Å), P V (1118, 1122Å), and S VI (933, 944Å).

Within its limits of sensitivity, (see Appendix C), the Copernicus instrument should permit us to map the properties of a wide selection of stellar types. The IUE telescope will allow the extension of such studies to rarer (and hence more distant) or intrinsically fainter stars outside the grasp of Copernicus. However, these two instruments together will be unable to explore the $\lambda < 1150$Å range for such faint but relatively hot objects as white dwarfs or the central stars in planetary nebulae. A far-UV spectrograph on a 1-meter telescope should open such objects to productive scrutiny. We might also capitalize on the possibility of examining fainter but hotter companions in binary systems (such as x-ray sources) by observing wavelengths shortward of the primary's black-body cutoff.

Solar System Studies

Even though the principal ultraviolet molecular and atomic emission lines occur above 1150Å, there are two problems which must be tackled at shorter wavelengths. First, argon may be an important atmospheric constituent, but its resonance lines occur at 1048 and 1067Å. Second, when studying the emission from the hydrogen envelopes around solar system objects, especially comets, one frequently faces the difficulty that the inner regions are optically deep at Lyman-α. A straightforward way of overcoming this problem is to examine radiation from higher terms in the Lyman series, all of which fall below the 1150Å limit.

The following observing program demonstrates the scope of tasks which can be accomplished during a seven-day Shuttle flight. In accord with the scientific objectives outlined above, we shall appropriate observing time among the following areas of research:

- Distant stars for interstellar matter research
- Highly reddened stars for interstellar matter research
- Subdwarf O-type stars
- Nuclei of planetary nebulae
- X-ray sources with optical identifications
- Emission lines from planets

We shall assume that observations may be made both in sunlight and in Earth's shadow and that on the average a target is available for 30 minutes per orbit. Although two such observing periods might be achieved in each orbit, we shall assume that the spectrograph is timesharing with other SUOT instruments. Thus if we assume about 96 orbits are available for observation during a seven-day mission, we will conservatively have 48 hours of actual observing time available.

For uniformity, Table 1 will list the quantity $N_S/\sigma(N)$ attainable for each object over 30 minutes of integration time. Crudely speaking $N_S/\sigma(N)$ is a representative signal-to-noise ratio, but see Appendix C for an exact definition. For complete spectral coverage, two 30-minute integrations would be necessary since the grating must be moved and the spectrum reobserved to fill in the gaps between the detectors (see section V-B). For all research areas except (2) and (6) above, $N_S/\sigma(N)$ was evaluated for 1030Å. Owing to the steepness in the average interstellar extinction curve at short wavelengths, we can probably record useful spectra for the highly reddened stars only above about 1050Å, hence $N_S/\sigma(N)$ is quoted for 1100Å.

The signal qualities of planetary observations are gauged by the photoelectrons accumulated over a 30-minute integration time for each Rayleigh of emission. In assigning time for the planets, we shall assume we are fortunate enough to

Table 1
Observing Program for Far UV Spectrograph
(Requires three days of orbital observing time)

(a) Distant Stars

HD	V	E(B-V)	Sp	v sin i	log $N_s/\sigma(N)$	ℓ^{II}	r (pc)	z (pc)	Observing Time (min)	Comments
164794	5.97	0.35	O5-O7	168	1.85	6	1200	1025	60	
149881	6.60	0.12	B0.5III	470:	1.58	31	1800	1050	60	Behind North Polar Spur
214080	6.80	0.05	B1Ib	102	2.17	45	3000	2500	30	
186994	7.30	0.0(?)	B0III	126	2.35	79	2900	500	15	
219188	6.90	0.12	B0.5III	185	2.09	83	1800	1360	60	
210809	7.55	0.33	O9Ib	114	1.58	100	3400	185	60	
218915	7.20	0.30	O9I	102	1.72	108	3200	-380	60	
14633	7.50	0.10	O8	126	2.09	141	3000	940	30	
41161	6.50	0.17	O9n	300	2.13	165	1400	320	30	
93521	6.90	0.10	O9Vp	303	2.22	183	1900	1700	30	Munch & Zirin show hi velocity gas
42088	7.55	0.37	O6	291	1.99	190	2400	+20	60	
52266	7.23	0.30	O9V	303	1.70	219	1700	-20	60	
97991	7.41	0.0	B2V	170	1.99	262	960	+752	60	
99171	6.11	0.11	B0III	240:	2.35	286	1400	+430	15	
86606	6.34	0.10	B1Ib	300:	2.15	290	2200	-505	30	
112244	5.40	0.32	O9Ib	138	2.03	304	1300	130	60	
135591	5.50	0.19	O9I	131	2.29	320	1700	-75	15	
150898	5.57	0.13	B0Iab	108	2.42	330	1900	-280	7	
155806	5.50	0.30	O8e	211	2.05	353	1450	70	60	
								Total	13.4 hours	

NOTE: Stars are listed in order of increasing galactic longitude

have Lα and other important emission (such as the 1048 and 1067Å argon lines) appear on the detectors simultaneously, without moving the grating and re-exposing. For each planet the angular size was assumed to be that at mean quadrature or maximum elongation from the Sun. We should recognize, of course, the availability of planets depends very much upon the actual launch date.

Table 1 (cont)

(b) Highly Reddened Stars

HD	V	E(B-V)	Sp	v sin i	log $N_S/\sigma(N)$	r (pc)	E(B-V)/r* (mag kpc^{-1})	Observing Time (min)	Comments
147889	7.86	1.10	B2V	100	0.30	260	4.26	60	
167971	7.52	1.05	O7.5If		0.54	1400	0.74	60	
169454	6.61	1.13	B1Ia		0.59	900	1.23	60	
194279	7.01	1.20	B1.5Ia		0.39	1050	1.14	60	
194839	7.50	1.18	B0.5Ia	79	0.33	1200	1.00	60	
195592	7.08	1.14	O9.5Ia	79	0.48	1200	0.97	60	
							Total	6 hours	

*A general average of E(B − V)/r in our part of the galaxy is 0.61 mag kpc^{-1}.

(c) sdO Stars

ID	V	E(B-V)*	log $N_S/\sigma(N)$	Observing Time (min)
BD +75° 325	9.2	0.10	1.77	60
F 34	11.21	0.10	1.36	60
F66	10.54	0.12	1.46	60
F67	11.86	0.06	1.32	60
HZ 44	11.71	0.13	1.20	60
HD127493	8.54	0.61	0.86	60
BD +33° 2642	10.84	0.23	1.17	60
BD +28° 4211	10.2	0.06	1.65	60
			Total	8 hours

*Intrinsic colors assumed to be $(B - V)_0 = -0.40$

Table 1 (cont)

(d) Planetary Nebula Nuclei

Nebula	V	E(B-V)	log $N_s/\sigma(N)$	Observing Time (min)
NGC40	11.64	0.35	0.77	60
NGC1535	11.92	0.20	1.02	60
IC418	9.37	0.24	1.45	60
A36	11.55	0.22	1.05	60
NGC6543	10.39	0.30	1.12	60
NGC6826	10.48	0.19	1.33	60
NGC7009	11.5	0.0	1.51	60
NGC246	11.95	0.03	1.36	60
NGC3242	12.03	0.17	1.06	60
NGC7662	11.80	0.15	1.14	60
NGC2392	10.43	0.16	1.40	60
			Total	11 hour

(e) Binary X-ray Sources

HD	Source	V	E(B-V)	Sp	log $N_s/\sigma(N)$	Observing* Time (min)
77581	3U0900-40	6.88	0.78	B0.5Ib	0.84	90
153919	3U1700-37	6.55	0.6	O7f	1.28	90
24534	x Per	6.35	0.56	O9.5 e4p	1.40	90
65818	v Pup	4.1	0.08	B1Vp+B2	2.83	60
					Total	5.5 hours

*Consists of many short observations at various phases of the orbit.

(f) Planets

Planet	30 Min Counts/R at 1216 Å	30 Min Counts/R at 1050 Å	Observing Time (min)
Venus	0.47	1.3	30
Mars	0.16	0.43	30
Jupiter	0.74	2.0	60
Saturn	0.34	0.92	120
		Total	4 hours

Except for groups e and f, the general strategy for assigning time is to give each object a maximum of two 30-minute observing intervals. Those targets which are bright enough to give $N_S/\sigma(N)$ greater than about 100 in a shorter time have their observations curtailed accordingly. Unfortunately, the signal quality for the highly reddened stars may be rather mediocre – a situation we must tolerate when using far ultraviolet radiation to probe dark interstellar clouds. The observed large variability in extinction at these wavelengths could very well cause these observations to be either of much higher quality or to consist of almost no signal at all.

In summary, we note that the three-day observing program laid out in Table 1 will provide far UV spectra (with a photometric precision of 1% in most cases) of 48 stars with a wide variety of astrophysical interest as well as of 4 planets. This program blends well with a direct-imaging program of the kind discussed in Section IIIA, both of which may be accomplished during a single 7-day mission.

C. Precisely Calibrated Spectrophotometry

Absolutely calibrated spectrophotometry is of fundamental interest to almost every area of astrophysics and cosmology. Space-based telescopes have unique advantages in making such measures not only because they have access to the entire electromagnetic spectrum but also because they avoid the time-variable wavelength dependent absorption problems of the earth's atmosphere. The SUOT will be the first one-meter class space telescope with adequate calibration control to extend such measures to moderately faint stars.

Absolute calibrations of stellar spectral energy distributions have been carried out with fully calibrated small instruments in sounding rockets and will be conducted with small Shuttle payloads for bright stars via techniques such as the synchrotron method of Bless, Code, and Fairchild. However, the objects which can be measured with high precision by small, absolutely calibrated instruments are far too bright for large instruments such as the LST to observe without severe overloading of counters. By analogy, the Oke multichannel scanner on the Palomar 5-meter and the Wampler IDS on the Lick 3-meter are restricted to objects fainter than about V = 10.0, while instruments with apertures of the order of 30 cm can produce high-precision data in reasonable times only for objects brighter than perhaps V = 7. The SUOT will be able to bridge this gap to establish a sequence of ultraviolet standards for the LST. For this reason alone, SUOT will be an extremely valuable, if not crucial, element in the fundamental problem of absolutely calibrated spectrophotometry.

In addition to the above LST service function, the SUOT spectrophotometers will be able to address directly numerous problems of great interest. For example, bolometric luminosities of hot stars are important for numerous problems but are still poorly known. Of special import in this context are the strong absorptions in the ultraviolet by abundant atomic species such as carbon. The SUOT spectrophotometer will be able to measure the complete spectrum, with high photometric precision, of a wide variety of stars of all population types and thereby provide empirical bolometric magnitudes. These would be particularly important for the understanding of Population II stellar atmospheres, for instance the blue horizontal branch stars in globular clusters which could be reached and isolated by the facility. Such observations in a vastly expanded sample will serve further to refine the understanding of the influence of departures from LTE and from static, plane-parallel atmospheres.

The Copernicus observation of the depletion of heavy elements in the interstellar gas makes the extension of the extinction curve determinations begun by OAO-2 (and the inclusion of polarimetric information in those determinations) of great importance since these data can place important constraints on the grain composition. This is particularly the case across the 2200Å feature seen in Figure 1 of Appendix D which is suggestive of graphite, and also at shorter wavelengths where the rapid increase is believed by Witt and Lillie to be due to scattering. This latter conclusion is further reinforced by the requirements on grain albedo shortward of the Lyman limit which Mezger et al. impose in order to explain the relative ionizations of hydrogen and helium in H II regions. The SUOT would be able to measure the ultraviolet extinction curves for the complexes of stars within H II regions, such as the Trapezium and the several stars which are collectively known as HD 164492 in NGC 6514. These stars are known to have anomalous visual extinction curves, which are presumably due to the hostile environment within the nebula. OAO-2 observations suggest effects in the 2200Å feature, but the accurate elimination of the nebular scattered light and the separation of the individual stars was not possible with the OAO but would be with the SUOT. This separation would further help to resolve the degree of circumstellar contribution to the anomaly.

Among the many extragalactic problems which might be addressed by the SUOT spectrophotometer, an excellent example is the discrimination between the various models proposed to explain the spectra of Seyfert galaxy nuclei. The relative importance of early-type stars and interstellar dust in galactic nuclei could also be determined by SUOT. Its angular resolution would be crucial in separating nuclear regions from other parts of the galaxy. Ultraviolet spectrophotometry of QSO's with intermediate redshifts would detect the same lines observed in optical wavelengths in high redshift objects. High-precision spectrophotometry of all of the emission lines in such QSO spectra would serve to define more accurately the physical conditions in these most interesting objects. In summary, the overall importance of spectrophotometric data argues strongly for the inclusion of such instrumentation on several SUOT missions.

To delineate a typical observing program we assume two 30 minute exposures per orbit, this giving a total of 192 exposures. Not all exposures will need to utilize the full 30 minutes; indeed, many would be substantially shorter. On the other hand, some windows will be lost to the South Atlantic anomaly when high voltages must be turned off and some will be lost to target identification problems, rest periods, maintenance, and other slippage. Thus, as a typical figure, we still adopt a norm of 180 exposures per mission.

A single such mission would probably suffice for the establishment of the sequence of faint spectrophotometric standards discussed above. For this purpose we will assume that on each target four separate exposures must be taken, one each for each of the grating-blaze/detector combinations required to cover the spectrum from 912Å to 10,000+Å (see Section V-C). If the sequence of absolutely calibrated bright standards consisted of the 12 stars of the Hayes (1970) system, the four exposures could be made during a single orbit window on each object. However each primary standard should be observed an average of three times during the mission (beginning, middle, and end) to monitor stability. Thus standardization would consume a total of 36 windows, which leaves 144 windows for program stars. If each of the program stars requires either a full window per wavelength region, or if, for the brighter ones, multiple observations are anticipated, then we could observe 36 sources, such as all of the faint standards in the list of Stone (1974) and all of the bluer white dwarfs in the list of Oke (1974). The result would be an internally consistent system of approximately 30 spectrophotometric standards well distributed over the sky, representing a dynamic range of more than 100 and calibrated from the Lyman limit to the redmost capability of photomultipliers – a most worthy project.

On subsequent missions not dedicated solely to calibration, it should be anticipated that of the order of 30 windows would be allocated to the calibration of that flight and the rechecking of selected standards. This would leave approximately 150 windows for other programs of spectrophotometry. Again allotting four windows per object, with some allowance for false starts and reobservation, approximately 30 sources per mission could be observed. This number would represent a substantial sample for any of the programs previously discussed. The extension of the missions to two weeks or a month would more than double or quadruple this productivity since the fractional allocation of time devoted to standardization would decrease. A single 30-day mission would probably suffice to measure virtually all of the unusual objects in the list of faint blue stars at high galactic latitude of Greenstein and Sargent (1974). A two-week mission would allow us to observe all the extragalactic objects in Table 2. Clearly a very substantial amount of important research can be done within the time constraints of expected Shuttle missions.

Table 2

Extragalactic Spectrophotometric Targets Observable in a Two Week Flight

(a) Bright QSOs

Name	V	B-V	U-B	Z	Polarization	Comments
3C 273	12.8	+0.21	-0.85	0.158	?	
PKS 1004+13	15.15	+0.13	–	0.240	–	
PKS 1302-102	15.25	-0.05	-0.82	–	–	
3C 351	15.28	+0.13	-0.75	0.371	–	
PKS 2135-14	15.53	+0.10	-0.83	0.200	–	
3C 249.1	15.72	-0.02	-0.77	0.311	–	
PKS 0837-12	15.76	+0.02	–	0.200	–	
TON 469	15.78	+0.10	-0.68	0.534	–	
3C 323.1	(15.8)	–	–	0.264	–	
PKS 2251+11	15.82	+0.20	-0.84	0.323	–	
TON 256	15.91	+0.57	-0.84	0.131	–	
PKS 2344+09	15.97	+0.25	-0.60	0.677	–	
PKS 2128-12	15.98	+0.13	-0.67	–	–	
MARKARIAN 132	16.00	+0.25	-0.84	1.758	–	
BL LAC	12.0-15.6	+0.99	-0.14	0.07?	2-10%	
PKS 0537-441	12.6-16.5	–	–	–	–	
OJ 287	13.1-13.8	–	–	–	2-15%	Like BL Lac
3C 345	14-18	+0.29	-0.50	0.594	2-10%	
PKS 0735+178	14(var)	+0.52	-0.43	0.424	2-30%	
PKS 1400+162	14(var)	–	–	–	5-10%	Like BL Lac
3C 66A	15.21	+0.50	-0.49	–	–	Like BL Lac

Table 2 (cont.)

(b) Bright Seyfert Galaxies

Name	m_{TOTAL}	$m_{NUCLEAR}$	B-V	Diameter	Z
1068	9.81	–	0.74	380"	0.004
1275	13.14	–	0.85	68"	0.018
1566	10.09	–	0.70	–	0.004
3227	11.75	–	0.87	330"	0.003
3516	12.86	14.0-15.0	0.79	80"	0.009
3783	(13.08)	–	0.56	72"	0.009
4051	11.23	14.6	0.65	280"	0.002
4151	11.48	12.2-13.4	0.74	450"	0.003
5548	13.54	14.7-15.7	0.60	80"	0.017
6814	12.46	–	0.89	136"	0.005
7469	13.06	14.7-15.5	0.67	89"	0.017
7603	14.01	–	0.72	55"	0.029
Mk 501	13.88	–	0.72	60"	0.033
Mk 3	13.34	–	1.15	44"	0.014
Mk 231	13.84	–	0.84	27"	0.041
Mk 335	13.85	–	0.41	16"	0.025
3C 120	14.27	–	0.58	42"	0.033

D. Solar System Studies

The high resolution and accessibility to the IR and UV regions of the spectrum, and the ability to observe at small solar elongation angles will make SUOT a valuable tool for the study of solar system objects including planets, satellites and comets. Also, the ability to monitor transient phenomena almost continuously over periods of one to four weeks gives SUOT another important advantage over ground-based telescopes.

Even though LST may also be used to observe solar system objects and will have the advantage of higher resolution and greater aperture, it is likely that specialized equipment such as polarimeters and medium- and narrow-band filters tuned for example, to isolate methane and ammonia absorption bands, sodium D lines or spectral absorption features of minerals will not be available on LST. Likewise, the presence of men with SUOT makes possible delicate and rapid maneuvering of both Shuttle and SUOT which will permit observation of planets and comets at much smaller elongation angles than LST can tolerate. The presence of man also makes possible quicker detection and better tracking of transient phenomena.

It is recommended that a very high resolution planetary camera be carried on every SUOT flight in order that synoptic imaging may be carried out as often as possible. Since exposures on planets will be short it is expected that relatively little observing time will be required to accumulate significant amounts of synoptic data on all the planets. It is expected that this camera will use all reflecting transfer optics to maintain broad spectral response and will be designed to ensure that resolution will be diffraction-limited and not detector limited. The resulting 0.1 arcsecond resolution at 4000Å translates to a linear resolution of 75 km at a distance of 1 AU. By use of image processing it is possible to make further improvement in resolution at some expense to photometric fidelity.

Although high resolution direct imaging would be the primary solar system observing program, extremely valuable spectrophotometric data can also be obtained by use of the spectrographs and spectrophotometers which are also expected to be available with SUOT.

The following section indicates on a planet-by-planet basis the scientific problems on which SUOT data would have a significant bearing.

Direct Imaging Programs

Mercury (Resolution approximately 75 km)—Medium-passband spectrophotometry and polarimetry would aid in the mapping of distinct geological provinces. At this resolution, it would not be possible to detect individual topographic features. Significant improvements in our knowledge of both the figure and obliquity of Mercury could be made.

Venus (Resolution 50 to 100 km)—Observations of the 100 m/s UV clouds would lead to a better understanding of zonal and meridional motions than has been acquired so far through Mariner 10 and ground-based imaging. Although the Mariner 10 photography has been very valuable in providing clues to the planet's atmospheric circulation, the interval of observation was less than 10 days and, therefore, represents only a momentary look at an atmosphere which ground-based photography suggests is constantly changing. The ability of Pioneer Venus Orbiter 1978 to provide imaging of UV clouds at sufficiently short time intervals is presently open to question.

Spectrophotometry and polarimetry at high angular resolution from the visible to vacuum ultraviolet regions of the spectrum should lead to positive identification of the composition and size distribution of cloud particles, and bring out any differences between the bright and dark UV clouds. The recent identification of bright cloud particles as uniform droplets of concentrated H_2SO_4 is not completely consistent with the observations.

Mars (Resolution 30 to 150 km)—Narrow-band filters would permit the monitoring of the time-dependent, spatial distribution of minor atmospheric constituents such as CO and O_3, important to studies of Martian aeronomy.

Observations of the initial stages of Martian dust storms would help to determine the conditions that cause them. Both continuity and high resolution in several spectral passbands are important. The Martian date of onset of major dust storms is usually predictable within a few weeks.

The association of the diurnally and seasonally variable discrete white clouds with large Martian volcanos is now well established. However, the details of day-to-day variations in cloud intensity and the precise locations of the clouds with respect to the individual volcanic summits is very poorly known. Detailed knowledge of this behavior would aid in determining whether the clouds are caused by orographic uplift or by local-source degassing, possibly associated with volcanic activity. Blue-light imaging at appropriate time intervals during the Martian season of maximum white cloud activity would provide such knowledge.

Jupiter (Resolution 300 to 450 km)—SUOT imaging with resolution comparable to or better than the best obtained by Pioneers 10 and 11 can be achieved (see the frontispiece). Mariner Jupiter/Saturn 1977 will obtain photographs with resolution better than 300 km for only 25 days out of a scheduled observing interval of 80 days.

Synoptic imaging at regular intervals over a ten-day time base can obtain the zonal and meridional components of the Jovian wind field with mean velocity errors of less than 0.2 m/s.

Observations of the Jovian wind field at the visible cloud surface, when combined with high resolution cloud morphology could lead to a better understanding of the planet's general circulation. It should be noted that the MJS77 mission can provide even better information on the motions and morphology of small scale cloud features. However, like the Earth, Jupiter undergoes large changes in cloud structure and flow patterns over periods of hundreds to thousands of days. Thus SUOT observations would tend to complement rather than duplicate results obtained from non-orbiting planetary spacecraft.

All of the comments which apply to the study of cloud motions in general apply equally well to the study of features of special interest such as the Great Red Spot, South Equatorial Belt disturbances and the North Temperate Belt (southern component) zonal jet. The activity associated with these and various other interesting atomospheric phenomena is often ephemeral in nature and can easily be missed during the short time interval of near encounter in a fly-by mission.

As with cloud motions, planetary spacecraft are better suited than the SUOT or the LST to make limb darkening measurements, not only because of the ability of the planetary spacecraft to obtain higher spatial resolution, but also because of their unique viewing geometry. However, the cloud structure and its scattering properties are undoubtedly time variable, and SUOT studies would again tend to complement those results obtained from planetary spacecraft.

High resolution imaging of Jupiter in the 8900Å absorption band of CH_4 would provide useful information on individual cloud heights. Similar photography in the 2200Å absorption band of NH_3 would give the planet-wide distribution of ammonia in the Jovian upper atmosphere. The response of the vidicons which will fly on MJS77 is such that neither of these bands can be observed.

Imaging of Jupiter at wavelengths short of 300 nm would give the temporal and spatial distribution of ultraviolet absorbing aerosols in an otherwise Rayleigh scattering atmosphere. The shortest wavelength at which MJS77 pictures can be taken is about 3000Å, although the MJS photopolarimeter can obtain line scans down to approximately 1800Å.

Saturn (Resolution approximately 650 km)—Most of the science objectives which are given for Jupiter apply equally well to Saturn. Mean errors associated with cloud motions will be approximately twice as large for Saturn.

There is little that the SUOT could do with the rings of Saturn that could not be done better by Pioneer 11 or MJS77, unless a SUOT Shuttle flight could be scheduled as early as 1980, when the earth passes through the Saturnian ring plane. Such observations would establish the amount of material which may exist within the ring plane, but situated either radially outside and/or inside of the visible rings.

Uranus (Resolution 1500 km)—No cloud markings have ever been photographed on Uranus. A search for cloud structure is important because, if found, discrete features would provide the first accurate value of the planet's rotation period. Limb darkening curves, superior to those obtained by flight 7 of Stratoscope II could be produced from deconvoluted SUOT imaging.

Neptune (Resolution 2200 km)—The science objectives given for Uranus apply to Neptune as well.

Pluto (Resolution 3000 km)—It is doubtful that SUOT imaging of Pluto would produce results of value.

Satellites (Resolution identical to that of their primaries)—In general, imaging of satellites would produce data that are appreciably inferior to those obtainable by planetary spacecraft. An exception would be Titan, where observations of its time-variable atmospheric cloud cover would complement Pioneer 11 and MJS77 imaging results.

Spectroscopic Programs

Useful spectroscopy can be done by SUOT at both UV and IR wavelengths. Ultraviolet spectroscopy would give the distribution of hydrogen around Jupiter, Saturn, Io and Titan as well as its isotopic abundances (H/D) at H Lα and D Lα. Argon in the Martian atmosphere could be estimated from the strengths of the resonance lines at 1048 and 1067Å.

Electronic transitions in biologically important organic molecules occur in the spectral region from 2000 to 3000Å. A search in the atmospheres of Jupiter, Saturn and Titan for such molecules would be a crucial step in determining whether or not chemical or biological evolution of organic molecules has taken place on these outer solar system bodies.

The precisely calibrated spectrophotometer will be useful for planetary studies. For example, its high angular resolution makes possible the measurement of UV albedos of small surface regions of nearby planets. These observations could be carried out synoptically with an efficiency nearly equal to that of the

LST since the detection of surface brightness depends only upon the f/ratio of the system. This factor is comparable between the two facilities, while the angular resolution superiority of the LST is only a factor of two or three greater and may, in this context, be unnecessary. Furthermore, the presence of the observer might be the best way to insure the acquisition and tracking of moving and transient features such as Martian dust clouds. The PCS should also be particularly well suited to high precision spectropolarimetry of planetary atmospheres with high angular resolution.

Although Fourier spectroscopy of the planets in the near infrared (1 to 4 um) can be accomplished from the NASA C141 infrared observatory, it is found that angular resolution is quite poor due primarily to turbulent air flow over the observing window. Therefore high angular resolution IR spectroscopy from SUOT will be highly desirable.

It is unlikely that a 7-day SUOT mission would be dedicated entirely to solar system observations. Therefore we have not formulated such an observing program but instead, have itemized a "typical" planetary direct imaging observing program which might be carried out daily during a SUOT mission.

We assume two filter wheels, one containing four polarizers and a clear aperture, the other, approximately eight color filters. As an example, the color filters might include four broad-band (500Å bandpass) filters centered at 2500, 4500, 6500 and 8500A and four narrow-band filters isolating prominent bands of methane, ammonia, ozone and pyroxene. It is further assumed that an observation of the five bright planets with a broad-band filter requires roughly 1 minute* and that an observation through a narrow-band filter requires roughly 2 minutes.

If we assume each bright planet will be observed once every 24 hours with two of the narrow-band filters, with each broad-band filter by itself and, finally, with the 4500Å filter and each of the polarizers, we arrive at an observing time of 12 minutes per planet. Thus observing all five bright planets once each day would require roughly 90 minutes (60 minutes plus maneuvering and set up time), i.e., about 6% of the total observing time. Similar observations of Uranus and Neptune will require considerably longer observing periods but would presumably be carried out less frequently.

*This time includes operational set up time and also envisions multiple exposures. Actual exposure times should be a fraction of a second for wide band filters. For example, if the planetary camera operates at f/60 and has a 10% quantum efficiency, the exposure for a 500A band pass should be about 10^{-2} sec for Venus, 10^{-1} sec for Mars and 0.5 sec for Jupiter. These exposures are sufficiently short to prevent loss of resolution due to motion of the planet relative to guide stars.

E. Other Programs

In addition to the above highest priority programs, the FDT also noted several areas of research which will be of obvious interest to SUOT users. These include moderate resolution spectroscopy at wavelengths from 1200 to 8000Å, IR Fourier spectroscopy from 1 to 4 μm, wide field high angular resolution spectroscopy, and filter photometry. With man's presence it may be possible to employ complex high-risk instruments such as a very high wavelength resolution Fabry-Perot spectrometer or a Michelson beam interferometer for measuring stellar diameters.

Even though at first sight some of these appear to strongly overlap the scientific objectives of LST instruments it should not be forgotten that SUOT instruments have a degree of flexibility not available to LST. Thus exotic detectors, new varieties of filters and gratings, new data handling methods, etc. may be accommodated by SUOT from mission to mission. And in many cases SUOT is able to observe more efficiently in the intermediate magnitude ranges too faint to be reached by IUE but too bright to be efficiently handled by the LST detectors.

The moderate resolution spectrograph would most likely be an echelle system giving a wavelength resolution in the 0.1 to 1Å range. Its design should emphasize high efficiency rather than high photometric accuracy so that stars in the 8th to 15th magnitude range could be observed with reasonable exposures. The scientific programs which it would accommodate include the following: abundance studies of horizontal branch stars in globular clusters and the galactic halo, abundance vs. luminosity and position studies of blue giants and supergiants in the Magellanic Clouds, spectroscopy of components of close binary stars, studies of the UV spectra of old novae, dwarf novae and flare stars, UV studies of magnetic variables and peculiar A stars, etc. Scaling from study results for LST, we estimate the following limiting magnitudes for spectroscopy in the visible (corresponding limits for UV spectroscopy are a function of spectral type). These assume a 1Å match to a single 30 μ m pixel, an overall system efficiency of 1% and a 10^4 sec integration time.

Standard Deviation	Limiting V Magnitude
10%	18.4
5	17.0
3	15.9

Nebular spectroscopy can benefit from the extended wavelength range, high resolution and comparatively large (1/2°) field provided by the SUOT. A program of prime interest with such an instrument would be the study of UV emission from supernova remnants. Lines of special interest are included in Table 3. Although x-ray emission is more useful in studying the very hot ($\sim 10^6$ °K), rarified portions of the remnants, UV and optical lines are very useful in studying the cooler,

Table 3
Spectral Lines of Special Interest in Supernovae Remnants

Line Identification	Emissivity Per Hydrogen Atom (10^{-23} ergs cm^{-3} s^{-1})	T max (10^5 °K)
C II 1334	3.34	0.5
CIII 977	15.8	0.8
CIV 1550	5.49	1
N III 992	1.70	1
O VI 1031	7.7	3.2
Ne VI] 1060	0.80	5
O IV] 1406	2.94	1.6
N III] 1750	0.87	0.8
Si III] 1885	0.53	0.63
Si III] 1892	0.34	0.63
C III] 1906	2.88	0.8
C III] 1909	1.91	0.8
C II] 2326	3.68	0.4
[Ne IV] 1609	0.318	1.6
[Ne IV] 2440	1.22	1.6
[Ne IV] 2438		
[Ne V] 3346	0.377	3.0
[Ne V] 3426	0.377	3.0
[Ne V] 2972		3.0
[Ne V] 1575		3.0
[O II] 3726	1.23	0.4
[O II] 3729	1.79	0.4
[Ne III] 3869	0.522	1.0
[Ne III] 3968	0.522	1.0
[O III] 4959	0.403	1.0
[O III] 5007	1.17	1.0
[Si VIII] 2764	5.3	9.3

denser regions. As an example of the value of UV data we can measure line ratios of transitions which occur in the same ion. Thus the ratio of the total flux in the [Ne IV] 1609, 1608Å lines to the total flux in the [Ne IV] 2441, 2438Å lines is a measure of the temperature of the gas in which the ions are located. The line ratio of the [Ne V] 1575Å and the [Ne V] 3346, 3426Å lines yields similar information. On the other hand, the ratio of the flux in the [Ne IV] 2441Å line to that in the [Ne IV] 2438Å line is a sensitive indicator of the gas density. In the far ultraviolet, two of the most important lines which should be looked for are O VI 1031Å and [Ne VI] 1060Å which are formed at intermediate temperatures, 3.2 to 5×10^5 °K, and are comparatively strong.

It is also important to determine ionic abundances in order to accurately understand the details of the shockwave theory and the overall heating effect of the supernova on the interstellar medium.

Crucial to these measurements is knowledge of the interstellar extinction between the remnant and the observer. Intensity ratios between auroral and transauroral lines are useful for this purpose. Examples of such ratios are [O III] 2321, 2332Å/[O III] 4363Å; [Ne V] 1562, 1574, 1592Å/[Ne V] 2975Å; [Ne IV] 1609Å/[Ne IV] 4715, 4725Å; [O II] 2470Å/[O II] 7319, 7330Å; [N II] 3063, 3070Å/[N II] 5754Å; [Ca V] 2412Å/[Ca V] 3996. Ideally, this information would be supplemented by photometry of hot stars in the neighborhood of the remnant.

When equipped with a Fourier spectrometer and semi-conductor detectors, SUOT should be a powerful tool for studying the spectra of stars and planets in the 1-4 micron region. Even though similar studies can be conducted from balloons or the NASA C141 Infrared Observatory, SUOT will have the advantage of greater angular resolution and reduced background radiation.

Absolute IR spectrophotometry should be particularly valuable in improving our knowledge of the bolometric radiation of cool stars and in determining opacity sources, relative abundances of atomic and molecular species and the physical conditions in the outer layers of the photosphere. In the 1 to 2 μm region, absolute spectrophotometry of selected standard stars would not only provide useful data for refining model atmospheres for cool stars but would also provide standards useful to both the LST and the Shuttle Infrared Telescope. Preliminary calculations show that SUOT should obtain data in the 1 to 2 μm region with a S/N of 30 and a resolving power of 2000 on 5th magnitude M0 stars.

Filter photometry is an obvious general purpose application of any telescope. By sacrificing spectral resolution, broad band photometry is able to provide greater photometric accuracy and can reach much fainter stars or finer time resolutions, than available from spectrophotometry. It is probable that scientific programs for such an instrument as SUOT would include high-accuracy UV photometry of barely resolved globular cluster stars and binary stars, refined follow up color data on newly discovered blue halo stars, QSO's, etc., and rapid photometry over a wide wavelength range of QSO's, pulsars, rapid variable stars, and planetary and lunar occultations of stars and satellites.

IV. FACILITY CONCEPT AND SPECIFICATIONS

A. Basic Concepts

The basic concept for SUOT is generally defined by the guidelines presented to the FDT. These are listed in Appendix A. The FDT found these guidelines reasonable although it was noted that cost considerations (Item 6) could not be dealt with by the FDT directly. It was also noted that the requirement not to exclude missions as long as 30 days (Item 9) might exclude any use of a pressurized Spacelab module either to provide an accessible focal plane configuration or to provide room for controls and displays of greater extent than could be provided within the Orbiter itself.

B. Pallet-Mounted vs. Accessible Focal Plane Configuration

The FDT considered the option of mounting the telescope externally on a Spacelab pallet versus mounting it in a way so that the focal plane is delivered into a pressurized Spacelab module. We noted that the accessible focal plane configuration would give direct access to instrumentation thus allowing finer and more detailed adjustments to complex instruments, greater ability to troubleshoot and repair malfunctioning instruments, unlimited scope for exchanging instruments, and greater flexibility in retrieving film and exchanging film magazines. However, opposing arguments included the likelihood that use of a pressurized module would prohibit missions as long as 30 days, that costs might be prohibitively large if extensive modifications to the module were required, and that the module might curtail the ability to share payload volume and mass with other payloads. A compelling scientific argument against the accessible focal plane concept is its requirement for a tertiary diagonal mirror which is objectionable both to experiments which wish to minimize reflections in order to reach the 912-1150Å spectral region and to experiments which involve polarimetry. It was concluded that the pallet-mounted configuration would receive the primary attention of the FDT but that future consideration of the accessible focal plane configuration would not be ruled out until the costs and other disadvantages of interfacing with a Spacelab module could be better defined.

C. Optical Parameters

Concerning telescope optical design the FDT agreed to the following basic principles:

1. Every effort would be made to maintain a diffraction-limited, flat field diameter of 0°.5 in order to take advantage of SUOT's wide-field high-resolution imaging capability. "Diffraction-limited" is taken to mean image diameters (70% encircled radiation) in the 0.2 to 0.3 arcsec range at 4000Å.

2. The 0°.5 field diameter will be fully baffled so that operation on the day and night sides of the Earth is possible. Full baffling is taken to mean that focal plane sensors can see neither the sky nor the tube of the telescope. Full baffling of the tracking field is also desirable since no loss in guiding accuracy can be tolerated in the sunlit portion of the orbit.

3. The linear obscuration ratio should not exceed 0.4 so as not to degrade unduly the diffraction-limited image quality. At this level, the percentage of the total light falling within the central peak (with a diameter of 0.2 arcsec at 4000A) is about 65%.

These principles were primary factors in the decision to adopt a focal ratio of f/15 for SUOT. Although highest resolution imagery would require a focal ratio of at least 25 if the 0.2 arcsec image diameter were matched to an easily achieved detector pixel size of 25 μm, such a ratio leads to a steeply curved field which cannot be corrected and flattened over a 0°.5 field diameter (this assumes that the focal ratio of the primary mirror cannot exceed f/2.5 in order to keep the telescope tube length within reasonable bounds). A large focal ratio also leads to difficulties in achieving full baffling. A reasonable compromise is reached at f/15 where the baffling and field diameter requirements are met while a 0.2 arcsec image diameter corresponds to a pixel diameter of 14.6 μm. This pixel diameter is currently achieved by electrographs and fine grained emulsions.

Two other factors influence the decision to adopt an f/15 focal ratio: the linear dimension of the 0°.5 field and the requirements of the far UV spectrograph. At f/15, 0°.5 corresponds to 130 mm whereas at f/25 it corresponds to 217 mm. Since magnetically focused image tubes with 140 mm photocathode diameters currently exist, it seems highly probable that electrographs of this size might also be developed within the next ten years. On the other hand it is unlikely that any sensor other than unaided photographic emulsion can accommodate a 217 mm field within this timeframe. Since the lengths of high resolution spectrographs are generally proportional to the focal ratios of their collimators there is a considerable length and volume advantage to operating at f/15. Beyond this, preliminary analysis of the far UV spectrograph indicates that the f/15 focal ratio optimizes its design in terms of correcting aberrations and matching detector sizes.

D. Instrument Mounting System

The guideline that two or more instruments be mounted for use on SUOT on each mission is highly desirable for at least three reasons: (1) in case one instrument fails, SUOT will not be completely incapacitated, (2) a number of scientific problems make near-simultaneous observations with different instruments highly desirable and (3) for efficient use of orbital time. When instruments are flown which operate best in the Earth's shadow, then other instruments must be flown to utilize the daylight portion of the orbit.

Still another dual instrument concept pertains to efficiency: since the direct-imaging survey is one of the primary objectives of SUOT, it is highly desirable that direct-imaging camera exposures be made on every field at which SUOT is pointed and stabilized. Particularly in the case of spectroscopy of stars it should be possible to conduct spectroscopy and direct imaging simultaneously by allowing the light from the single star to pass through a hole in a diagonal mirror which diverts the remainder of the field to the direct-imaging camera. This concept, together with the requirement that both the far UV spectrograph and the high-accuracy spectrophotometer should avoid all unnecessary reflections leads to an instrument configuration in which one of these spectrographs is mounted on axis while the direct imaging camera is mounted 90° to the optical axis on nearly all flights.

At least three other 90° positions are also available. The FDT feels that one of these should be occupied by the very high resolution planetary camera which is carried on nearly all missions and another by a field-viewing vidicon arrangement to be utilized for field identification and general troubleshooting on all missions. The remaining position might be occupied by another spectrograph (dimensional constraints may not permit this), a filter photometer or by whatever other instruments might be eventually proposed for SUOT. It must be recognized that if SUOT is mounted on a conventional yoke mount the instruments at two of these 90° positions can extend no further than 0.5 meter off the optical axis. If the "inside-out gimbal" Instrument Pointing System (IPS) being developed by ESRO is used as a mount, then currently proposed constraints indicate that instruments may extend as far as 1 meter from the optical axis.

It is envisioned that either a rotating or a linear array of diagonal mirrors can be used to shunt the light beam of SUOT to the various instruments. Some of these mirrors must be perforated to allow simultaneous use of a spectrograph with the imaging camera. When direct imaging is conducted in this mode it is necessary to tolerate a field with a central hole 2 cm in diameter surrounded by vignetted halo with a total diameter of 4 cm. Although the loss of this area may appear undesirable, it should be noted that it constitutes only 9% of the total field area. The size of the mirror perforation is determined by the need to place field correctors approximately 200 mm in front of the focal plane for direct imaging. This distance plus space for the diagonal mirror requires a distance of about 300 mm from the center of the mirror to the focal plane. Thus the f/15 converging beam of the spectrograph star requires a 2 cm hole in the diagonal mirror.

It is generally conceded (to reduce the dimensions of pick off mirrors and to optimize the quality of focal plane tracking in the direct imaging mode) that the focal plane tracking system should be associated with the beam directed to the direct imaging camera. This presents no particular problem in guiding for other instruments other than the requirement that the diagonals for those instruments incorporate an annular mirror situated so as to divert the rim of the field to the star trackers.

E. Pointing and Stabilization System

For reasons of economy NASA has interpreted Guideline 11 to mean that SUOT should make use of the Spacelab Instrument Pointing System (IPS) as a basic mount for pointing and stability. In principle this does not seem unreasonable, but since the detailed performance specifications of IPS are not yet clearly defined there remain large areas of uncertainty in the feasibility of this approach. The IPS performance specifications which are recommended by the NASA Payload Planning Steering Group are listed in Table 4. These specifications, so far as they go, meet the requirements of SUOT well. The stability of ±1 arcsec along the optical axis requires that the telescope incorporate a secondary stabilization system to achieve the ±0.02 arcsec stability which is ultimately required, but this is to be expected. The roll stability of ±2 arcsec is adequate to provide full stability control in roll. SUOT could tolerate no more than a ±4 arcsec (1σ) stability in roll since this would translate into a motion of ±0.02 arcsec in an image lying at the edge of a 900 arcsec field radius.

However, the specifications in Table 4 do not cover important areas of the interface between SUOT and the IPS. Optical studies indicate that tilt of the secondary mirror to accomplish fine stabilization of the images must not exceed ±9 arcsec else appreciable degradation of image quality will result. Thus it is clear that, whether Shuttle is in a free drift or a limit cycle mode, the IPS must be an integral part of the fine stabilization system. Not only must it be able to accept signals from the SUOT focal plane sensors (a concept currently accepted by IPS designers) but it must also accomplish its compensating motions with accuracies and time constants compatible with the SUOT focal plane guiding system. The current technology for this system envisions a 0.3 sec sampling rate in the focal plane sensors, but this is subject to change as advances in this type of technology improves over the next several years. If we accept the 0.3 sec time constant, then the tracking motions must be designed so that unanticipated image displace-

Table 4

IPS Requirements Requested by the NASA Payload Planning Steering Group

Requirements	Units	1980 thru 1983			After 1983			Remarks
		Stellar	Solar	Earth	Stellar	Solar	Earth	
Physical:								Earth Pointing instruments will require specialized pointing systems. Commonality with stellar & solar pointing IPS uncertain.
Payload Capacity (A)								
Diameter	m	2[a]	1.6	2	3.7	2	18[b]	
Length	m	6	7	1.5	9.5	7	18[b]	
Mass	kg	3000	1200	1000	5000	1300	1500	
Payload Capacity (B)								
Diameter	m	0.8	0.8	–	0.8	0.8	–	
Length	m	3	4	–	3	4	–	a) This value is based on cooling with LHe. The use of supercritical He would increase this value to 2.4m.
Mass	kg	400	300	–	400	300	–	
Gimbal Range								
LOS Angle	deg	±50	± 5	±70	±90	± 5	±70	
Roll Angle	deg	±90	±90	–	±90	±90	±90	
Performance: (3σ)[c]								b) Deployed antenna.
Pointing Acc.-LOS	sec	±1	± 1	±180	±1	±1	±5	
-Roll	sec	±120	±60	±360	±120	±60	±30	c) Pointing and stability to be maintained within specified boundary with a 3σ (99.7%) probability.
Stability - LOS	sec	±1	±1	±1	±1	±1	±1	
- Roll	sec	±2	±10	±2	±2	±10	±2	
Gimbal Slew Rate[d]	deg/min	30	5	90	30	5	90	
Typ. Stability Duration	sec	3600-5400	10-1000	60	3600-5400	10-1000	2700	
Interfaces:								d) Ave. rate for traveling full gimbal range
Cryogens	Type	LHe, LN_2	None	None	LHe, LN	None	None	
Electrical Wires	No.	250-300 plus 10 coax	10-20 plus 10 coax	10-20 plus 1 coax	250-300 plus 10 coax	10-20 plus 10 coax	10-20 plus 1 coax	LOS ≡ Line of Sight (Cone half angle)
								Roll ≡ Angle about instrument LOS

Table 5
SUOT Requirements on the IPS
(All values are 1σ)

	Stability	Acquisition Error	Setting Accuracy	Max. Rate for Guiding	Max. Deviation of Guiding Rate	Slew Rate	Settling Time
Pitch & Yaw	±2"*	±1'	±2"	≥ Shuttle orbital rate (~4°/min)	±0".1/sec ***	30°/min	One minute to reach ±0".1/sec after initial lock on.
Roll	±4"**	±1°	±400"				

*The ultimate SUOT stabilization requirement is ±0".02.

**Assumes that all roll control will be sensed and controlled by IPS.

***Based on 0.3 sec time constant in focal plane guidance system and the requirement that image position not deviate by more than ±0".02.

ments greater than 0.02 arcsec cannot occur in an interval shorter than 0.3 sec. These and more general requirements placed on the IPS by SUOT are listed in Table 5.

It is a basic SUOT requirement to minimize firing of the vernier thrusters. Preliminary studies indicate that the best available servo guiding systems will allow the image to deviate by about 5 arcsec and will require approximately one second to restore ±0.1 arcsec accuracy after each thruster firing. Under these circumstances thruster firing more often than approximately once a minute would be very undesirable. It is also desirable to minimize thruster firing to avoid contamination effects. If the thrusters must be used, it would be extremely helpful for the Shuttle to provide a gate signal just prior to a thruster firing so that an instrument could be turned off while the environment is temporarily contaminated. The option of stabilization with a control moment gyro kit charged to the payload should also be pursued.

The FDT recommends that strong consideration be given to placing Shuttle in a free drift mode during exposures. As long as average drift rates do not exceed $0^\circ.02$/sec there should be no problem in making exposures as long as 40 minutes without thrusting. However, if gravity gradients cause higher rates in this time interval then the possiblity of using appropriate rate limits in the digital autopilot or manual thruster control to reduce the attitude rate must be considered.

It is necessary that the IPS compensate for the Shuttle drift rate during the exposure. It is therefore desirable that the IPS be able to track at a rate as high as $0^\circ.02$/sec while maintaining a positional accuracy of ±0.02 arcsec. It is recognized that this requirement may be a rather stringent one and that it may be necessary to find ways to keep the rates somewhat lower without incurring an undue number of thruster firings.

V. ILLUSTRATIVE FOCAL PLANE INSTRUMENTS

It is expected that SUOT will permit the use of a wide variety of focal plane instruments. Most of these will be designed and built under the supervision of scientists interested in particular scientific objectives. However, it should be seriously considered that some instruments be provided as part of the facility, for the general use of all astronomers. The relationship between the design of a telescope and its basic instrument complement is so intimate that it is necessary to consider in some detail the design and performance of its basic instrumentation before arriving at a final design for the telescope. It is logical that the instrumentation for the four high priority programs listed in Section II serve this purpose for SUOT. A brief description of the current concept of each of these instruments, its performance specifications and its technological problems, if any, follow.

A. Direct Imaging Camera (DIC)

The basic performance required of this camera is that it produce image diameters of 0.3 arcsec or less over a flat field having a diameter of at least 0.5 degree diameter and over a wavelength range from 2000A to 8000Å. Chromatic aberration should be controlled so that light in as large a wavelength range as possible can be integrated in a single exposure. We note that, within the proposed optical constraints, fused silica will yield a wavelength range from 2800Å to 8000Å and CaF_2 will yield 2400 to 8000Å. If direct imaging at shorter wavelengths is desired it is expected that the refractive elements will be removed and that the consequent loss of field diameter will be accepted. Field curvature will limit this field to a diameter of about 0.1 degree. It is not foreseen that direct imaging at far UV wavelengths will be of primary importance to SUOT.

As currently conceived by the FDT, the DIC includes field correctors, sensors for the focal plane guidance system, a filter system, a field flattener, a detector and interchangeable film magazines. The guidance sensors may either lie behind the field correctors and use them to achieve their required image quality or they may lie in front of the correctors and employ their own corrector system. The FDT is willing to consider sensors which extend into the data field so long as their width is not much greater than 10mm. If such a system were used it is then highly desirable to place the sensors behind the correctors and as close as possible to the focal plane in order to minimize vignetting in the converging beam. However in this case it will be necessary to provide annular field correctors for the guidance system whenever direct imaging without refractive elements is desired. It is doubtful that it would be feasible to convert from far UV image sensing to visible light image sensing due to the mechanical complexity of interchanging these elements, removing the field flattener, refocussing, etc. This is an operation which might be considered only if an accessible focal plane configuration were adopted thus allowing these changes to be made manually.

The FDT recommends that the DIC be constructed so that detectors may be easily changed between missions since it is likely that a variety of detectors may be used for different observational programs.

The ideal detector for the DIC has three basic requirements: (1) a sensing surface at least 130 mm in diameter, (2) a pixel diameter of 14.6 μm or less and (3) as high as possible a quantum efficiency, hopefully on the order of 15%. No one sensor currently exists which meets all these requirements. However, three current sensors meet two out of the three requirements: fine-grained photographic emulsions, certain image tubes, and electrographs. Since each of these three sensors may potentially be improved to also meet the third requirement, the FDT is optimistic that with only a minimal investment in development an "ideal" detector for SUOT will be available by the 1980's. In the meantime, any one of the above detectors at their current level of development may be considered a suitable detector for particular direct imaging objectives.

Fine-grained photographic emulsions meet the requirements for field size and pixel size but have relatively low quantum efficiencies. Kodak III a-J is probably the most suitable of the currently available emulsions and when properly sensitized and processed yields a detective quantum efficiency of about 3%. In its current form it would be useful for many of the wide-field survey-type functions listed in Section IIIA if exposure times of up to 20 hours per field were permitted. However, this time requirement plus the lack of any current expectation of an increase in resolution or sensitivity renders the bare photographic emulsion the least promising of the three detectors.

At least one currently available image tube, the magnetically focussed ITT 140 mm tube, satisfies the requirements for field size and quantum efficiency. Its current pixel diameter is about 50 μ m but there is hope that this may be improved by a factor of two or more with only a modest development effort. One of the most encouraging aspects of this detector is that its resolution is currently limited by the resolution of the phosphor and the problem of transferring the image from the phosphor to the photographic emulsion. Thus it demonstrates the ability of a relatively simple and rugged magnetic focussing system to maintain sharp focus over such a large field. It remains to be demonstrated whether the basic quality of the electron image can be held to a 10 μm pixel size but current workers in the field are optimistic that such quality can be achieved. Even in its current form the ITT 140-mm tube would be an effective detector for programs such as 3d, e, f, g and 4a in Section III A where high linear resolution is not a prime requirement. It would also be useful in any program where it is permissible to use projection optics to increase the linear size of the optical image at the expense of angular field diameter. One potential problem to be investigated is the effect of the particle radiation environment on detectors using phosphor output such as the ITT tube.

Currently available electrographs satisfy both the requirements for pixel size and quantum efficiency but so far none have been operated with photocathode diameters in excess of 50 mm. However, in view of the demonstrated capability of the ITT image tube mentioned above, workers in the field are optimistic that such a large format electrograph giving pixel diameters of 10 μ m is feasible. Such an instrument would be ideal for SUOT as well as for many other astronomical applications and the FDT recommends that NASA give all possible support to the development of such a detector.

It must be acknowledged that the complexity of operation of current ground-based electrographs is a factor which discourages their use. This complexity arises from the fact that the bi-alkali and tri-alkali photocathodes used for visible and near infrared wavelengths are extremely sensitive to chemical deterioration when exposed to even minute amounts of water vapor. Thus they must be protected not only from exposure to the atmosphere but also from the water outgassed by the recording emulsions. Either extensive pumpdown and outgassing of the emulsion is required before it is exposed to the photocathode or else a very thin membrane capable of transmitting high-energy electrons but not water molecules must be interposed between the emulsion and the photocathode. Space telescopes have two special advantages which mitigate these problems. First, the photocathodes sensitive in the region from 1100 to 3000Å (KBr, CsI, and CsTe) are relatively unaffected by water vapor and may be operated without the complex protective procedures. Secondly, when the bi-alkali and tri-alkali photocathodes must be used, space operation provides a vacuum environment in which outgassing of large amounts of emulsion can be effected with a minimum of effort. This is not to imply that these photocathodes can be exposed to the ambient atmosphere of the Shuttle environment. Even this will be detrimental to these surfaces and further pump down of the emulsion is necessary. However, such pumping effort should be minimized by the preliminary outgassing to the space vacuum. A further factor in improving the utility of electrographs both on the ground and in space are recent improvements in thin protective membranes which may be used to protect the photocathode from the emulsion and thus eliminate any need for outgassing or further pump down of the emulsion.

Two other factors which make electrographs highly desirable detectors should be noted here. The first is the availability of several different photocathode materials which are sensitive to various regions of the UV spectrum but not to visible light. Thus these photocathodes provide long wavelength sensitivity cutoffs in the UV which cannot be efficiently accomplished by any available transmission filter. This is still an unsurmounted handicap when one contemplates isolating broad bands in the UV with bare photographic emulsion as the detector. The second factor is the very wide dynamic range and the linear response of the nuclear track emulsions used to record the electron images in electrographs. Thus the information storage capacity is much greater than that of ordinary photographic emulsion and it is much easier to calibrate and interpret the density vs. intensity relation of the emulsion.

One aspect of both the image tube and the electrograph which bears careful consideration when configuring the focal plane instruments is the volume required by their focussing systems. For example, the ITT 140 mm image tube has a basic magnet diameter of about 300 mm but this is increased to about 500 mm if magnetic shielding is required.

B. Far UV Spectrograph (FUS)

The current concept of the FUS is described in section b of Appendix C and is illustrated in Figure 1. A Rowland configuration is dictated by the need to minimize the number of reflections in the instrument since each reflection causes a light loss of at least 50% in this wavelength region. This requirement also necessitates aligning the FUS optical axis with the optical axis of SUOT in order to avoid the use of a diagonal mirror. The length of the FUS also dictates this configuration. Optical design studies of SUOT have demonstrated the feasibility of placing the FUS detectors in front of the telescope f/15 focal plane as implied in Figure 1.

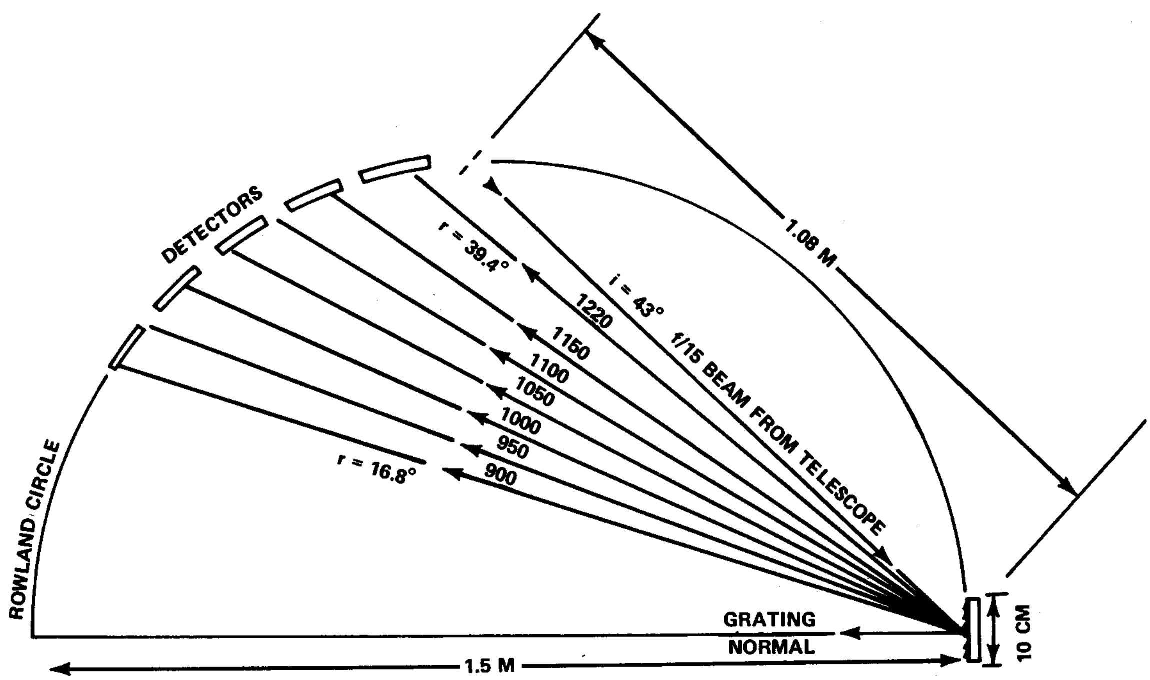

Figure 1. Schematic Layout of the Far-UV Rowland Spactrograph

It is highly desirable that the resolution of the FUS exceed that (2×10^4) of the Copernicus spectrometer by a significant factor since the Copernicus data is found to have a velocity resolution which is marginal for some interesting astrophysical problems. As Appendix C indicates, the resolution of the FUS will probably be limited by detector resolution. The 4×10^4 resolution of Appendix C is based on a conservative value of detector resolution ($50 \mu m$) and it would be surprising if this might not be improved by a factor of two to three by the time this instrument reaches final design.

It is also highly desirable to record large sections of the spectrum simultaneously in order to reach fainter stars than can be reached by the Copernicus scanning spectrometer system. This seems entirely feasible and, as Appendix C (Section c) indicates, the current concept is to use multiple image intensifiers such as microchannel plates with proximity focussing of electrons onto charge coupled devices. Technology is currently advancing rapidly in these areas and it does not seem overly optimistic that highly efficient linear array detectors suitable for spectroscopy will be available by the 1980s. Indeed, it would probably be unwise to design a telescope about a more conservative concept at this time.

C. Precisely Calibrated Spectrophotometer (PCS)

The heart of the proposed instrument would be a spectrometer which is shown schematically in Figure 2. As shown it is a Monk-Gillieson monochromator optimized for third-order aberrations according to the scheme described by Schroeder (1970). It consists of a single concave mirror and a plane grating. A plane grating in a converging beam as shown results in coma and since coma depends upon an odd power of the offaxis angle, the coma of the mirror can be used to compensate for the aberration which results from differing angles of incedence in different parts of the beam. Astigmatism is also negated in this scheme and there is no difficulty in maintaining a 10Å spectral purity over the useful blaze of most gratings. In order that optimum grating-blaze, detector combinations be available over the widest possible range of wavelengths, it will be assumed that gratings and detectors can be mounted on turrets or carrousels for quick interchange. Gratings should also be rotatable in order to change effective wavelengths. The optical system should have sufficient unvignetted field of view to allow for dual-channel operation, which in the simple spectrometer mode of operation would be used for simultaneous sky/background measurement. The entrance apertures would be in pairs, one for object and one for sky. In this connection, an interesting possibility for further study would be the feasibility of accomplishing the switching of the roles of the object and sky apertures as is standard practice in ground-based systems (e. g. the Lick-Wampler scanner) by means of articulating the telescope secondary in the manner of IR observers. If this could be done at frequencies of 1 sec^{-1} or faster, with simultaneous switching of counter registers allocated to sky and to background and electronic switching of the guider system, then compensation for rapidly variable particle-induced background could be accomplished with an attendant increase in the capability of the system for the observation of faint sources. In addition to the entrance aperture plate, the focal plane region could usefully include television cameras (intensified) for target acquisition, centering, and off-set finding/guiding.

A short distance downstream from the entrance aperture would be located a filter wheel, which in addition to containing order separation filters can contain all that is needed to turn the instrument into a spectropolarimeter. The scheme of Nordsieck (1974) consists simply of two retardation plates of different thicknesses with

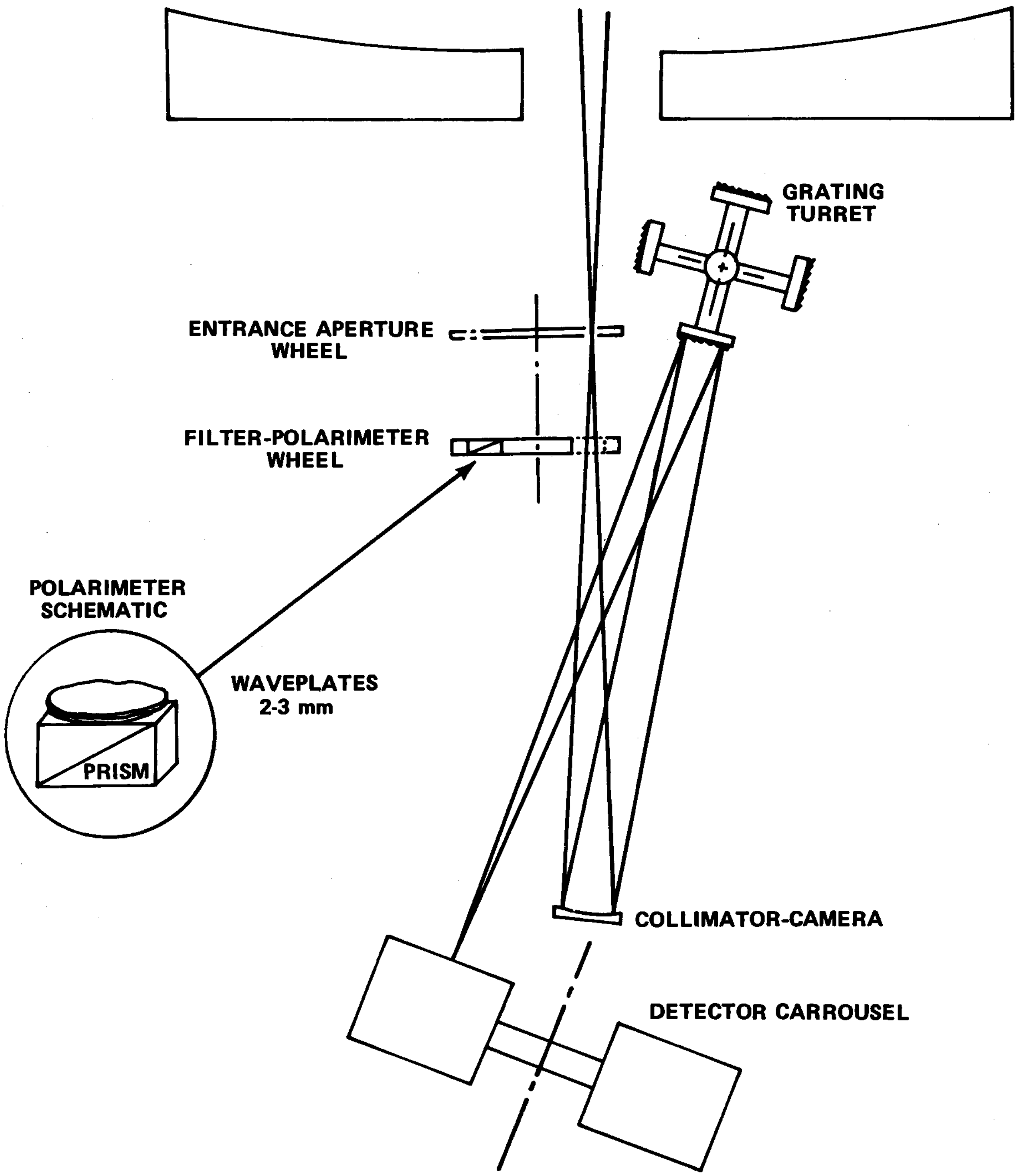

Figure 2. Schematic Layout of the Precisely Calibrated Spectrophotometer

their optic axes at a 45° angle to each other followed by an analyzer. The analyzer would be a beam-splitting prism enabling both senses of polarization to be measured simultaneously by the double detector array. The retardation plates modulate, as a function of wavelength, the polarized component of the radiation. From this modulation the four Stokes parameters I, Q, U, and V may be determined as follows: If A and B are the spectral intensities observed simultaneously in the two sets of detectors, corrected for instrumental response, then:

$$I(\lambda) = A + B$$

and

$$p(\lambda) = \frac{A - B}{A + B} = q(\lambda) \cos t_2 + u(\lambda) \sin t_2 \sin t_1 - v(\lambda) \sin t_2 \cos t_1$$

where q, u, v = (Q, U, or V)/I and $t_i = 2\pi(\Delta n)d_i/\lambda$, Δn is the birefringence of the retardation plates and d_i their thicknesses. The Stokes parameters can be extracted from the data on line by simple Fourier routines.

The detector which would be adequate for this system is a roughly 100 by 2 array of channeltrons each with its own pulse amplifier-discriminator and counter register. Smaller arrays of these devices have been built, both with and without windows, and have been space qualified so there is no essential reason that the detector requirements of this system cannot be met. Furthermore there is the distinct possibility that there will soon be available even more advantageous devices such as a microchannel plate intensified, buffered read-out charge coupled device or a MCP ≈ 500 × 2 element digicon. In order to handle the data generated by such a system we would expect to require the dedicated services of a nova class computer with some high-density storage such as a disk. With appropriately designed hardware controllers and an adequately flexible software system such as FORTH, it should be possible for the payload specialist to reduce one block of data while the next is being collected and thus to return from orbit with fully reduced data.

D. Planetary Camera

A detailed concept for the planetary camera remains to be developed. However, the planetary camera is expected to consist of:

- all-reflecting transfer optics
- interchangeable spectral and polarizing filters
- a shutter

- a detector (with a quantum efficiency on the order of 10%)
- an internal photometric calibration source.

The transfer optics would correct for any zonal residual abberations in the main optical system and would increase the effective focal ratio of SUOT to ensure that the overall system is diffraction limited and not detector limited. Detectors under consideration are silicon vidicons and charge coupled devices with or without intensifiers. Such detectors would require an effective focal ratio of approximately f/60 or f/75.

VI. OPERATIONAL CONCEPTS

A. Make-up and Functions of Shuttle Payload Crew

The FDT recommends as a fundamental principle that every effort be made to operate SUOT continuously while in orbit and that missions be extended as long as possible, at least to 20 days and hopefully to 30 days. It is possible for a two-man payload crew to carry out such a mission but to expect each man to operate 12 hours a day for a 30-day mission would be to invite inefficiency due to fatigue and lost observing time due to the possible incapacitation of one crewman. Therefore it is considered highly desirable that the SUOT payload crew consist of at least three men and possibly of four. In view of the tradeoffs which may exist between the number of crewmen and length of stay in orbit, a three-man crew would appear to be the best compromise for present planning purposes.

Presumably this crew would consist of a Mission Specialist and two Payload Specialists. It is recommended that the Mission Specialist be an astronomer by scientific profession who is thoroughly familiar with and nominally in charge of the operation of SUOT in orbit and that the Payload Specialists are astronomers who are onboard to carry out specific observing programs. In general (and especially on early missions) the Payload Specialists are expected to be staff members from the institutions providing the focal plane instruments and therefore will act as the onboard experts in the operation and troubleshooting of these instruments. After instrument reliability is thoroughly established then it is to be expected that many of the Payload Specialists will be "guest investigators" who are experts in the significance of the data obtained but who may not necessarily be intimately acquainted with the instrumentation. In this case the Mission Specialist with the support of the ground team must supervise instrument operation and maintenance also.

It is recommended that the primary functions of these crewmen include both the real time monitoring of the quality and the significance of the scientific data as well as the real time operation of the facility. Although the monitoring of data quality will be carried out in a more thorough and complete manner by the ground team, it seems reasonable that onboard personnel who are completely aware of all aspects of the Shuttle environment (changes from night to day, unusual crew motions or thruster operations, water dumps, etc.) and who have continuous and undelayed access to the incoming data will be better able to promptly detect and react to unusual aspects of instrument performance or of the scientific data. On the other hand it is expected that the ground team will be better equipped to evaluate the finer nuances of instrument performance or of scientific significance but that this will require extended periods of time and can be expected to influence the long-term planning aspects of the mission rather than the minute-by-minute control of the telescope and instruments.

It is expected that greater operating efficiency can be obtained by allowing the payload crew to exercise primary control of SUOT and its instrument complement. The chief reason for this is the expectation that real time communication between Shuttle and the ground will be available only 80% of the time and that, even then, there may be some delays in the communication cycle. However it is expected that the ground team will be able to communicate with the SUOT control computer and can control SUOT if circumstances make this desirable. Although "hard wire" control of vital functions should be possible as a backup mode it is envisioned in view of the current rapid advances in computerized control of ground-based telescopes, that control will normally be exercised through a computer. It is probable that operation of the telescope and instruments will be programmed several orbits at a time and that the crew will monitor such operation and will provide inputs of human judgment when the computer so requests or when an obvious error in the automatic system is detected. Functions where the computer should request human approval before proceeding are: verification of correct target and safety of the maneuver before a change in telescope pointing is made, verification of target identification and centering before exposure is begun, etc. On complex fields it is expected that human judgment will be routinely required to decide which star or which nebular knot should be centered on a spectrograph or photometer entrance aperture. And in the case of many partial failures of pointing systems, stabilization systems, instrument systems, etc. direct human control may be used to continue operation even though it may be at reduced efficiency.

Skylab experience indicates that one of the more frequently required functions of man in orbit is to troubleshoot and repair malfunctioning equipment. Unfortunately, unless an accessible focal plane configuration proves possible, the access to the focal plane instruments for such repair is limited to EVA operations. Planned EVA for the interchange of film packs on extended (30 day) flights is highly desirable and SUOT will be designed to simplify this procedure. The possible duration of EVA with corresponding interruptions in data acquisition may prohibit such activities on 7 day missions. Even though EVA may be costly in time (it must be remembered that advances in pressure suit technology could very possibly reduce this time cost by the mid-1980's) it is recommended that critical failure points (particularly those in the telescope facility) be designed for EVA accessibility. It is particularly recommended that in case of failure of the pointing system that a manual means to return to a reentry stowage configuration be made possible via EVA in order to avoid possible jettisoning of the telescope.

Man's usefulness in repairing equipment can be an advantage for those components contained within the Orbiter cabin. Careful consideration should be given to designing these for easy accessibility and replacement of modules.

The work cycle for a three-man payload crew may be arranged in several ways. The most logical would be to operate three overlapping 12-hour shifts, i.e., with one man on duty from 0 hours to 12 hours, the second from 8 hours to 20 hours and the third from 16 hours to 4 hours. Thus each shift has eight hours of dual operation and four hours of solo operation. Such a system has the advantage of providing long overlap of shift handovers and only small displacement in work cycles when one man is due for a rest day.

In addition to taking a regular shift for instrument operation the Mission Specialist should expect to be on 24-hour call when malfunctions of the SUOT systems occur.

B. Ground Team Function

Even though it is to be hoped that the Shuttle crew will be capable of sustained operation even in the event of communication difficulties, the value of a ground team during normal operations is unquestioned. The majority of instruments on SUOT will probably employ electronic detectors from which the data may be telemetered to the ground. For these instruments a ground team of several scientists and technicians should conduct detailed monitoring of both the quality and the scientific interest of the data. It is expected that long range planning of observing programs would be accomplished by the ground team on the basis of this preliminary analysis of the data.

Other functions of the ground team would include implementing changes in observing programs by supplying telescope control sequences, providing information on guide stars, star identification charts etc. and analysing complex malfunctions the solution of which is not obvious to the men in orbit.

C. Orbital Constraints

The most important orbital constraint will be to achieve orbits in which the sun will lie near the orbital plane for as long a period as possible throughout the mission in order to maximize the length of orbital night. It is assumed that a number of instruments (the direct imaging camera in particular) will be significantly affected by the brighter sky background during the sunlit portion of the orbit. For one-week missions there should be little difficulty in meeting this constraint but for 30-day missions it will be impossible to satisfy completely due to orbital precession.

The optimum orbital altitudes lie between 200 and 400 nautical miles – high enough to avoid significant aerodynamic drag interference with orbiter attitude but not so high that van Allen belt particles will significantly affect electronic detectors. At these altitudes the orbital period will be roughly 95 minutes of which up to 40 minutes will be in Earth's shadow (if the Sun lies in the orbital plane). The depression of the horizon will be about 15° and objects in the orbit plane will be more than 5° above the horizon for about 50 minutes of each orbit. Objects lying out of the orbit plane will be visible for a larger fraction of the orbit. Thus for objects which can be observed only in the Earth's shadow the maximum interval of observation will be 40 minutes and for objects which may be observed in the shadow or out the interval ranges from 50 minutes in the orbit plane to unlimited for objects within 10° of the orbit poles.

Since time in orbit is the essence of a mission it is expected that missions will be planned so that two or three objects may be observed in each orbit and that the time to slew the orbiter and/or the telescope to a new object will be on the order of five minutes. It is highly undesirable that more than 10 minutes be consumed from the time observations of one object end and the time observations of the next object begin.

D. SUOT — Orbiter Interfaces

The interfaces of interest include (a) stabilization, (b) attitude control and maneuvering, (c) contamination, and (d) utilities.

1. Stabilization. It is to be expected that SUOT will generally require Shuttle to be stabilized in a wide dead band mode or to be in a free drift mode during observations. It is desirable to minimize firing of all thrusters during observations in order to minimize contamination and to eliminate the guiding excursions which will inevitably result from such angular accelerations. Whether a wide dead banding mode or a free drift mode is better depends mainly on the magnitude of the angular accelerations which will act on Shuttle in the free drift mode. Studies of these effects are currently in progress.

If the average drift rate over a 40-minute exposure is 0. 01 deg/sec or less then the telescope pointing system can probably counteract the drift. Although such rates probably can be achieved, if the x-axis of Shuttle is kept vertical in the gravity field, this is an undesirable constraint since the telescope pointing system will then be required to compensate for the 4°/min orbiral rate and since objects close to the orbital plane will be occulted by the nose of the Orbiter. It is to be hoped that other attitudes may be found where average drift rates of 0. 01 deg/sec or less may be maintained for periods of several minutes.

2. Attitude, Pointing and Maneuvering. As noted above, attitude affects both the feasibility of using the free drift mode and also the ability to see all areas of the sky. Further study is required before all aspects of these trade-offs are understood. Since the rate at which the Orbiter is maneuvered to a new attitude affects the amount of contamination incurred there are tradeoffs in this area which require further study also.

The best conclusion at this time is that SUOT will wish the Orbiter to maneuver at the maximum rate to any arbitrary attitude, to settle into a minimum drift rate at that attitude (with or without dead banding) and to accomplish such a maneuver over 90° in the course of five minutes or less. It is expected that at least two and as many as four such maneuvers may be required in each orbit.

Current information on RCS fuel requirements indicates that adequate fuel exists in the basic RCS-OMS system to support the SUOT requirements for both attitude holding and maneuvering.

3. Contamination. Contamination from the vernier thrusters is an important consideration when attitude holding and maneuvering is considered. Contamination from other sources (outgassing of Shuttle and the payload bay, water dumps, etc.) are also of critical concern to SUOT. Such contamination has three undesirable effects for astronomical telescopes: (a) thin films of contamination deposited on mirror surfaces may drastically reduce reflectivity in both the ultraviolet and the infrared regions of the spectrum, (b) column densities of molecules surrounding the spacecraft may be sufficiently high to impress molecular absorption on the spectra of the cosmic sources being observed and (c) even very tenuous clouds of molecules or solid particles will add substantially to the background sky brightness on the day side of the orbit and will critically affect the ability to observe faint objects for at least 60% of the orbital observing time.

The FDT has been informed of the current status of contamination control studies but has not been able to assess in detail the adequacy of these for SUOT observations. However it is clear that current limits on sky brightness and molecular column densities are marginal for SUOT and will be of continuing concern. It is expected that the effects of one major source of contamination, the RCS thrusters, may be alleviated by reducing the use of these thrusters to a bare minimum.

4. Utilities. By "utilities" we mean Shuttle provided power, communications, thermal cooling, and support of the payload crew.

The power requirements of SUOT are estimated to average 1 kilowatt. Although it is clear that SUOT will require more than the basic 50 kwh supplied to the payload by the Orbiter, the addition of a single power kit should supply SUOT for a full 30-day mission. A matter of much greater concern for 30-day missions is the problem of supplying power for the Orbiter itself.

At the current time it appears that the Shuttle communications system, though minimal, is adequate for SUOT, and that thermal cooling will not be required except, perhaps, for the electronic equipment in the Orbiter cabin. The nominal weight penalties for carrying extra crewmen do not appear excessive. However when these are added to other weight penalties required to operate a 30-day mission it is expected that the ability to support more than two payload crewmen may become critical. In this case SUOT management would probably elect to take extra time in orbit at the expense of extra crewmen. If this is not a critical area then SUOT would probably desire to use up to four payload crewmen.

Appendix A

Guidelines for the SUOT Study

The following set of guidelines for this study were suggested by the GSFC study scientist. They were reviewed and adopted by the FDT with only minor complaints.

1. The SUOT will be operated as a Spacelab or Shuttle Sortie facility. Its possible use as a free-flying, automated satellite is not to be invoked.

2. The SUOT will be a general purpose astronomical telescope. It should

   a. reflect foreseeable scientific requirements of a broad spectrum of astronomical users,

   b. be useable with a variety of focal-plane instruments,

   c. provide relatively simple and well-defined interfaces (optical, mechanical, thermal, electrical, computational, etc.) for the general user and,

   d. provide a benign environment for astronomical instrumentation.

3. The SUOT will be programmatically flexible. It should

   a. be amenable to ground refurbishment and reflight as often as 2 to 3 times per year for a decade, and defined so as to make cost-effective use of that capability,

   b. allow cost-effective upgrading of its performance over its lifetime, and

   c. be capable of sharing a given flight with other disciplines – most especially with Solar Physics, High Energy Astrophysics or automated satellite deployment/recovery flights – wherein orbiter orientation, mission timeline and resource allocation will be optimized to serve the needs of the total payload.

4. The SUOT facility concept will be driven by the requirement to optimize, within program constraints, operations efficiency so as to assure the return of as much high quality data as possible from each flight.

5. The SUOT will be useable as a national facility with focal plane instruments developed primarily by Principal Investigators.

6. The SUOT will be a relatively low-cost facility. At least one concept for SUOT will be defined within a cost target $\$1 \times 10^7$ (1974 dollars), including all telescope-unique hardware and an initial set of focal plane instruments. More costly concepts may be considered but it should be recognized that the probability of program implementation will be substantially reduced as costs approach or exceed $\$2 \times 10^7$.

7. In the definition of the SUOT, requirements for new technology development will be minimized. Currently understood design approaches and current technology will be used to the greatest possible degree. The results of previous telescope studies will be used where possible.

8. In terms of weight, volume and resource requirements, the SUOT will constitute the equivalent of one-half a Spacelab pallet-only payload or less for a seven day flight.

9. The SUOT will be fully productive during Spacelab flights of 7 days duration. The facility definition will assure that out-gassing, thermal equilibration, etc., will not unduly hamper the use of the SUOT during 7 day missions. The SUOT will be capable of use on Spacelab flights as long as 30 days duration. The facility definition will carefully consider crew consummables and other resources required to extend mission duration from 7 to 30 days and will assure that the weight penalties so incurred will not prevent the SUOT from being used in 30 day flights.

10. The SUOT will be capable of carrying and utilizing two or more focal plane instruments per flight so as to enhance mission reliability and flexibility.

11. The SUOT will utilize Shuttle-Spacelab-ASP resources where possible. The facility definition will seek to minimize any reliance on telescope-unique systems.

12. The SUOT will be consistent with Shuttle-Spacelab-ASP programmatic and technical constraints including those related to payload center of gravity, safety, contamination, cross-interference with other payloads, payload integration, crew structure, telemetry and communications, etc.

13. The final SUOT definition will be the responsibility of NASA, taking into account the FDT study results, related engineering studies and program requirements. Issues of major controversy or issues with major programmatic impact may be resolved by the ASP project or by NASA Headquarters.

Appendix B

Limiting Magnitudes for SUOT Field Imagery

Table 1 gives a numerical analysis of the relative capabilities of the SUOT, the LST and the groundbased 200-inch telescope when observing point sources. Signal-to-noise ratios based on photon statistics have been calculated, in most instances, for 30 min exposures and 1000Å bandpasses. The night sky brightness is taken as V = 23.0 mag/arcsec^2 for SUOT and LST and as V = 22.0 mag/arcsec^2 for the 200-inch. The day sky brightness for SUOT and LST is taken as V = 20.0 mag/arcsec^2. Other basic constants used include the photon flux per Å per sec per cm^2 from a V = 0.0 A0 V star (10^3) and the overall efficiency for the telescope and director (0.1). Both sky brightness and star brightness are assumed constant with wavelength in these calculations. In the near infrared (0.6 to 1.0 μm) the sky brightness will actually be 2 to 3 magnitudes fainter than on the ground.

Problems of detector noise and detector saturation have been evaluated assuming an electrograph operating with an S-11 photocathode and L4 emulsion. It is assumed that seven photoelectrons per square micron produce a density of one in this emulsion and that the uncooled photocathode produces instrument background fog at the rate of 0.001 density units per minute. It is found that the instrument noise is slightly stronger (a factor of 1.5) than sky noise for SUOT and considerably stronger (a factor of 4) than sky noise for LST and, therefore, affects limiting magnitudes. However, since detector noise can be reduced by a factor of about 100 by cooling, it is assumed that it may be effectively eliminated and therefore, is not included in tables 1 and 2.

It is interesting to note that, for isolated point sources, the SUOT and the 200-inch have equal S/N ratios for matching exposures at about V = 25.5 and at fainter magnitudes SUOT is faster than the 200-inch. For faint point sources in crowded fields or superposed on a bright background (for example, stars in globular clusters or nearby galaxies) SUOT will have an insuperable advantage over any groundbased telescope. It will also be significantly faster than the 200-inch for isolated point sources in the near infrared. At magnitude V = 27 the LST/SUOT ratio of S/N is 3.76, which indicates that SUOT can reach the same S/N as LST by exposing 14 times as long. Since SUOT has 100 times the field area of LST, SUOT is therefore, faster than LST by a factor of 7 in conducting large area surveys to equal S/N at V = 27.

Table 2 gives data on S/N for the 3 telescopes when observing extended objects. In this case, focal ratio is the prime factor in speed and SUOT is faster than LST by a factor 2.6. For similar reasons the 200-inch is faster than SUOT and LST in spite of its higher sky background. However, a simple focal reducing camera in the SUOT focal plane would reduce its f/ratio to values comparable to that of the 200-inch so that advantage might be efficiently taken of the fainter sky brightness in space.

To reach the faintest possible limiting magnitudes on spectrally continuous sources, space telescopes can employ the entire spectral range available to their detectors. Ground-based telescopes are limited to much smaller spectral ranges by airglow and man-made radiation as well as by atmospheric absorption. Examples of S/N ratios for both SUOT and LST employing a 5000Å bandpass on point sources are given in Table 1. Similar increases in S/N would apply to Table 2.

At high brightness levels SUOT can achieve S/N = 100 in 30 minutes exposure for 0.2 arcsec resolution elements on extended objects with V = 16.5 mag/arcsec^2.

It is interesting to consider whether or not detection of faint galaxies is an extended area problem for each telescope. Assuming that giant elliptical galaxies have a diameter of 20 kpc and Mv = -22.0, then their angular diameter will be 0.2 arcsec at V = 25; assuming no intergalactic absorption. Thus, such a galaxy will be resolved by LST, barely resolved by SUOT and unresolved by the 200-inch.

Table B-1

Limiting Magnitudes For Point Sources

Quantity		SUOT	LST (2.4m)	200-inch
Mirror Area	(cm^2)	6892*	39,700	184,500
Photoelectrons/sec/1000Å/ 25 mag (V)		0.0689	0.397	1.84
Focal Ratio		15	24	3.5
Plate Scale	(arcsec/mm)	13.75	3.58	11.60
Image Diameter (70% encircled energy)	(arcsec)	0.2	0.1	1.0
Image Diameter (70% encircled energy)	(μm)	14.5	27.9	86.2
Image Area	(arcsec^2)	0.0314	0.00785	0.785
Image Area	(μm^2)	166	611	5836

Table B-1. (Continued)

Quantity		SUOT	LST (2.4m)	200-inch
Night Sky Magnitude Per Image Area		26.76	28.26	22.26
Night Sky Photoelectrons/Image Area/30 min/1000Å		24.5	35.5	41,320
Night Sky Photoelectrons/μ m/ 30 min/1000Å		0.148	0.058	7.1
Star Photoelectrons/Image Area/ 30 min/1000Å**	24 mag	218	1256	5823
	25 mag	87	500	2318
	26 mag	34	200	922
	27 mag	14	79	367
Star S/N/30 min/1000Å (night)	24 mag	13.3	34.5	19.6
	25 mag	7.4	20.9	7.9
	26 mag	3.8	12.2	3.2
	27 mag	1.7	6.4	1.2
Sky Density/30 min/1000Å with L4 emulsion		0.021	0.008	1.0
Star S/N/30 min/5000Å (night)	24 mag	29.7	77.1	--
	25 mag	16.5	46.7	--
	26 mag	8.5	27.3	--
	27 mag	3.8	14.3	--
Sky Density/30 min/5000Å with L4		0.1	0.04	(5.1)
Day Sky Photoelectrons/ Image Area/30 min/1000Å		388	563	--
Star S/N/30 min/1000Å (day)	23 mag	15.0	48.2	--
	24 mag	6.9	25.7	--
	25 mag	3.0	12.4	--
	26 mag	1.2	5.5	--

Table B-1. (Continued)

Quantity	SUOT	LST (2.4m)	200-inch
Sky Density/30 min/1000Å with L4 (day)	0.33	0.13	--

*Includes 0.35 central obscuration
**assumes 70% total energy within image area.

Table B-2

Limiting Magnitudes For Extended Objects

Quantity		SUOT	LST	200-inch
Sky Photoelectrons/30 min/1000Å/15 μm pixel		26.15	10.25	1255
Source Photoelectrons/30 min/1000Å/15 μm pixel	21 mag/arcsec	165	65	3152
	22 mag/arcsec	66	26	1255
	23 mag/arcsec	26	10	500
	24 mag/arcsec	10	4	199
S/N/30 min/1000Å/15 μm pixel	21 mag/arcsec	11.2	7.0	41.9
	22 mag/arcsec	6.1	3.8	20.4
	23 mag/arcsec	2.9	1.8	9.1
	24 mag/arcsec	1.3	0.82	3.8

Appendix C

Capability of the Far UV Spectrograph

Since the main thrust of section II-B (Scientific Objectives) deals with the study of absorption lines produced by the interstellar gas, our discussion of the principles which govern instrumental capabilities will adhere to this context. For other fields of research, such as stellar atmospheres, some modification and generalization of the arguments will likewise yield a perspective on the attainability of certain goals.

(a) Sensitivity

i. Basic Equations—A photoelectron count rate per unit frequency interval

$$N_\nu = \frac{\pi F_\nu}{h\nu}\left(\frac{R_*}{d_*}\right)^2 \frac{\pi}{4}(1 - \beta_0^2)\, a^2 \epsilon_\lambda\, H_z^{-1}\, s^{-1} \qquad (1)$$

will be registered by a telescope – spectrometer having

β_0 = secondary mirror diameter divided by primary mirror diameter

a = primary mirror diameter

ϵ_λ = product of mirror reflectivities, grating efficiency and detector which views an unreddened star with

R_* = radius of the star

d_* = distance to the star

πF_ν = surface continuum flux (in ergs cm^{-2} Hz^{-1} s^{-1}) at a frequency ν.

Interstellar reddening will reduce the flux by a factor

$$R_\nu = 10^{-0.4 E_{B-V}\left(\frac{E_{\lambda-V} + A_V}{E_{B-V}}\right)} \qquad (2)$$

where E_{B-V} is the B-V color excess.

A_V is the absorption at V wavelengths and is generally assumed to be $3.0\ E_{B-V}$.

$E_{\lambda-V}$ is the additional absorption which occurs at shorter wavelengths λ. To express R_ν in terms of the total column density of hydrogen N_H (in all forms: atoms, molecules, or photons) we may replace E_{B-V} by $N_H/(7.5 \times 10^{21}\ cm^{-2})$.

For unsaturated absorption lines, we may determine the column density N of atoms or molecules from the measured equivalent widths W_ν from the relation

$$N = W_\nu mc/\pi e^2 f \tag{3}$$

If the continuum level is smooth and well defined, photoelectron statistics will limit the accuracy of the measurement to an error (at one standard deviation) of $\sigma(W_\nu)$ given by

$$\sigma(W_\nu) = (\nu \Delta v/cN_\nu t)^{1/2} \tag{4}$$

where t is the integration time and Δv is the doppler velocity passband over which one must measure W_ν (equal to either the actual profile velocity spread, uncertainty in expected radial velocity, or instrumental resolution, whichever is greater). If we combine equations 1, 3 and 4, we find the error in column density deduced from an unsaturated line is

$$\sigma(N) = 3.38 \times 10^{-7} \frac{d_*}{a\lambda f R_*} \left[\frac{\Delta v}{R_\nu F_\nu \epsilon_\lambda t(1-\beta_0^2)}\right]^{1/2} \tag{5}$$

For an assessment of the versatility of an observing instrument under some specified conditions, it is useful to compare $\sigma(N)$ with N_S, the representative column density for which an absorption line becomes saturated. While one may work with saturated lines in deriving abundances of various species, the results become increasingly inaccurate and more dependent on assumed velocity distributions as the saturation becomes stronger. If we adopt N_S to be the column density where one attains a central optical depth of unity for a gaussian velocity profile with a velocity dispersion of $b/\sqrt{2}$, we find

$$N_S = 66.7b/\lambda f. \tag{6}$$

A good figure of merit for observations is expressed by the ratio

$$N_S/\sigma(N) = 1.98 \times 10^8 \frac{bR_* a}{d_*} \left[\frac{R_\nu F_\nu \epsilon_\lambda t(1-\beta_0^2)}{\Delta v}\right]^{1/2} \tag{7}$$

which may be viewed as either a representative "dynamic range" for meaningful observations of line strengths, or as the signal-to-noise ratio for measurements of moderately strong (but unsaturated) lines under certain observing conditions.

ii. Representative Numerical Calculations—For an integration time of 30 minutes with $\beta_0 = 0.3$, $a = 100$ cm, $b = 5$ km s^{-1} and $\Delta v = 4.24b$ (giving an integration of W_ν over $\pm 3\sigma$ of the gaussian velocity profile) equation (7) reduces to

$$\log [N_S/\sigma(N)] = 4.66 + 0.5 \log F_\nu \epsilon_\lambda - 2.67 \times 10^{-23} \text{ cm}^2 N_H \left[\left(\frac{E_{\lambda-V}}{E_{B-V}}\right) + 3.0\right] \quad (8)$$

if we adopt for a moderately difficult case the observation of a hot star having a value of 6×10^9 for the ratio of d_* to R_* (or 0.2 if R_* is expressed in terms of 10^{11} cm and d_* in kpc). This corresponds, for instance, to a B1 IV star at 1 kpc or a B1 I star at 4 kpc (the corresponding V magnitudes of these stars would range from about 6 to 8, depending on reddening).

For F_ν we shall adopt the fluxes tabulated by Carbon and Gingerich for $T_e = 25{,}000°$ K and $\log g = 4.0$. As presently envisioned, the 1 meter facility will have a configuration very similar to that of the Copernicus instrument (i.e. two reflecting surfaces, one grating and a photocathode). Thus, except for the factor 2 loss at the entrance slit of the Copernicus spectrometer, probably the most reliable indication for realistic values of ϵ_λ can be taken from the measured efficiencies of this system at various wavelengths. Values for $E_{\lambda-V}/E_{B-V}$ are taken from OAO-2 and Copernicus observations.

Table C-1

λ(A)	F_ν	ϵ_λ	$(E_{\lambda-V}/E_{B-V}) + 3.0$
940	1.26 (-3)	5.6 (-4)	15.6
955	3.12 (-3)	8.9 (-4)	15.2
965	3.54 (-3)	1.2 (-3)	14.9
975	1.56 (-3)	1.8 (-3)	14.7
1000	3.86 (-3)	5.0 (-3)	14.0
1015	3.71 (-3)	6.8 (-3)	13.6
1030	2.71 (-3)	8.6 (-3)	13.2
1050	3.80 (-3)	1.1 (-2)	12.7
1100	3.73 (-3)	8.7 (-3)	11.4
1190	3.56 (-3)	4.0 (-3)	10.0

The behavior of log$[N_S/\sigma(N)]$ with λ was computed using equation (8) and the numbers in Table 1; the results are shown in Figure C-1 for three representative values of N_H. For the observing conditions here, reasonably accurate conclusions could be drawn from observations above about 940Å for low color excesses, while one must go above 1040Å when the reddening reaches 0.40 magnitudes. With these graphs we may easily evaluate the behavior of log $[N_S/\sigma(N)]$ for other values of t, R*, d*, b, etc. by noting how these parameters scale in Equation (7).

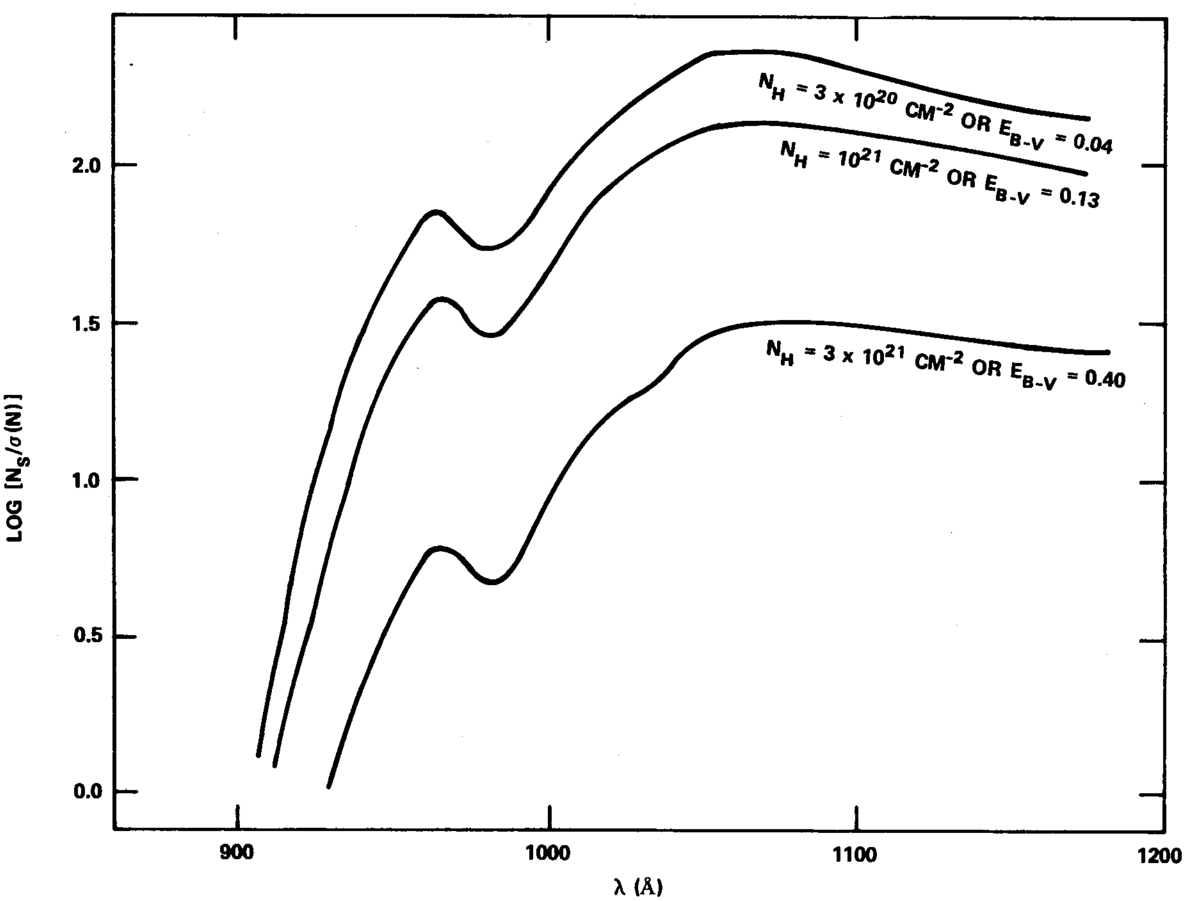

Figure C-1. Signal Quality Versus Wavelength

Equation (6) indicates that near 1000Å $fN_S = 3 \times 10^{12}$ cm^{-2} when b = 5 km s^{-1}. Hence the sensitivity (one sigma error) in measuring weak lines for $N_H = 10^{21}$ cm^{-2} (middle curve in Figure 1) corresponds to about $3.5 \times 10^{-11}/f$ times the total hydrogen abundance (f-values for permitted transitions typically range from around 0.001 to several tenths). Generally speaking, this puts within easy grasp those elements having an interstellar abundance greater than about 10^{-8}

that of hydrogen, provided they have transitions in our wavelength range from favored ion states.

Up to now, we have examined the performance, as a function of wavelength, for an imaging spectrograph measuring a moderately faint star. We now focus our attention on a single wavelength, let us say 1030Å where efficiencies are good, and question how many stars are available which can yield results whose quality exceeds a given amount. Again if we think in terms of a 30 minute integration time and the telescope parameters specified earlier, we can define $N_S/\sigma(N)$ as function of V magnitude, E(B–V) and spectral type. Instead of using a model atmosphere to define F_ν, we shall rely on empirical results from Copernicus observations of observed count rates times $10^{0.4V}$ for various spectral types, after corrections for reddening. Stars with low projected rotation velocities are seen to have sharp and strong photospheric features which introduce confusion in the analysis of absorption by interstellar gas. Hence in counting the available stars in the sky only those which are known to have v sin i $\geq$ 100 km s^{-1} are included.

Figure C-2 gives a cumulative number distribution of hot stars which should yield results whose $N_S/\sigma(N)$ should exceed the value specified on the abscissa scale. Owing to the incompleteness of the catalogues, especially the compilations of v sin i, the curve levels off on the left hand side. The curve tells us, for instance, there are about 60 stars which could give us $N_S/\sigma(N) > 300$ in a half hour exposure, while 175 stars would give us $N_S/\sigma(N)$ of at least 100 over the same integration time.

iii. Sensitivity to Diffuse Emission Lines (from planets, comets, interplanetary gas, etc.)—An emission line brightness of 1 Rayleigh corresponds to 1.87×10^{-6} phot cm^{-2} s^{-1} $arcsec^{-2}$. For a spectrometer entrance slit width corresponding to an angle Δi and a source angular length (or spectrometer acceptance angle perpendicular to the dispersion direction, whichever is less) Δj, we find 1 Rayleigh gives a photoelectron count rate

$$N = 1.87 \times 10^{-6} \frac{\pi}{4} (1 - \beta_0^2)\, a^2 \epsilon_\lambda \Delta i \, \Delta j \; (\Delta i,\ \Delta j \text{ in sec}) \qquad (9)$$

integrated over all wavelength channels. For numerical values given in the beginning of the previous section we find $N = 1.07 \times 10^{-5}$ Δj at $\lambda = 1216$ Å(Lyman-α) and $N = 2.94 \times 10^{-5} \Delta j$ at $\lambda = 1050$ Å (near the argon emission lines) if $\Delta i = 0.2$ sec.

(b) Wavelength Resolution—The shape of the focused spectrum image combined with the angular configuration of incident and diffracted beams with respect to

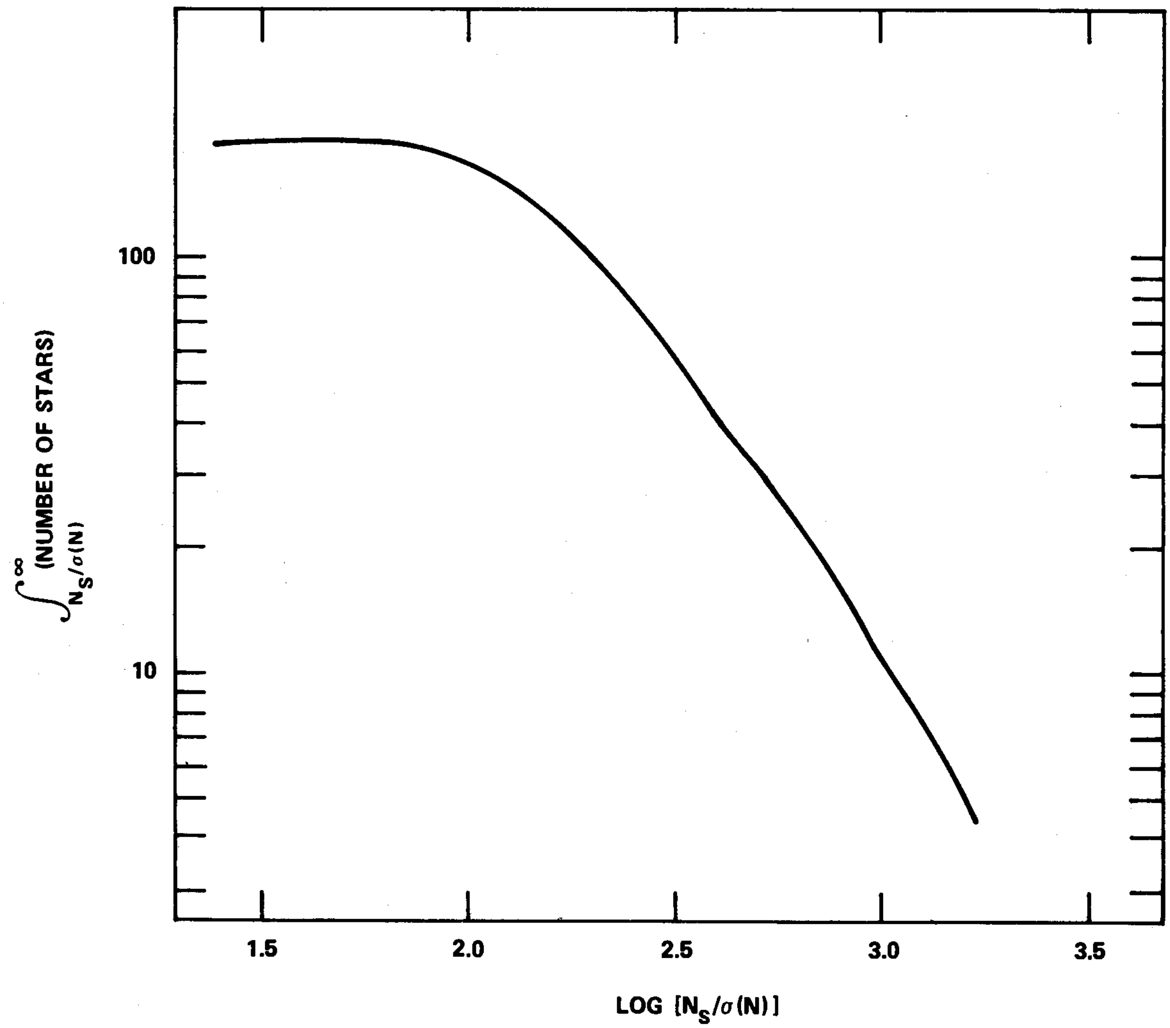

Figure C-2. Cumulative Number of Stars Versus Signal Quality

the grating are the ultimate factors which govern the wavelength resolution of a spectrograph. If optical imperfections in the main telescope and image motions enlarge the apparent angular diameter of a star to 0".2, without aberrations the image size will be $9.7 \times 10^{-7}\ \ell$ where ℓ is the focal length of the telescope. For a 1 meter f/15 telescope the image will be 15 microns in diameter, which is smaller than (or at best comparable to) the resolution limit of photoelectric imaging detectors in the far ultraviolet. Hence the minimum resolvable element size for the detector replaces the aberrationless image size as a driver of spectral resolution.

We can increase the resolving power of the spectrograph by enlarging the diameter of the Rowland circle, since the linear resolving power of the detector is fixed. The largest diameter which will probably fit behind the telescope is 1.5m. With the f/15 beam this results in a grating whose dimensions must be 10 cm cos i high (perpendicular to the dispersion plane) and 10 cm in width, where i is the angle of incidence. If we adopt 50μ as a conservatively large detector element size, the resolving power is $\lambda/\Delta\lambda$ = (1500 mm/.05 mm) (sin i + sin r) sec r, where r is the angle of diffraction from the grating normal. To obtain a reasonable blaze efficiency we require i not to be greatly different than r. Also, if we wish to have reasonable control over aberrations, we should avoid excessively large angles.

Figure 1 of the main text shows one possible configuration for the spectrograph which represents a reasonable compromise between awkward angles and any sacrifice in resolution. The spectral coverage ranges from 900Å, just below the Lyman series limit, to around 1220Å which is high enough to include the Lyman-α transition at 1216Å. The grating is ruled with 3600 lines/mm, and the spectrograph works in 3rd order. We may avoid interference from other orders: 4th order light at the position of 3rd order 1220 is below the Lyman limit and 2nd order radiation at the short wavelength limit can be eliminated by using a photocathode material insensitive to photons longward of 1350Å.

For a spherical concave grating whose radius of curvature 1500 mm equals the diameter of the Rowland circle, the image will be elongated perpendicular to the dispersion direction by astigmatism given by

$$y_1 = (100\text{mm})\,(\sin i \tan i + \sin r \tan r) \cos r \cos i \tag{10}$$

where the 100 mm represents the height of the grating rulings. These elongated images will have some curvature produced by coma, resulting in a cusp shaped spectrum line. The distance y_2 along the dispersion direction from the cusps to the center is given by

$$y_2 = \frac{(100\text{mm})^2 \cos^2 i}{8(1500\text{mm})} \left\{ \sin i \tan^2 i - \sin r + \frac{\tan r}{\cos r} \left[1 - \frac{y_1}{(100\text{mm}) \cos i} \right]^2 \right\}. \tag{11}$$

The center of the cusp spectrum line will be broadened by 3rd order spherical aberration given by

$$y_3 = \frac{(100\text{mm})^3}{8(1500\text{mm})^2} (\sin i \tan i + \sin r \tan r) \cos r. \tag{12}$$

With proper sampling of the spectrum in the image plane, astigmatism and coma have no impact on resolution; on the other hand, spherical aberration actually widens the image and reduces the resolution. Values for r, $\lambda/\Delta\lambda$, y_1, y_2 and y_3 for various wavelengths along the circle are given in Table 2.

Table C-2

λ (Å)	r (degrees)	$\lambda/\Delta\lambda$ (50 μ)	y_1 (mm)	y_2 (mm)	y_3 (mm)
900	16.8	3.0×10^4	50.6	0.148	0.038
950	20.1	3.3×10^4	52.3	0.125	0.039
1000	23.4	3.5×10^4	54.2	0.101	0.041
1050	26.9	3.8×10^4	56.4	0.076	0.042
1100	30.4	4.1×10^4	58.8	0.050	0.044
1150	34.0	4.5×10^4	61.4	0.024	0.046
1200	37.9	4.9×10^4	64.2	-0.007	0.048

Unacceptably large values for y_1 appear over the whole wavelength range. To reduce the astigmatism, we propose to reduce the radius of curvature of the grating perpendicular to the dispersion by a small amount, giving us a torroidal surface. If the compensation is complete at any one wavelength, we will be unable to disentangle the smearing by coma, resulting in a serious compromise in wavelength resolution. Hence the compensation for astigmatism should be nearly complete at the short wavelength end, which leaves about 14 mm of remaining astigmatism for the longest wavelengths. For all but the shortest wavelengths, the spectrum width may somewhat exceed the width of conveniently available detector strips. Fortunately, the optical efficiency of the telescope and spectrograph is relatively large at the longer wavelengths (see Figure 1), and hence the loss of flux will tend to reduce the disparity of exposure rates at short and long wavelengths.

The y_3 term represents the spread of the image at the paraxial focus. Improvement by approximately a factor of 4 can be realized if the image plane is repositioned at the circle of least confusion, just in front of the paraxial focus.

(c) Possible Detectors–In the introductory remarks it was made clear that the photons must have direct access to the photoemissive surface, without any intervening transmission elements such as a cathode faceplate. Opaque photocathodes with magnetic focusing or microchannel plates followed by proximity focusing are two possibilities for accomplishing our objective. Actual detection of electrons may occur with either a charge-coupled detector, reticon or ranicon. At present, it is not clear which of the possible combinations is the best choice for the spectrograph.

Whichever system is adopted, it is clear that we cannot cover the entire spectral range with a single detector. It would be reasonable, however, to envision a linear chain of devices along the Rowland circle. There would probably be unavoidable gaps between these detectors. If, for instance, the gaps were 1/3 the length of each device, one could expose 2/3 of the complete spectrum in one exposure. After rotating the grating by a small amount, the remaining pieces (1/3) of the spectrum could be covered with some overlap with the previous exposure. In general, we should think of two exposures per object if complete wavelength coverage is desired.

Appendix D

Capability of the Precisely Calibrated Spectrophotometer-Polarimeter

For the purposes of this discussion we will adopt the following simple model system. The telescope will have an aperture of one meter and an obscuration ratio of 0.33, which results in an effective area of 7×10^3 cm^2. The overall responsive quantum efficiency of the system will be taken to be 0.05, which assumes three MgF_2 coated aluminum reflections at 90% each, a grating efficiency of just under 70%, and a detector quantum efficiency of 10%. The sky brightness at λ 4250 (B) in magnitudes per square arc second will be taken to be 23.0 on the night side of the orbit and 20.0 under solar illumination, and the maximum integration time on any one object per orbit will be taken to be 30 minutes. We shall take "high-precision spectrophotometry" to imply band-passes of 10Å and that during a typical integration at least 10^4 photons be detected in each channel in order that the photometric precision not be limited to worse than one percent by the photon statistics. This should not be construed to be a guaranty of one percent precision as there are likely to be other factors beyond photon statistics which will limit precision. Furthermore, both of these restrictions may be relaxed under conditions defined by the particular scientific program. Within the framework of this model system we then require a flux at the telescope of 1.58×10^{-3} photons cm^{-2} sec^{-1} $Å^{-1}$ in order to accumulate 10^4 counts in a single channel during a single orbit. Figure D-1 shows the expected fluxes in these units from various sources.

A number of conclusions are immediately apparent from Figure D-1. First, even if the brightness of the sky due to the scattering of sunlight from materials in the immediate vicinity of the Shuttle Orbiter is considerably worse than the current estimate of B = 20 mag/arcsec^2, the sky background will not represent an important limit on high-precision spectrophotometry so long as entrance apertures of less than about 3 arc sec diameter can be used. Second, if entrances of only 1 arc sec can be used, then by relaxation of the precision criterion of 10 counts/channel/orbit, by the summing of channels, by multiple orbit exposures, or by some combination thereof, the system can be pushed several magnitudes fainter than the high-precision limit and remain insensitive to the sky brightness. Thus it would seem reasonable to expect that the spectrophotometric equipment on the SUOT would be intensively used throughout the daylight portion of the orbit and share a typical mission with instrumentation which requires dark sky, e.g. a direct camera or a broad-band or extended area filter photometer. Thus in discussions following, we will assume that two 30-minute exposures can be made during each orbit and that the dark part of the orbit will be left to an alternate instrument which requires it.

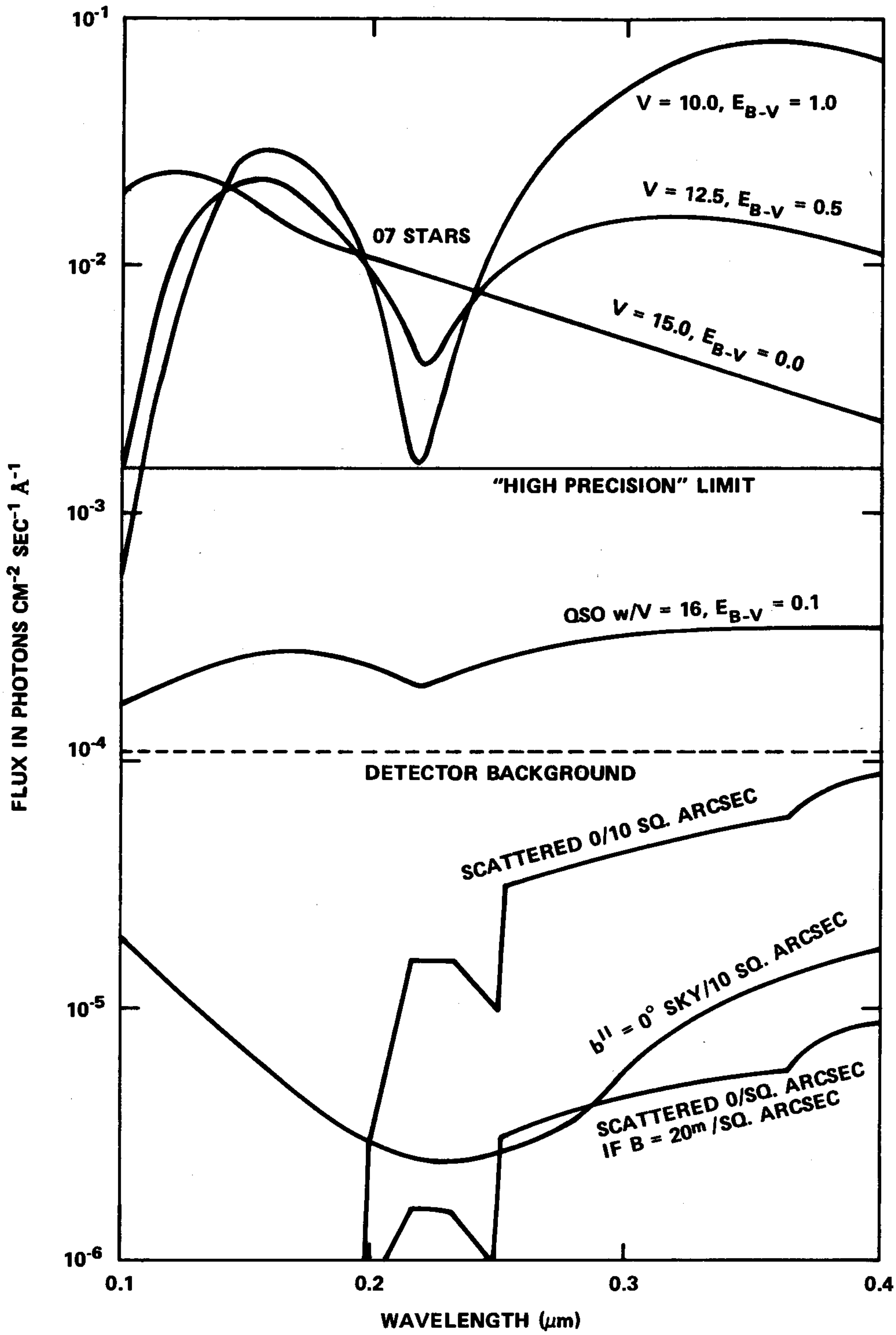

Figure D-1. Expected Fluxes From Various Sources Versus Wavelength

A third important point illustrated by Figure D-1 is that a high degree of multiplicity of detectors is highly desirable. The precision limit of Figure D-1 is set by requiring 10^4 counts in a single channel in a 30-minute exposure. For every 10 wavelengths which must be measured by a single detector, the limiting magnitude decreases by at least 2.5 magnitudes, and perhaps more, since adjustments in the wavelength of a detector require time not only to make but also to calibrate. Fortunately detectors do exist which have been, or probably can be, space qualified and which can be fabricated in arrays such that virtually the entire spectrum within the useful blaze of a dispersing element can be covered simultaneously or nearly so in 10Å chunks. These possibilities are discussed in Section Vc. We will thus assume that all of the spectrum within a range of about 2500Å will be covered in each 30-minute exposure.

One final point bearing on measurability limits is that of detector background. The experience with the OAO-2 has shown that the background levels in detectors in space are many times the levels of the same detectors in the laboratory. This appears to be the result of the high energy particle environment in space, and in particular to be largely due to fluorescence and phosphorescence of photomultiplier windows, since the phenomenon is greatly suppressed in far UV, windowless detectors. The OAO-2 results apply to standard photomultipliers with large (e.g. several cm^2) window-photocathode areas used in the standard exit aperture-Fabry lens configuration of ground-based photometry. The levels often amounted to many tens of counts per second. If the phenomenon is directly related to the area of the detector, then a multichannel array directly in the spectrometer focal plane would also help to reduce the detector background per channel to acceptable levels. If we can assume a detector of area 2 mm^2, e.g. a single 1 mm × 2 mm channeltron, the detector background level can be estimated from OAO-2 data and plotted in the units of Figure D-1. The OAO-2 count rate was about 40 counts/sec/cm^2 of cathode in photometer S3 in orbits avoiding the South Atlantic anomaly, and greater by at least 100 in and for many minutes after passage through the SAA. Take as typical 400 counts/cm^2, then per angstrom and per cm^2 of the 1-meter primary of the SUOT, this gives for our 10Å wide small detector a rate of 1.1×10^{-4}; which is plotted by a dashed line in Figure 1. As this is perhaps an optimistic estimate which is somewhat greater than the pessimistic estimate of sky background contribution, it would probably be prudent to require the data system to include the possibility of object-background chopping.

In addition to the photon flux limits on the capabilities of the SUOT spectrophotometer, it is necessary to consider the number of potential targets. Although surveys to the ultraviolet flux limits considered here are nonexistent, extrapolations can be made from OAO-2 data which are derived from the 3.3×10^{-2} photons cm^{-2} sec^{-1} $Å^{-1}$ limit of the OAO-2 photometer. Figure D-2 shows the

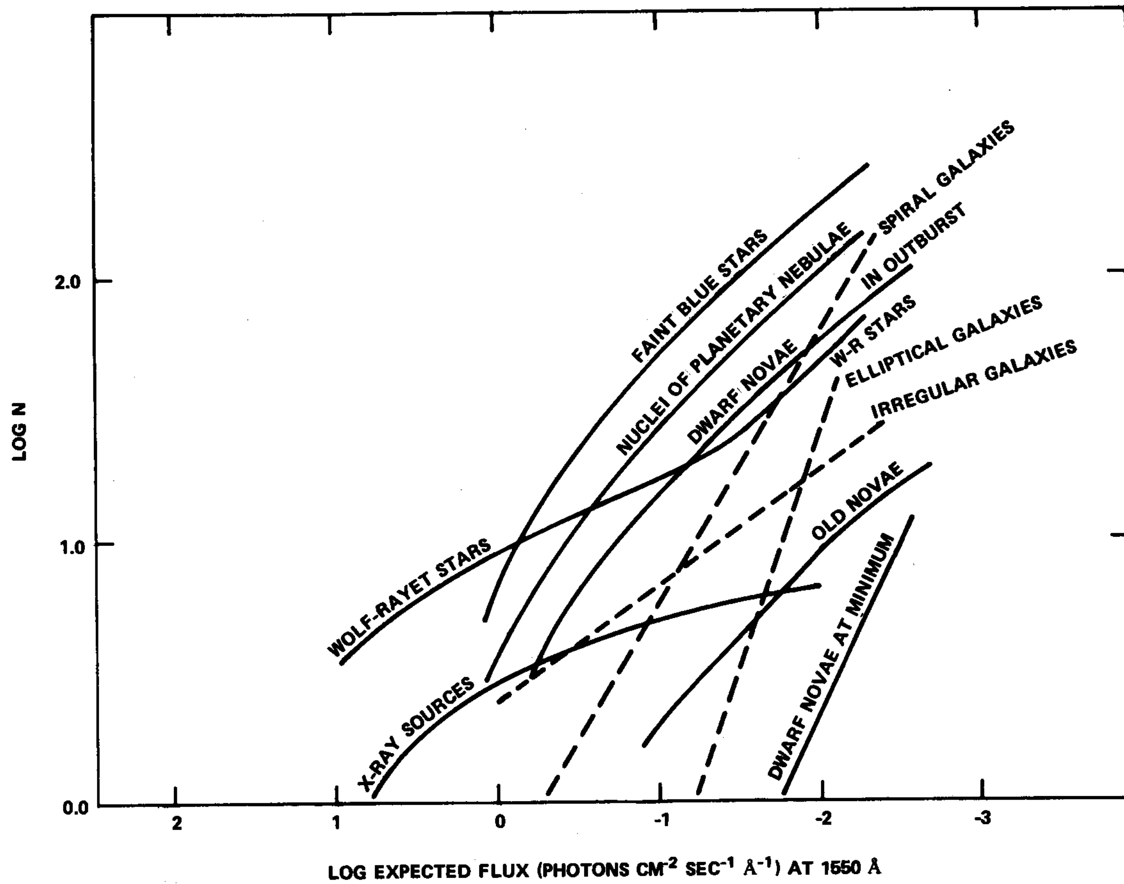

Figure D-2. Cumulative Object Count Versus Expected Flux at 1550Å.

integral luminosity function, i.e. the log of the number of objects of a given type with fluxes at 1550Å greater than the abscissa value, for several classes of interesting objects. Inspection of this graph shows that we can expect to make high-precision measures on many scores of objects in most classes.

SECTION II. B

SUOT OPTICAL DESIGN CONCEPTS STUDY IN SUPPORT OF THE FACILITY DEFINITION TEAM, INTERIM REPORT APRIL, 1975

FOREWORD

This interim report on the Telescope Optical Design Concepts Study in support of the Facility Definition Team was prepared by Ball Brothers Research Corporation (BBRC), Boulder, Colorado, for NASA/GSFC under contract number NAS5-24048 Mod. No. 17. Dr. D. S. Leckrone was the GSFC study scientist and Mr. A. F. White the technical monitor.

At BBRC, the study was conducted by Dr. M. Bottema, with cooperation of G. E. Morris (optical design), R. L. Cleavinger (star-position sensors) and D. S. Johnson (detectors).

SUMMARY

This report describes a 1-m aperture, 15-m focal length modified Ritchey-Chrétien telescope, designed for ultraviolet-optical astronomical observations from Shuttle in the "pallet-only" mode.

The total field of view is 0.8°. The central 0.5° represents the data field. Part of the outer portion of the field of view (0.7° to 0.8° diameter) is available for off-set guiding by means of an image-motion compensation system that controls the secondary mirror.

By means of refractive correctors, a flat, well-corrected 0.5° data field can be provided for the wavelength range 220 nm to 520 nm. Extension towards the near infrared is feasible with some sacrifice in spectral coverage in the ultraviolet.

The telescope is compatible with a wide variety of scientific instruments. On each flight, two major instruments can be accommodated. One instrument is placed at the conventional cassegrain focus (axial data field). Lengths up to 1.5 m are permitted. The second instrument is accessed by means of a removable diagonal mirror (radial data field). The length of this instrument is limited to about 0.5 m.

The radial exit is particularly suited for imaging in the corrected flat field. The telescope provides an angular resolution of 0.2 arc-sec over most of the area, decreasing to about 0.3 arc-sec at the extreme edge.

The axial field is reserved for measurements that prohibit the use of a diagonal mirror, such as far-ultraviolet spectrography and polarimetry.

Each of the two instruments is equipped with an off-set guiding sensor to assure accurate reacquisition in multiple-orbit observations. A single additional fixed startracker, mounted outside the telescope, provides roll information. Image stabilization to 0.02 arc-sec rms is feasible.

A TV camera is available for visual inspection of the central 0.2° portion of the data field. It can be engaged without disrupting the fine guiding for the instrument in operation.

A high-resolution, 1.5 arc-min camera can be incorporated on each flight for synoptic planetary observations.

The telescope assembly is compatible with the Shuttle constraints as established at present. Some uncertainty remains, however, in the interface between the telescope pointing system and the image-motion compensation system with regard to proper matching of frequency responses.

INTRODUCTION

This report describes the parameters and performance characteristics of a preliminary concept for a general-purpose ultraviolet-optical telescope of 1 meter aperture on Shuttle. This telescope can accommodate a variety of scientific instruments, at least two being carried on each mission. The telescope-instrument assembly is mounted on one of the Spacelab pallets and is not attached to a pressurized module ("pallet-only" mode).

The 1-meter ultraviolet-optical telescope was recommended by the Shuttle Astronomy Payload Planning Working Group as one of the major instruments needed for a balanced assortment of facilities for space astronomy from Shuttle (Reference 1). The scientific programs to which this telescope could be applied are discussed in the National Academy of Sciences report of the Woods Hole conference of 1973 (Reference 2). These encompass photography and electrography in medium-wide fields (of the order of 0.5°) as well as spectroscopy of isolated small objects, photometry and synoptic planetary observations.

A careful balance of telescope parameters is needed to execute a large diversity of scientific programs effectively. In the fall of 1974, Goddard Space Flight Center (GSFC) contracted Ball Brothers Research Corporation (BBRC) to study the feasibility of such a telescope and to define a preliminary set of optical parameters. This study (henceforth called Preliminary Study, Reference 3) identified an f/15 Ritchey-Chrétien as a suitable configuration for narrow-field observations and also demonstrated that a well-corrected flat field of 0.4° diameter could be obtained by means of refractive correctors for imaging in the near ultraviolet and visible wavelength ranges.

In December 1974, a Facility Definition Team (FDT) was formed, consisting of representatives of various areas of research in astronomy, who undertook to identify the scientific instruments and programs that would have priority for early Shuttle missions. In January 1975, GSFC let an additional contract to BBRC to further study the optical design concepts and also to support the FDT in its task. The present volume is an interim report on this activity and discusses the impact of the FDT's considerations on the telescope design (most importantly, in increase of the corrected flat field to 0.5° minimum) as well as some concepts for accommodation of the recommended instruments.

In addition to the present study, a separate study is conducted at BBRC on the engineering aspects of the facility (Reference 4). Obviously, the two BBRC studies are closely interrelated, the present study serving as an input to the engineering study on one hand and a feedback to the FDT on the other. In this manner, the present study hopes to assist the FDT in its efforts to recommend to NASA a facility that has scientific merit, is technically feasible and can be built and operated at reasonable cost.

The following report consists of two sections. The first describes the status of the telescope concept as developed in cooperation with the FDT on the basis of the Preliminary Study. The second section deals with the instrument accommodation and the interfaces between these and the image stabilization system, as far as established to date.

1. GENERAL-PURPOSE TELESCOPE

1.1 DEVELOPMENT OF CONCEPT

The telescope concept, as it stands at the completion of this interim report, is largely based on the results of the Preliminary Study. The f/15 Ritchey-Chrétien, recommended by that study, was found to be compatible with most scientific objectives identified by the FDT, excepting very specialized functions such as fast f-ratio, wide-field photography of faint luminous features in galaxies These must be delegated to specialized instruments and fall outside the realm of a general-purpose telescope.

The development of the f/15 concept is reviewed below, starting from the performance goals baselined for the Preliminary Study, followed by an account of our design approach, a comparison of telescope characteristics as a function of f-number and a detailed description of the present status of the recommended configuration. At this time, we do not expect major changes before the conclusion of the study.

1.1.1 Performance Goals

The Preliminary Study was based on a number of performance requirements, formulated by the Shuttle Astronomy Payload Planning Working Group. Among these, the most important were:

- Moderately wide angular field (0.5 to 3.0°).
- Excellent image quality over the entire field of view (0.1 to 0.3 arc-sec in the visible and near ultraviolet, Rayleigh criterion).
- Optimized for resolution of fine detail in low-contrast astronomical images (good MTF properties).
- Desired wavelength range 90 nm to 1000 nm or longer.
- Focal plane images matched to:
    - a. Plausible photographic emulsions
    - b. Plausible image intensifiers
- Fine stabilization (approximately 0.01 arc-sec from a baseline of 10 arc-sec), achievable by optical articulation within the telescope or in the focal plane.

Obviously, no single telescope exists that would meet all the principal requirements simultaneously. Therefore, the Preliminary Study concentrated on a compromise for a general-purpose telescope that would be suitable for a wide variety of narrow-field instruments (spectrographs, photometers, etc.) and, at the same time, offer an adequate field with good image quality for imaging astronomy.

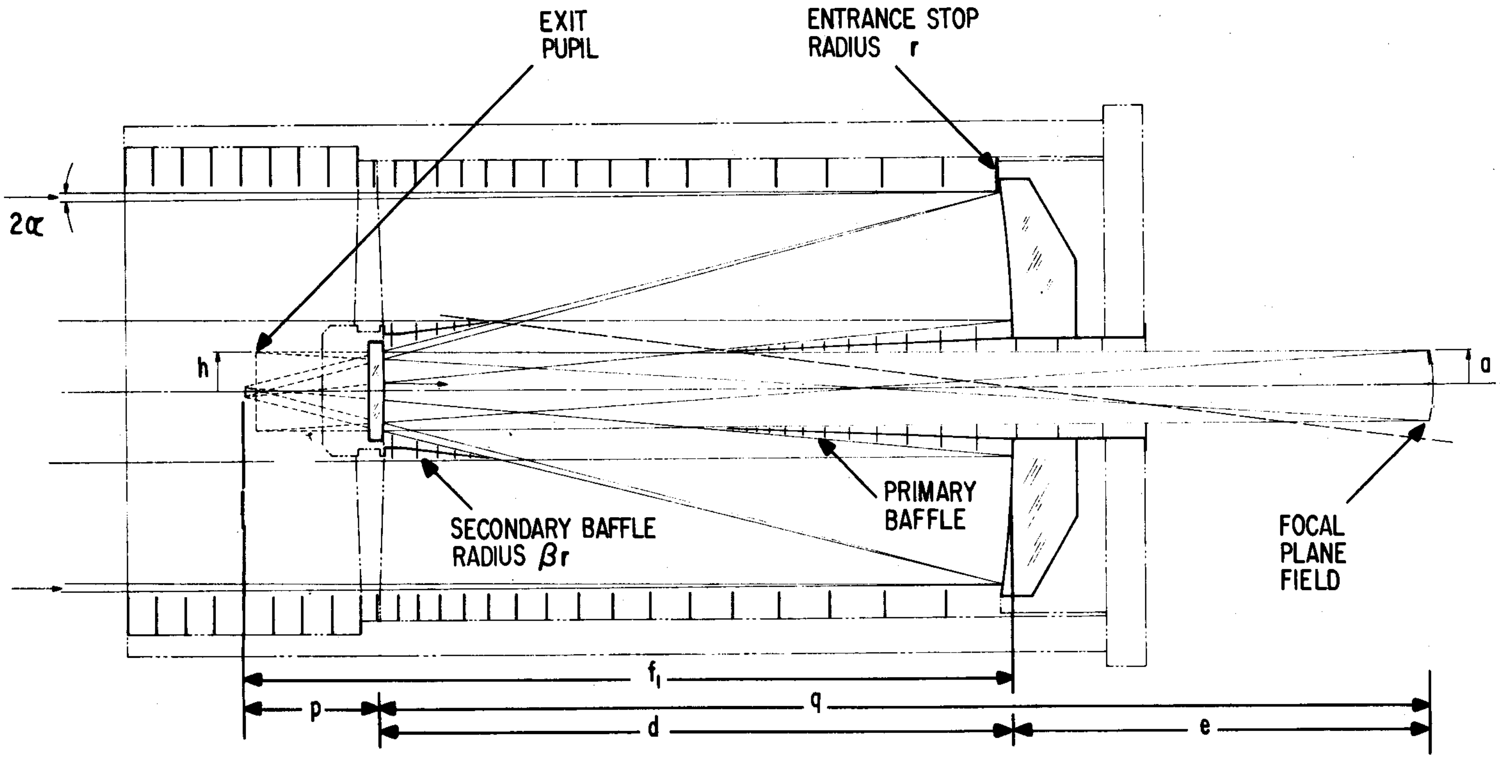

Figure 1. One-Meter f/15 Telescope with Full-Field Baffling

1.1.2 Ground Rules for Optical Design

Among the general performance requirements tabulated above, the Astronomy Payload Planning Working Group stressed, in particular, the need for excellent image quality over the entire field, good rendition of fine detail in images of low-contrast astronomical objects, and high image stability. Recognizing the importance of these requirements, we established the following ground rules for our approach:

- Full-field baffling for efficient straylight suppression.
- Small central obscuration for minimum degradation of the modulation transfer function.
- Allocation of part of the telescope field to guide-star position sensors for most effective coupling between the fine guidance system and the data field.

Full-field baffling is necessary for effective suppression of stray light originating from the sun, the earth, the Shuttle, or other luminous sources, especially for imaging of faint or low-contrast objects. The principle of full-field baffling, applied in most space telescopes and lately also in ground-based telescopes, is illustrated by Figure 1. Conical baffles are installed at the primary and secondary mirrors, which are dimensioned such that all direct paths to the focal plane field are blocked (limit shown by broken line). The secondary baffle determines the size of the central obscuration. The ratio of its diameter to that of the primary mirror (entrance stop) is called the obscuration ratio, β, and should be kept reasonably small in order to assure good modulation transfer (MTF) characteristics, as will be discussed in detail in Section 1.2.

Finally, by allocating the outer portion of the focal-plane field to sensors for the fine-guidance system, the highest degree of image stability is assured. An example of the division of the field of view into a data field and a tracking field is shown in Figure 2.

The intermediate area may be used as an extension of the data field, but may be partly vignetted by structures and mechanisms, as discussed in more detail in Section 2. The sensor signals are used to articulate the secondary mirror, thus providing internal image-motion compensation (IMC). The residual pointing errors and pointing jitter of the telescope stabilization system (actually called Instrument Pointing System, IPS) are thus compensated as well as all first-order effects of misalignment between the telescope mirrors. The long-term stability of the image and the accuracy of repositioning after reacquisition in multiple-orbit observations are exclusively determined by the mechanical and thermal stability of the structure between the IMC sensor and the instrument slit or image plane. The principal characteristics of the IMC are discussed in Section 2.3.

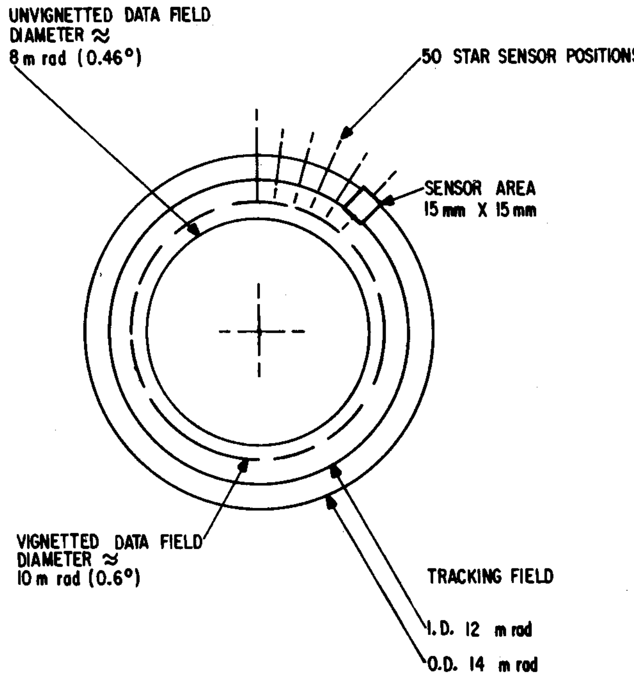

Figure 2. Division of Field of View

1.1.3 Criteria for Parameter Selection

The parameter selection is primarily driven by the requirements for good image quality in the full data field. These place an upper limit on the usable field diameter as well as on that of the central obscuration. Criteria for these two parameters are discussed below.

Field Diameter and Petzval Curvature. To be compatible with photographic plates, film, or image intensifiers, the field must be flat and the residual aberrations of the telescope must be corrected. For this reason, the Ritchey-Chrétien is selected as the basic configuration. Its only significant aberration is astigmatism, which can be eliminated by means of a simple corrector, invented by Gascoigne (Reference 5). Basically, this is a flat plate of which one surface is slightly aspheric. To create a flat field, an additional field-flattening lens is needed, which is commonly placed just in front of the focal plane, as shown in Figure 3.

The corrector elements place a lower limit on the usable wavelength range, primarily because the refractive index of all suitable materials increases rapidly near their ultraviolet transmission limit. Some examples are shown in Figure 4.

In the course of the BBRC studies, various corrector combinations were evaluated. This experience has shown us that adequate image quality can be achieved

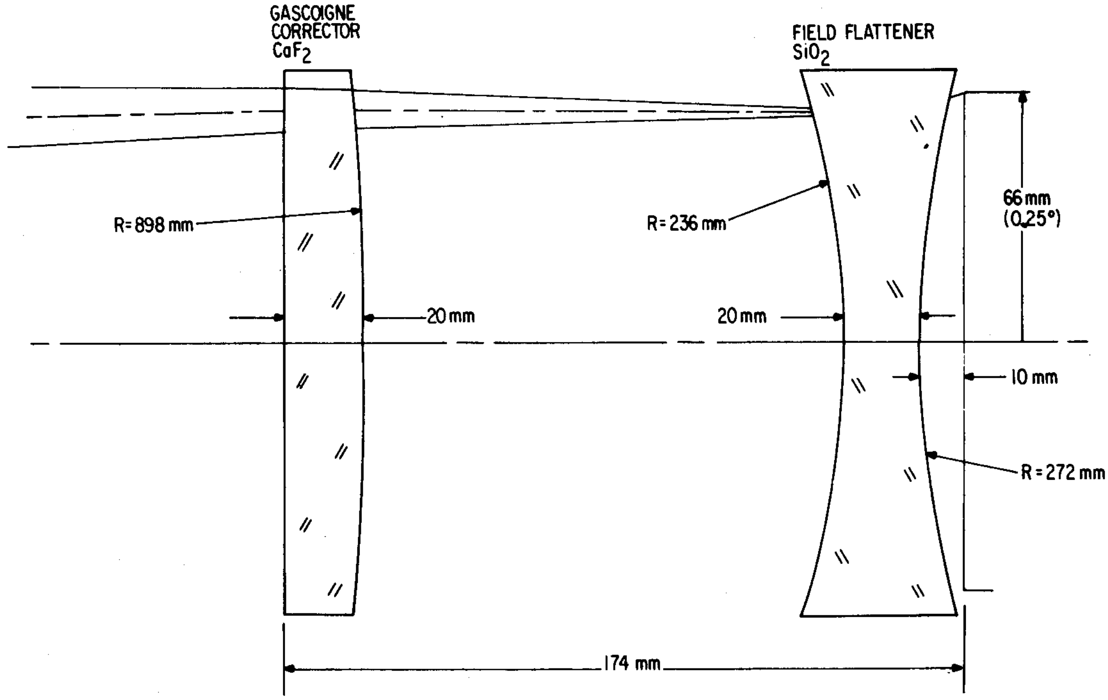

Figure 3. Gascoigne Corrector and Field Flattener for 0.5° Data Field in Modified f/15 Ritchey-Chrétien Telescope

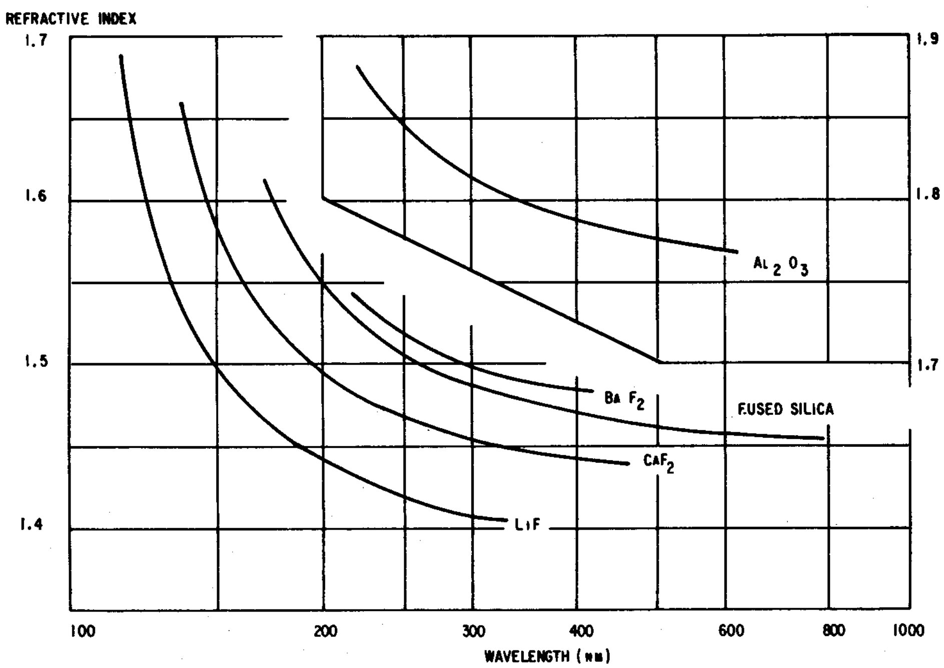

Figure 4. Refractive Index of Various UV Materials

in the wavelength range from 215 nm to 520 nm despite the large variation in refractive index. This wavelength range covers photographic materials such as Kodak III-a-J, as well as the bialkali response, combined with a suitable window or filter, such as Corning 9-54. However, this work also showed that there is an upper limit for the field diameter, above which adequate correction is not feasible, at least not with the above approach. This can be explained as follows:

If only astigmatism is corrected, the images are stigmatic but lie on a curved surface, called the Petzval surface, the radius of which is given by

$$R_p^{-1} = f_2^{-1} - f_1^{-1} \tag{1}$$

where f_2 and f_1 are the focal lengths of the secondary and primary mirror, respectively. The focal length of the field flattener must be selected to compensate this curvature, i.e.

$$f_{fl} = R_p/n, \tag{2}$$

where n is the average refractive index of the flattener. The aberrations in the flattener increase rapidly with field angle. In case coverage of a wide wavelength range is necessary, the dominant aberration is lateral color, i.e. the variation of image height with wavelength. Thus, on the basis of various examples studied, we established the empirical guideline that the field diameter should not exceed $R_p/3$ and preferably be limited to $R_p/4$.

Central Obscuration. The effect of the central obscuration on the image quality is a loss of contrast in details that are a few times larger than the angle just resolved by a diffraction-limited unobscured telescope. The tolerable upper limit of the obscuration ratio β depends on the degree of image degradation caused by other effects (mirror imperfections, residual pointing jitter, environmental effects), but should certainly not exceed $\beta = 0.4$ and preferably be kept near $\beta = 0.3$. These limits will be used below to establish acceptable telescope parameter ranges. A detailed discussion of the obscuration effect is given in Section 1.2.

1.1.4 Comparison of f/10, f/15 and f/30 Concepts

The Shuttle Astronomy Payload Planning Working Group recommended a high f-number (f/30) for the general-purpose telescope, in order to assure a sufficiently large plate scale for telescope-limited angular resoltuion with commonly used photographic materials. On the other hand, some members of the FDT expressed a preference for low f-numbers (f/10 or smaller) for higher irradiance in faint-object imagery. A comparison of these extremes and the f-number recommended in the Preliminary Study is given below, based on the criteria established in the previous section.

To provide a common base, it is assumed that all telescopes have the same back-focal distance e, i.e. the distance between the vertex of the primary and the focal plane. For a given telescope focal length, one finds, by variation of the secondary magnification m, consecutively:

primary focal length	f_1	$= -f/m$	(3)
back-focal ratio	δ	$= -e/f$	(4)
secondary focal length	f_2	$= -(\delta + 1) f/(m^2 - 1)$	(5)
Petzval radius R	Eq. (1)		
high-quality data field	$2a_o$	$= R_p/(4f)$	(6)
maximum data field	$2a_o$	$= R_p/(3f)$	(7)

An estimate of the total field of view can now be obtained, for instance, by adding a tracking field of 0.4° equivalent area (for justification of this number, see Section 2.3) separated from the high-quality data field by an intermediate zone, e.g. 1 mrad wide (Cf. Figure 2).

Once the field diameter has thus been established, the obscuration ratio can be found graphically or be calculated by trial and error, which can easily be done by computer. The program used by BBRC actually produced the ratio for the exact limiting ray. To find the true obscuration ratio, allowing for baffle thicknesses, mechanical tolerances and a safety margin, this value must be increased by about 0.02.

Illustrative parameters for f/10, f/15 and f/30 telescopes, derived by the above procedure, are shown in Table 1. A back-focal distance of 600 nm is assumed. A larger value is needed to accommodate two or more scientific instruments (Section 2.1), but this is of minor consequence for the present discussion.

f/30 Telescope. For obscuration ratios between 0.30 and 0.40, the well-corrected field diameter ($R_p/4$) lies between 0.10° and 0.23° , which falls well below the goals established in Reference 1 and endorsed by the FDT. Even the maximum possible field diameter ($R_p/3$) hardly exceeds 0.3°. The reason for the small field lies in the strong Petzval curvature, caused by the fast secondary necessary to provide adequate magnification (Eq. 1). It would be possible to increase the field by allowing a larger central obscuration, but then the image quality degrades to the point that the loss in angular resolution defies the purpose of the large plate scale.

f/10 Telescope. At the other end of the scale, the f/10 telescope provides a field of the order of a degree, but the achievable angular resolution with conventional photographic materials is only of the order of 0.4 arc-sec. An advantage is that the exposure time is an order of magnitude smaller than at f/30. K. Henize, Johnson Space Center, estimates that the sky-limited exposure time, assuming a 10 percent detector quantum efficiency, is only about one hour at f/10, as compared to about nine hours at f/30.

From an engineering point of view, the fast primary needed for the f/10 telescope must be considered a disadvantage. According to information received from

Table 1

Comparison of Telescope Concepts

F-Number	Plate Scale (mm/arc-sec)	Obscur. Ratio	Prim. Focal Length (m)	Second. Magn.	Field Diameters (Degrees)			Relative Sky-Limited Exposure (hrs.)
					Data, High Qual.	Data, Max.	Total F.O.V.	
10	0.048	0.30	1.30	7.7	0.45	0.60	0.75	1.0
		0.35	1.60	6.3	0.66	0.90*	0.89	
		0.40	1.85	5.4	0.91	1.22*	1.10	
15	0.073	0.30	1.70	8.8	0.29	0.40	0.57	2.25
		0.35	2.10	7.1	0.45	0.60	0.69	
		0.40	2.40	6.3	0.60	0.80	0.83	
30	0.145	0.30	2.20	13.5	0.10	0.15	0.44	9.0
		0.35	2.70	11.1	0.16	0.21	0.49	
		0.40	3.25	9.2	0.23	0.32	0.53	

*These diameters exceed the total F.O.V. only because of the specific criterion applied ($R_p/3$).

optical houses, a sharp increase in cost occurs for focal lengths below 2 m, because more complicated fabrication and test procedures are necessary. In fact, a focal length of 1.6 m appears to be at the very limit of technical feasibility.

A further disadvantage is that manipulation of the output beam and adequate separation of data and tracking field become very difficult at f/10, if vignetting has to be avoided (Cf. Figures 11 and 12).

f/15 Telescope. By comparison, the f/15 configuration represents a good compromise with respect to all of the parameters considered above. A well-corrected data field of 0.5° can be achieved with central obscurations between 0.35 and 40. The MTF characteristics roughly match those of commonly used photographic emulsions, as will be discussed in detail in Section 1.2. The primary mirror focal length lies in the range where good surface quality at reasonable cost may be expected, whereas the beam divergence with regard to isolation of the tracking field is quite manageable (Section 2.1).

In the above tradeoffs, narrow-field instruments have not been considered. In most cases the instrument can be matched to a wide range of telescope f-numbers by selection of the internal magnification (ratio of camera focal length to collimator focal length in spectrographs, for instance). An exception is the Rowland spectrograph, which must accept the telescope beam unmodified (Section 2.2). It was found, however, that an f/15 beam was quite acceptable and, in fact, represented an optimum with regard to aberration balancing in the particular case investigated. So far, no analysis has been made with regard to aberrations as a function of telescope f-number in other representative instruments. This must be left to the remaining part of this study.

1.1.5 Parameters of f/15 Modified Ritchey-Chrétien Telescope

The telescope parameters that are presently used as a baseline for the two BBRC studies are listed in Table 2, column 1. The primary focal length and the secondary magnification are those recommended by the Preliminary Study. The primary focal ratio was selected on the basis of the performance-cost trade discussed above. The secondary magnification was chosen primarily to optimize the obscuration ratio. If, for a given primary focal length and field of view, the secondary magnification is varied, the central obscuration reaches a minimum roughly where the field diameter equals the exit pupil diameter. In the case at hand, this leads to an optimum magnification between 7 and 8. In the present study, optimization of the central obscuration is de-emphasized, but since the original parameters are quite agreeable with the correctability criterion established in the previous section, they have so far been maintained. The large back-focal distance shown in Table 2, column 1 is necessary to accommodate the scientific instruments and their folding optics (Section 2.1). Likewise, the inner diameter of the tracking field (IMC field) must be considerably larger than the data field in order to prevent undue vignetting of the latter.

In order to reduce the total length and mass of the telescope assembly, it is highly desirable to make the back-focal distance smaller. This is illustrated by column 2

Table 2

Preliminary Parameters for f/15 Telescope

			1	2
Primary focal length	$-f_1$	(m)	2.0	2.0
Mirror separation	$-d$	(m)	1.636	1.662
Secondary focal length	$-f_2$	(m)	0.420	0.390
Image distance	q	(m)	2.730	2.535
Back-focal distance	e	(m)	1.094	0.873
Secondary magnification	m		7.5	7.5
Back-focal ratio	$\delta = -e/f$		0.547	0.437
Pupil ratio	$\mu = h/r$		0.204	0.190
Exit pupil radius	h	(mm)	102.1	95.0
Petzval radius	R_p	(m)	0.532	0.484
Data field, 215-520 nm				
Angular diameter			0.5° 0.4°	0.5°, corrected to 0.3" 0.4°, corrected to 0.2"
Linear diameter		(mm)	130	130
Data field, uncorrected, flat				
Angular diameter			0.1°	0.1° (image blur 0.2")
IMC field				
O.D.		(mrad)	14	14 (0.8°, 210 mm)
I.D.		(mrad)	12	12 (0.7°, 180 mm)
Obscuration ratio			0.37	0.37

For additional explanation of symbols, see Figure 1.

in Table 1. Efforts in this direction will be made in the remainder of the study. Incidentally, the particular data shown were selected for no other reason than to create round-number values for the major telescope parameters.

1.2 IMAGE QUALITY

The image quality depends on the composite effects of

- Geometrical aberrations
- Diffraction and central obscuration
- Mirror imperfections

- Aberrations and jitter introduced by the image-motion compensation (IMC) system
- Environment (defocus and misalignment)

These effects are discussed below, in particular in reference to the 0.5° data field, corrected for astigmatism and field curvature.

1.2.1 Geometrical Aberrations

The geometrical aberrations are completely controlled by the optical design of the telescope and the correctors. In order to leave as much margin as possible for other image-degrading effects, the geometrical aberrations should be reduced to a level at which their effect is negligible. In the Preliminary Study a modified Ritchey-Chrétien with a sixth-order Gascoigne corrector and a spherical field flattener (both fused silica) was designed that produced image blurs smaller than 0.1 arc-sec in a 0.4° field. However, this design could accommodate only a range of refractive indices from 1.48 to 1.52. This corresponds to a wavelength interval from 230 nm to 330 nm, which is compatible with a solar blind CsTe photocathode, combined with a Corning 9-54 filter or window.

For the present study, an effort was made to design correctors for the full range from 215 nm to 520 nm, which corresponds to the sensitivity range of photographic materials commonly used in astronomy. At the same time, the field was increased to 0.5°. A preliminary result is shown in Figure 5. Near the axis the image is practically stigmatic, but the image blur increases to 0.2 arc-sec at field angle 0.2° and 0.3 arc-sec at field angle 0.25°. In this example, the corrector material is CaF_2, which has a slightly smaller dispersion than SiO . The latter material was maintained for the flattener, but it was found necessary to make this element strongly aspheric. Further optimization may be possible, e.g. by other combinations of materials, but was deferred until the general optical design would be more firmly established. As is clear from Figure 5, the main problems are chromatic aberration (variation of image size with wavelength) and lateral color (variation of image off-axis distance with wavelength), caused by the high dispersion in the ultraviolet.

The correctors introduce some spherical aberration and coma, which must be compensated by small deviations from the pure Ritchey-Chrétien design parameters. For this reason, the telescope is called a modified Ritchey-Chrétien. A detailed discussion of the impact on the image quality without correctors (far-UV applications) is given in Reference 3, Section 3.2 and, in essence, remains applicable here.

1.2.2 Diffraction and Central Obscuration

The monochromatic modulation transfer function (MTF) of a perfect, unobscured telescope shows an almost linear decrease of modulation with spatial frequency, reaching zero at the limiting frequency (expressed in cycles per radian)

$$\nu_o = 2r/\lambda \qquad (8)$$

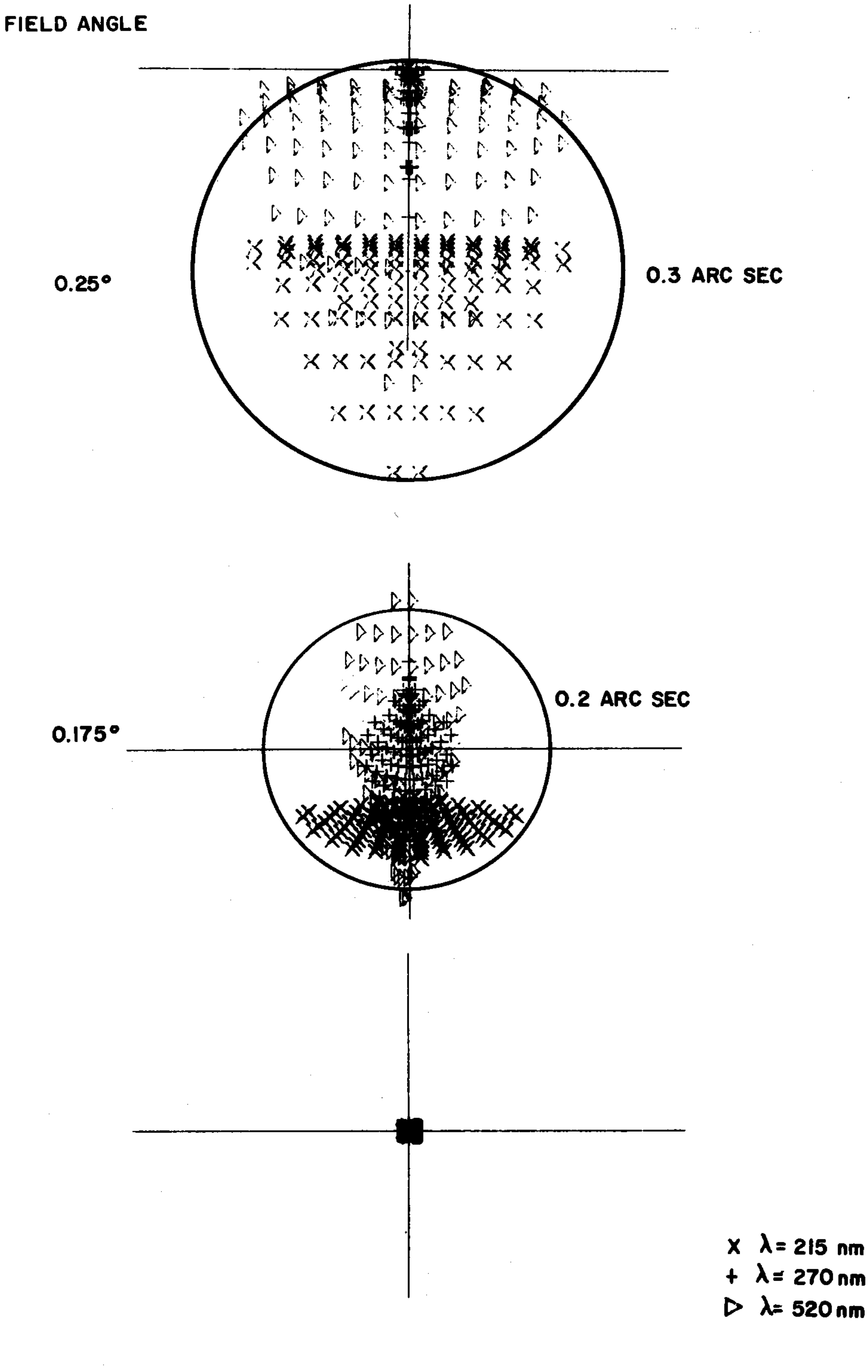

Figure 5. Computer-Generated Spot Diagrams at Various Field Angles in Corrected, Flat, 0.5° Data Field of f/15 Modified Ritchey-Chrétien Telescope

where λ is the wavelength and 2r the telescope entrance pupil diameter, which usually lies at the primary mirror. This function is shown in Figure 6 ($\beta = 0$), where the abscissa represents the normalized spatial frequency ν/ν_o.

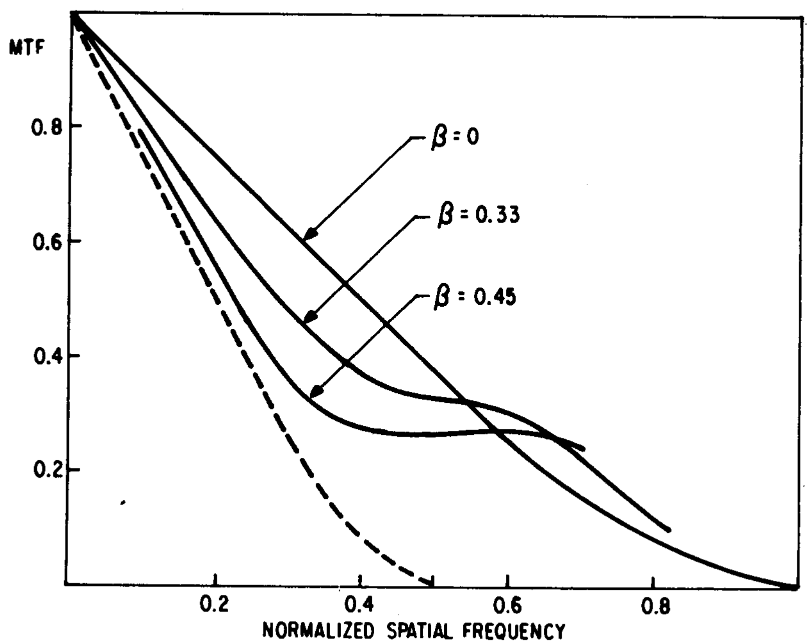

Figure 6. Modulation Transfer Function for Various Obscurations

The effect of the central obscuration is a decrease in modulation at middle normalized frequencies, as shown in Figure 6 for obscuration ratios $\beta = 0.33$ and $\beta = 0.45$.

1.2.3 Mirror Imperfections

According to studies on large-diameter mirrors by optical manufacturers, it is possible to figure a 1-m aspherical mirror surface to a precision of about 1/50 rms of the test wavelength, usually the 632.8-nm laser line (Reference 6). The smaller secondary might even be more precise, e.g. about 1/70 λ rms. The effect on the image quality depends very much on the distribution of the surface deviations. Concentric zones are not uncommon with some finishing techniques, but many other forms may occur. A statistical analysis is hardly meaningful, since each mirror has its own characteristic shape. Mathematical models have been developed to treat the surface errors in a similar manner as aberrations, i.e. by expanding the deviation in suitable polynomials. These are presently evaluated as part of this study, primarily for the purpose of establishing meaningful criteria for mirror specifications, mounting techniques and thermal control requirements.

A simple model of wavefront deviations that might occur in practice can be constructed, for instance, by assuming a concentric sinusoidal surface deviation on the primary with 1.5 waves across the diameter and a similar deviation on the secondary with 2.5 waves across the surface. These are represented by

Primary $$\Delta_1 = \Delta_{o,1} \cos (1.5 \pi r_1/r_{o,1}) \quad (9)$$

Secondary $$\Delta_2 = \Delta_{0,2} \cos (2.5\pi r_2/r_{o,2}) \quad (10)$$

For $\Delta_{o,1} = 0.018\ \mu m$ and $\Delta_{o,2} = 0.013\ \mu m$, this results in rms surface errors as given above.

The effect on the image structure was evaluated by means of the POLYPAGOS computer program. The resulting point-spread functions (PSF) are shown in Figure 7 for $\lambda = 480$ nm, $\lambda = 240$ nm and $\lambda = 120$ nm, using the telescope configuration of Table 2, column 1. At 480 nm, the PSF differs very little from the diffraction pattern in a perfect telescope with a 37 percent central obscuration. At 240 nm, there is a noticeable enhancement of the first and second diffraction ring, with an associated loss of irradiance in the central peak. At 120 nm, the effect is even stronger and includes the first four diffraction rings.

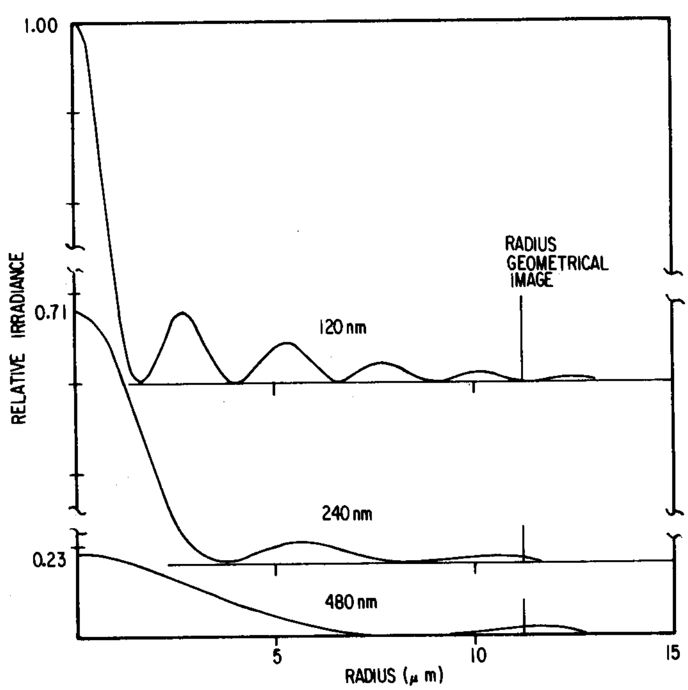

Figure 7. Point-Spread Functions in the Presence of Zonal Surface Errors on the Primary Mirror (0.013 μm rms) and Secondary Mirror (0.009 μm rms)

For comparison, the radius of the geometrical image is also shown. This represents the maximum geometrical aberration, caused by superposition of Δ_1 and Δ_2, i.e.

$$\text{Geom. radius} = 2f(d\Delta_1/dr_1)_{max} + 2q(d\Delta_2/dr_2)_{max}. \tag{11}$$

The effect of the surface errors on the angular resolution can best be assessed by comparison of the MTFs at the three wavelengths. These were also computed by the POLYPAGOS program and are shown in Figure 8. At 480 nm, the modulation including wavefront errors (solid line) is only slightly less than that for diffraction and central obscuration alone (broken line). The difference is largest at middle and low frequencies, as would be expected from the enhancement of the first and second diffraction rings.

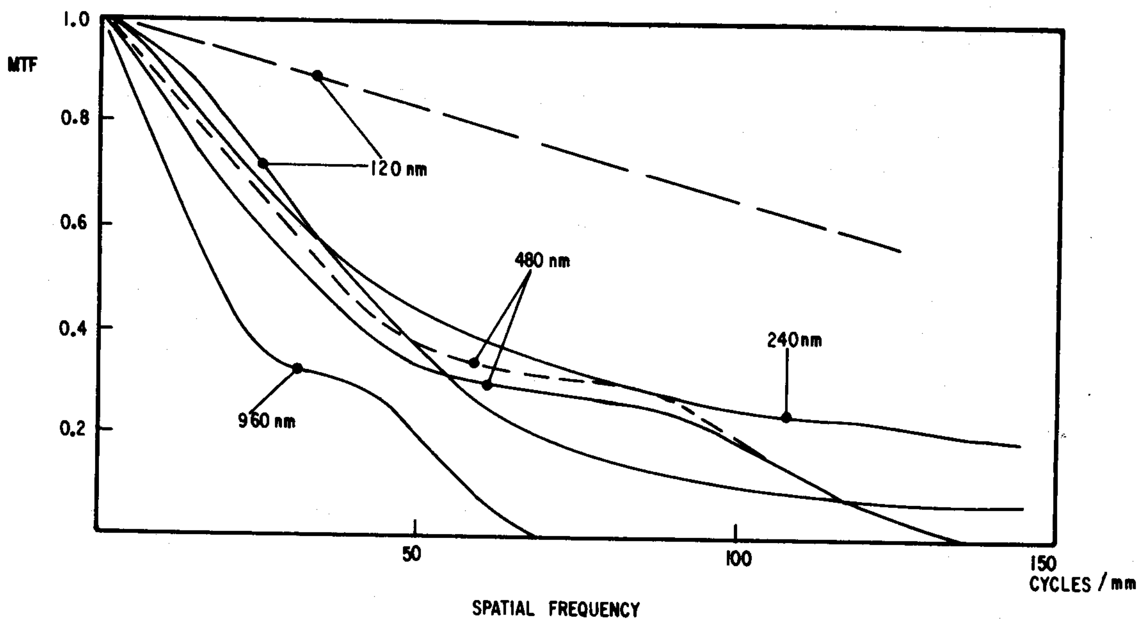

Figure 8. Monochromatic Modulation Transfer Functions in the Presence of Zonal Surface Errors on the Primary Mirror (0.013 μm rms) and the Secondary Mirror (0.009 μm rms)

At 120 nm, all resemblance between the MTFs with and without surface errors is gone. We note that the function including surface errors roughly follows that at 480 nm and 240 nm. Although this may be a characteristic of the particular example selected, it would seem that, regardless of wavelength, the MTF is comparable to that of a perfect telescope at wavelengths where the combined wavefront errors become less than about 0.05 λ rms.

In the wavelength interval of 120 nm to 480 nm, the angular resolution would then be about 0.16 arc-sec by the Rayleigh criterion applied at 633 nm.

At wavelengths longer than 480 nm, the MTF is almost exclusively controlled by diffraction. An example is shown in Figure 8 for $\lambda = 960$ nm. The angular resolution decreases accordingly.

1.2.4 IMC-Induced Aberrations and Jitter

The first-order effect of residual pointing jitter is a decrease of MTF, given by

$$MTF_{IMC} = \exp(-2\pi^2 \nu^2 \sigma^2), \tag{12}$$

where ν is the spatial frequency and σ the rms image motion. In general, if σ is about 1/10 of the image diameter, the MTF degrades not more than 5 to 10 percent at middle frequencies. This value of σ is, therefore, accepted as a goal for IMC performance.

In the IMC concept adopted here, the telescope pointing errors are compensated by tilt of the secondary mirror and thus introduce coma. The sagittal angular coma is given by

$$\eta_c = (3/8)(m^2 - 1)(r/f)^2 \, a_p, \tag{13}$$

where r is the radius of the telescope entrance stop and a_p the pointing error. For m = 7.5 and a_p = 4 arc-sec, this amounts to 0.1 arc-sec coma. This shows that the effect is tolerable for pointing errors of a few arc-sec, but becomes of concern in case the telescope pointing would be less precise.

1.2.5 Environmental Effects

The environmental effects are primarily defocus and misalignment due to changes in temperature and temperature distribution in the telescope structure.

For the visible, the focal tolerance is set by diffraction and is commonly assumed to be

$$\Delta f = \pm(1/2)\lambda (f/r)^2, \tag{14}$$

which amounts to about ±0.2 mm. In the far ultraviolet, a geometrical criterion may be more applicable. An image swell of 0.1 arc-sec corresponds to a defocusing of ±0.1 mm. This shows that maintaining focus passively may present problems. Active focus control, e.g. occasional adjustment by the payload specialist seems highly desirable. However, no concept for implementation has been developed to date, the definition of the telescope structure and an evaluation of its stability still being in progress.

Misalignment of the secondary is caused by a combination of tilt and decentering of the secondary support structure. The first must be budgeted into Eq. (13).

Since a tilt error α_s is equivalent to a pointing error

$$\alpha_p = 2(q/f)\,\alpha_s \approx 0.36\,\alpha_s, \qquad (15)$$

where q is the secondary image distance (Table 2), tilts of a few arc-sec are quite acceptable.

Decentering of the secondary by a distance Δr_2, under the condition that the image position is maintained by IMC, causes sagittal coma equal to

$$\eta_c = (3/8)\left\{(m-1)(m+1)^2 + 2(m+s)\right\}(r^2/f^3)\Delta r_2, \qquad (16)$$

where s = -q/d (Table 2, Figure 1).

A displacement of 0.05 mm, for instance, causes about 0.14 arc-sec coma. This places extremely high requirements on the mechanical and thermal stability of the telescope structure. An analysis of the tolerance budget is presently in progress as part of the facility study (Reference 4).

1.2.6 Compound MTF Characteristics

For wide-band photography, the image characteristics can best be described by means of the polychromatic MTF. This is the weighted sum of MTFs at representative wavelengths in the range of interest. An example is shown below, which applies to the bialkali response, cut off at about 215 nm by means of a Corning 9-54 filter:

Wavelength	Weight Factor
250	0.18
310	0.24
370	0.24
430	0.21
490	0.13

For the telescope configuration of Table 2, the polychromatic MTF thus calculated is shown in Figure 9. The upper curve represents the MTF on axis and also the tangential MTF at 0.2° field angle. This angle was chosen as a fair sample of the achievable geometrical correction in the 0.5° field (Cf. Figure 5). The MTF calculations include a 37 percent central obscuration, geometrical aberrations, diffraction and the mirror imperfections described by Eqs. (9) and (10). The identity of the on-axis MTF and the tangential MTF demonstrates that geometrical correction within 0.2 arc-sec at the extreme ends of the wavelength range is quite adequate. Whether the tolerance can further be increased (e.g. to widen the wavelength range), remains to be investigated.

The lower curve represents the radial MTF at 0.2°. The large deviation from the tangential curve must largely be attributed to the particular mirror surface deviation models used. Earlier work, that did not include surface errors, show a much smaller deviation, due mainly to the apparent decentering of the central

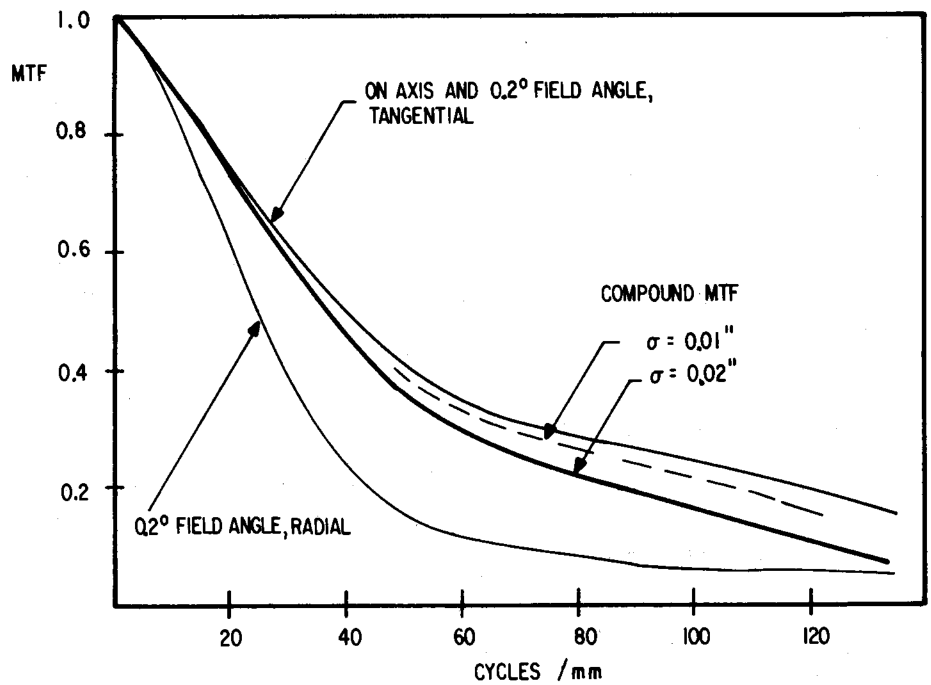

Figure 9. Polychromatic Modulation Transfer Function in Corrected, Flat, 0.5° Data Field in the Presence of Zonal Surface Errors on the Primary and Secondary Mirrors. Wavelength Range 215 nm to 520 nm.

obscuration as seen from the edge of the field. Further investigations, using less systematic surface deviations, are planned to clarify this matter.

If the upper curve is considered representative for at least the central portion of the field, the effects of residual IMC jitter can be incorporated simply by multiplication by Eq. (12). The compound MTF for 0.02 arc-sec rms jitter is shown by the heavy curve. This includes all effects listed in Section 1.2, except those due to environment. For comparison, the compound MTF for 0.01 arc-sec rms jitter is also shown (broken line), but this curve would apply only in cases where bright guide stars are available.

The above example shows that resolutions of 30 to 35 line pairs per mm at 50 percent modulation should be achievable for wide wavelength coverage in most of the 0.5° data field. This corresponds to an angular resolution capability between 2 and 2.5 cycles per arc-sec at 50 percent modulation. The angular resolution by the Rayleigh criterion (20 percent dip in the superimposed PSFs of just-resolved stars) would be considerably better and be about 0.2 or 0.25 arc-sec. Further evaluation of the achievable angular resolution is planned for the remainder of the study.

1.3 STRAYLIGHT SUPPRESSION

Straylight suppression is achieved by full-field baffling and by additional baffles inside the main telescope tube (Figure 1). The prime sources of scattered light are bright objects (sun, earth, etc.) that illuminate the inside of the telescope directly. To trap this light effectively, the baffles are spaced closely near the end of the tube, but can be widely separated, if not entirely omitted, near the primary mirror. In this manner, the number of baffle edges, which might become sources of scattered light themselves, is kept at a minimum. The same applies to the additional baffle rings on the primary and secondary baffle.

A deep baffle array is planned at the end of the telescope tube. This will be adequate in most cases to trap light from sources at large angles to the telescope axis. For observations close to the sun (Mercury, Venus) an additional sun shield is needed. This has been baselined in the design of the telescope tube (Reference 4), but does not necessarily have to be carried on all missions.

The secondary spiders are the only elements in the optical path that may scatter light into the field of view directly. In some scientific instruments, it may be possible to intercept this light in places where real images of the spider are formed, but this procedure will not be generally applicable. It may be helpful to slant the spiders backwards, in order to minimize direct illumination at intermediate angles. Both scattering and diffraction by the spiders are subject to further study.

2. SCIENTIFIC INSTRUMENTS

In the early part of 1975, the FDT identified a number of candidate instruments for early Shuttle mission. High priorities were assigned to an intensified film camera and a versatile spectrophotometer for the middle UV-visible region, and an electrographic camera and Rowland spectrograph for the far UV. Furthermore, the FDT stressed the importance of having at least two major instruments available on each flight. This not only offers redundancy in case of failure, but also provides a more diversified use of mission opportunities and available observation time. In addition, the FDT recommended to carry a high-resolution, narrow-field, photon-counting camera on most if not all missions, primarily for synoptic planetary observations.

For efficient operation on orbit, the facility must also be equipped with the necessary support instrumentation. Of prime importance is a TV camera (viewing camera) for acquisition verification and visual inspection of the data field. A supplemental slit camera may be desirable for some instruments, but this should perhaps be considered part of the instrument in question and need not necessarily be a permanent fixture of the facility.

In the following sections, the accommodation of the above instruments and the interfaces with the telescope are discussed, as well as some of the instrument characteristics, most relevant to these subjects.

2.1 INSTRUMENT ACCOMMODATION

2.1.1 Common Guide-Star Sensors

If two or more instruments are to be used alternatingly, moveable or interchangeable mirrors are needed to direct the telescope beam to the instrument in operation. A straightforward approach is shown in Figure 10. A diagonal mirror is mounted on a turret (instrument selector), which rotates around the axis Z'. In this manner, an axial focal plane and a radial focal plane become available. Two more radial exits may be added by means of a multiple-position instrument selector, as indicated in Figure 10. The axial focal plane must be reserved for instruments for which the diagonal mirror is prohibitive, i.e. far-UV instruments and polarimeters. The radial exits are suitable for the intensified film camera, the viewing camera, etc. Conceivably, the turret could be replaced by a linear slide, moving in the direction of the X axis.

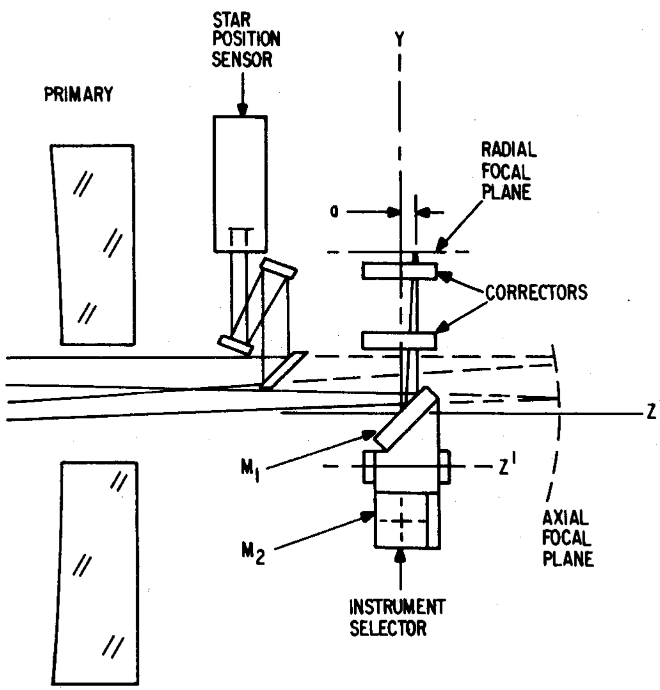

Figure 10. Scientific Instrument Arrangement with Common Guide-Star Sensors

Figure 10 also shows a simple way to incorporate the guide-star sensors. The complete sensor, with folding mirror, relay optics and correctors (not shown) rotates around the Z axis (Cf. Figure 2). A second unit could be added to provide roll information. This approach has two disadvantages, however. The movement of the heavy units (even if folded more compactly than in Figure 10) may disturb the telescope pointing system and presents an awkward problem with regard to mechanization and cabling. In addition, the folding mirror causes considerable local vignetting of the data field. The radius of the area, unvignetted at all sensor positions, may not be more than 2 mrad (a in Figure 10) for reasonable packaging dimensions.

2.1.2 Dedicated Guide-Star Sensors

In the arrangement of Figure 10, linear stabilities of the order of 1 μm and angular stabilities of the order of 0.5 arc-sec are required for the instrument selector, in order to assure image shifts less than 0.1 image diameter. In multiple-orbit observations, similar tolerances exist on repositioning accuracy. To eliminate these problems, we have explored an arrangement in which each major instrument has its own dedicated guide-star sensor, to which it is optically coupled by a fixed perforated mirror. The instrument selector tolerances can then be relaxed by an order of magnitude or more because repositioning errors and positional drift are fully compensated by the IMC system. Also, in multiple-orbit observations, the relation between an instrument and its dedicated sensor need not be broken. Upon reacquisition, the target image must of necessity return to its original position, which then depends exclusively on the control voltages of the guide-star sensor.

A tentative arrangement is shown in Figure 11. The axial and radial exits are coupled to their individual sensors by mirrors M_3 and M_2, respectively. The instrument selector mirror M_1 need not be positioned accurately, provided its drift rate and range are reasonably small compared to that of the IMC system.

The details of the sensor configuration are shown in Figure 12. The sensor itself is fixed and the tracking field is searched by a small rotating mirror unit or rhomb prism. This completely eliminates the problem of moving the rather bulky sensor units and their cabling, as needed in the concept of Figure 10.

A consequence of this approach is that roll sensing must be done externally. However, this is by no means a disadvantage. External roll sensing can be implemented by means of a single, fixed sensor (field of view e.g. 1°), mounted outside the telescope at 90° to the telescope axis. This sensor can be used for both instruments and is, therefore, much simpler than additional sensors in the focal plane.

In Figure 12, unvignetted data fields of 0.48° diameter are available at both the axial and radial exit. Allowing some vignetting, the field can be extended to about 0.6°. Sufficient space is available at the radial focal plane to accommodate an intensified film camera or other voluminous instruments. Filterwheels, shutters or exchange mechanisms for correctors, if needed, can also be accommodated. The same applies to the axial exit. If desired, two instruments can be placed side by side, provided that astigmatic telescope images are acceptable. In addition, a generous area inside the axial focus is available for mounting and for slit mechanisms or other extensions of the instrument (Cf. Section 2.2.2).

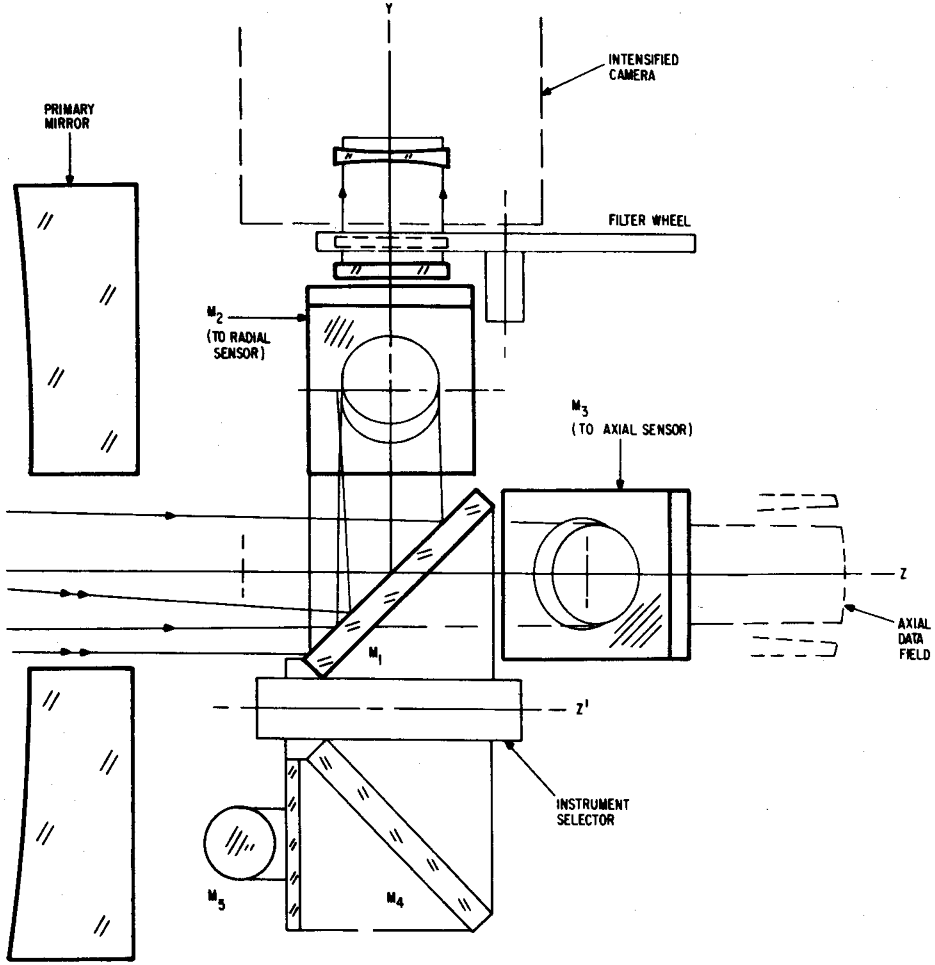

Figure 11. Instrument Arrangement with Dedicated Guide-Star Sensors for Axial and Radial Focal Plane

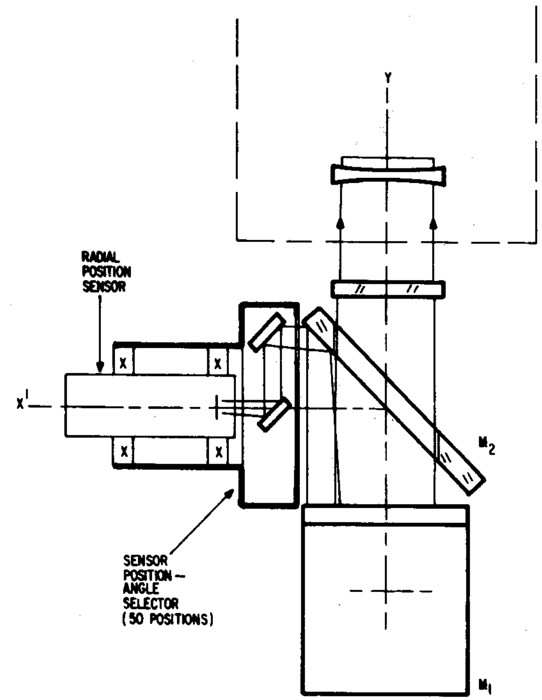

Figure 12. Radial Focal Plane with Dedicated Guide-Star Sensor

For selection of the axial or radial exit, two positions of the instrument selector would suffice. However, by adding two more positions, the viewing camera can be engaged and operated while stabilizing its image by either IMC sensor. In this manner, an observation can be interrupted to verify pointing and be resumed without disturbing the IMC system. Only during the brief transition from instru- to camera and back is suppression of the IMC signals necessary. The implementation is shown in Figure 11. By rotating the selector 180°, mirror M_5 deflects the central portion of the data field in the direction of the X axis towards an SEC orthicon camera (not shown). The mirror M_5 is mounted on a transparent plate that transmits the tracking field. M_5 is sized so as not to vignet the latter. The field diameter is about 4 mrad (0.2°) and is nompatible with a 50 mm x 50 mm photocathode scan.

The planetary camera can be accessed in the same manner, by increasing the number of selector positions to six. Of course, one of the sensors must be moved from its dedicated position so that precise reacquisition with that particular instrument may not be possible. An alternate solution is to give the planetary camera a fixed, off-axis position in the axial data field, or else engage it by a separate, fail-safe flip mirror. These options and possible other approaches to instrument accommodation remain under investigation.

2.2 ILLUSTRATIVE CANDIDATE INSTRUMENTS

2.2.1 Intensified Film Camera, Figure 13

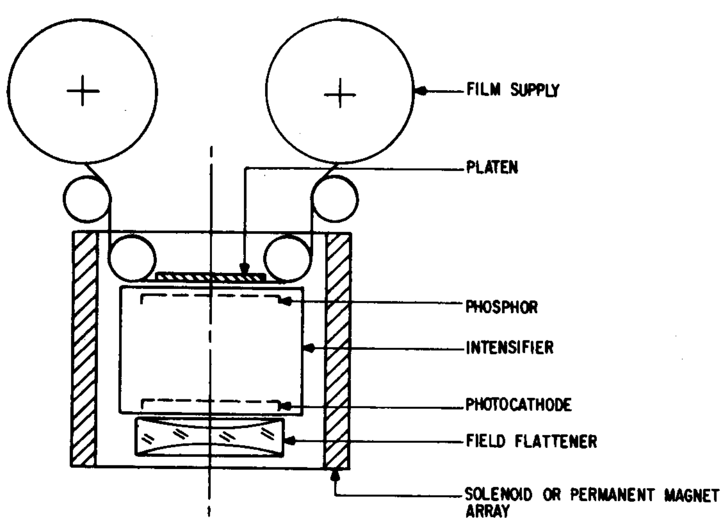

Figure 13. Intensified Film Camera

Intensified film cameras are applied in ground-based astronomy as well as in cartography and reconnaissance from airplanes.

For astronomy, the single-stage intensifier would be preferred, since its spatial resolution is better than that of the multiple-stage intensifier. Accurate data on achievable resolution are only sparsely available, but indicate that resolutions of 20 line pairs per mm at 50 percent modulation or 70 line apirs per mm at 10 percent modulation can be achieved at present. The angular resolution would, therefore, be limited almost exclusively by the intensifier and is of the order of 0.7 arc-sec at 50 percent modulation and approximately 0.4 arc-sec by the Rayleigh criterion. Evidently, considerable improvement is needed to achieve telescope-limited angular resolution at f/15. Intensifier diameters of 144 and 162 mm are available, which are amply adequate to accommodate a 0.5° data field (diameter 131 mm).

In the engineering studies, the intensified camera is primarily used to identify packaging, accommodation and interface problems. A severe thermal problem is caused by the dissipation of the focussing coil. However, a promising development of permanent-magnet focussing devices is underway at various research institutes, which would eliminate this problem.

Other wide-field instruments that will be taken into consideration in the engineering studies are, for instance, photographic plate cameras, electrographic cameras, and astrometric instruments. All these would be suitable for placement at the radial exit.

2.2.2 Rowland Spectrograph, Figure 14

The Rowland spectrograph was identified as a prime candidate for astronomy from Shuttle, in particular if it would be possible to increase the telescope transmission for the 90 nm to 125 nm wavelength region by using LiF coated optics on some specific flights. For this reason, the Rowland spectrograph was selected to serve as a model for axial instrument accommodation. A length of 1.5 m is desirable to make high spectral resolution possible. With a near-normal spectrum, resolutions of 1.5×10^4 are achievable with Reticon detectors that could be developed within reasonable time (a few months) and with reasonable cost (a few tens of thousands of dollars). A much higher spectral resolution can be achieved by off-normal operation, but is not feasible in the foreseeable future, unless sacrifices in efficiency at longer wavelengths are made in order to accommodate detectors of available dimensions.

As is evident from Figure 14, the detector assembly protrudes in front of the focal plane, especially in the high-resolution version. If the spectrograph is properly oriented with respect to M_3 (Figure 11), this presents no problem.

Another instrument that requires mounting at the axial focus is, for instance, an echelle spectrograph, where adequate length is also essential for high spectral resolution. Here, too, the configuration of Figure 11 leaves sufficient room for slit mechanisms, mounting structures and slit cameras, if needed.

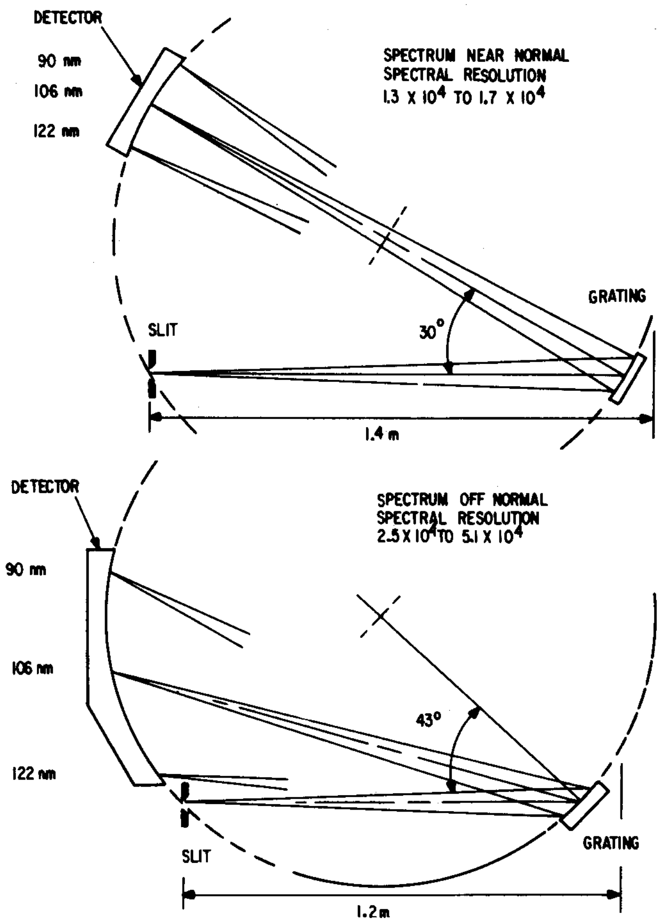

Figure 14. Examples of Rowland Spectrographs

2.3 IMAGE-MOTION COMPENSATION (IMC)

The IMC system consists of guide-star position sensors in the focal plane, actuators for biaxial control of the secondary mirror and servo-control electronics. The latter must include a computer to derive the correct control signals from the combined error signals generated by the focal-plane sensor in use and by the external roll sensor.

In the concept of Figure 11, the guide-star field has an inner diameter of 12 mrad and an outer diameter of 14 mrad. This is equivalent to 0.13 square degrees, and offers a probability of 95 percent for the presence of at least one star of visual magnitude $m_v = 13$.

For the sensors, photon-counting image-dissecting sensors are recommended, as is discussed in detail in Reference 4. The achievable position-sensing accuracy depends on the dwell time that is available at each sampling position. Four samples, one in each quadrant around the star, constitute a star-position update period. If this period is 0.1 sec or larger, the position-sensing accuracy for an m_v = 13 star is 0.02 arc-sec rms or better.

Just before the conclusion of this report, it was found that the stability of the Instrument Pointing System (IPS), as presently conceived, might not be adequate to permit update periods of the necessary duration. Some solutions to this problem, if it would occur, are suggested in Reference 4. In addition, the instrument configuration of Section 2.1.2 permits the following alternatives:

1. Radial focal plane. Since the centering of the image in the 0.5° field is not critical, the search for a guide star, if not successful, can be continued by shifting the telescope pointing direction by 1 mrad, thus essentially tripling the tracking field.

2. Axial focal plane. Since this exit is primarily intended for narrow-field instruments, a decrease of the inner diameter of the tracking field to 10.7 mrad (compatible with a 25-mm sensor) is feasible.

Further evaluation of this problem must, however, be deferred to the remaining part of this study.

The sensor signals are used to control the secondary mirror. Limits for the permitted pointing errors have been established in Section 1.2.4. For the control mechanisms, piezo-electric devices are attractive, because of the small angular range and high angular accuracy required. An alternate solution is a stepper-motor driven cam, combined with a mechanical reducer. This offers also a convenient way to generate mirror position signals for the IPS. A high reduction ratio (e.g. 100X) is needed, but would seem technically feasible. The possibility of roll-compensation within the instruments (of interest only for the 0.5° field) remains to be studied. This might pose a severe problem, that can be eliminated, however, if adequate roll control can be provided by the IPS. To assure a tangential stability of 0.02 arc-sec rms, an IPS stability of 4 arc-sec rms would suffice, provided the roll error signals and line-of-sight signals can be combined to place the effective axis of rotation along the telescope axis. An IPS roll stability of 2 arc-sec rms would remove the necessity of this complication.

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SECTION III.

ACCOMMODATION STUDIES OF SMALL ASTRONOMY PAYLOADS FOR SPACELAB

SECTION III. A.

SUMMARY PROCEEDINGS OF THE FIRST SPACELAB ASTRONOMY SMALL PAYLOADS WORKSHOP — GODDARD SPACE FLIGHT CENTER, FEBRUARY 13-14, 1975.

ATTENDANCE OF SMALL PAYLOADS WORKSHOP

George L. Anderson	Ball Brothers Research Corp.
Richard R. Anderson	Ball Brothers Research Corp.
Gerald R. Baker	GSFC
Dr. Nancy W. Boggess	NASA Headquarters
Dr. Ralph Bohlin	GSFC
William J. Bolster	GSFC
Dr. Stuart Bowyer	Univ. of California, Berkeley
Dr. A. L. Broadfoot	Kitt Peak National Observatory
John Cameron	GSFC
Dr. George R. Carruthers	Naval Research Labs
Webster Cash	Univ. of California, Berkeley
Dr. Arthur D. Code	Univ. of Wisconsin
Michael Coyle	GSFC
Mark Daehler	Naval Research Lab
J. L. Diggins	GSFC
Dr. Maurice Dubin	GSFC
Dr. Palmer Dyal	NASA/Ames Research Center
Gary M. Fereno	Operations Research, Inc.
Dr. David Fischel	GSFC
Frank W. Gaetano	NASA Headquarters
Bruce Greer	Operations Research, Inc.
Dr. D. A. (Al) Harper	Univ. of Chicago
Dr. Michael Hauser	GSFC
Dr. Sara R. Heap	GSFC
Carl Henrikson	Ball Brothers Research Corp.
Robert E. Heuser	GSFC
Dr. E. B. Jenkins	Princeton Univ. Observatory
R. W. Johnson	NASA Headquarters
T. Kaminski	GSFC
Dr. Roger Kaul	Operations Research, Inc.
Dr. Yoji Kondo	NASA - Johnson Space Center
R. J. Laurance	European Space Research Organization/ European Space Research and Technology Centre
Dr. David S. Leckrone	GSFC
Roy C. Lester	Marshall Space Flight Center
H. J. Lewis	NASA Headquarters
Dr. C. F. Lillie	Univ. of Colorado - LASP
Carl R. Maag	Mega Research
Rover Malina	Univ. of California, Berkeley
Harry McCain	GSFC

R. McDonnell	GSFC
John F. McNall	Univ. of Wisconsin
Donald E. Michalski	Univ. of Wisconsin
Don Miller	GSFC
Walt Nagel	GSFC
Dr. Robert W. Noyes	Center for Astrophysics (Harvard/SAO)
J. Niswander	GSFC
Jim O'Brien	GSFC
Dr. Chet B. Opal	Naval Research Laboratory
Stan Ollendorf	GSFC
Richard Ott	GSFC
R. Pincus	GSFC
James J. Rast	GSFC
John R. Roach	Ball Brothers Research Corp.
Dr. Jeffrey D. Rosendahl	NASA Headquarters
Dr. Paul Rudnick	GSFC
Ewald E. Schmidt	GSFC
W. Scull	GSFC
Dr. G. Sharp	NASA Headquarters
Dr. K. Shivanandan	Naval Research Laboratory
Dr. R. F. Silverberg	GSFC
Dr. A. M. Smith	GSFC
Dr. S. Sobieski	GSFC
John Sos	GSFC
Glen Strevey	Ball Brothers Research Corp.
Henry Sweet	GSFC
Peter Z. Takais	NRL
J. C. Tebay	GSFC
Roger V. Tetrick	GSFC
Dr. Anne B. Underhill	GSFC
Dr. Russell G. Walker	Air Force Cambridge Research Laboratory
Curtis Wells	Lockheed at Johnson Space Center
Art White	GSFC
R. M. Windsor	GSFC
Fred Wilshusen	University of Colorado - LASP

FOREWORD

In the 1980's Shuttle/Spacelab flights of 7 days duration or longer will offer astronomers the opportunity to utilize small, special purpose (sounding rocket class) experiments with integration times, spacecraft support facilities, and operational flexibility far exceeding that now available in rocket astronomy. The Astronomy Spacelab Payloads (ASP) study at Goddard Space Flight Center is beginning to define feasible concepts for the use of small payloads in Spacelab. We are particularly interested in establishing the requirements for hardware test facilities, interfaces, and program implementation procedures, which should provide the astronomical community with relatively simple and routine access to flight opportunities. A small, rocket-class payload is loosely defined as a payload with a minor impact on the complete spacelab system, a short lead time for development, and a relatively low cost. The weight limit will be about 400 kg and the size should be smaller than one Spacelab pallet element (3m length). Pointing and stabilization requirements are in the arc second range.

The First Workshop on Small Astronomy Payloads for Spacelab in the ultraviolet, optical and infrared disciplines was convened primarily for the purpose of acquainting the Goddard Subsystem engineers with the payload requirements of scientists who have experience with flight hardware. Conversely, to inform the prospective users about the ASP study program, the agenda also included discussions of the Shuttle/Spacelab system, possible mission profiles, and the ongoing efforts at GSFC to define the necessary pointing and other subsystem capabilities. The list of invited scientists was restricted to the UV-optical-IR areas, because other groups are conducting similar studies in solar, atmospheric, and high-energy and X-ray astronomy. The proposed payloads will make comprehensive mission studies more realistic, as well as providing motivation for the design of support subsystems.

This report is not a transcript of the proceedings of the Workshop but is only a summary of the information presented. More detailed documentation on subsystems support will be available from the ASP study office after July 1975. Bruce Greer of Operations Research, Inc. assisted in preparing this document.

INTRODUCTION TO SHUTTLE/SPACELAB

The Shuttle is a system comprised of an Orbiter, external fuel tank to power liquid fuel rocket engines, and solid booster rockets. Upon liftoff, all of the rockets fire in parallel, with the solid boosters dropping off soon after lift off. They are then retrieved, refurbished, and reused. The external tank continues to fuel the rockets in the Orbiter until just before orbit is obtained, at which time it is jettisoned. The Orbiter goes on to obtain orbit with fuel stored in its on-board tanks. This method of launching payloads into orbit is intended to be cost-effective, because the high-cost items, the vehicle itself with its many subsystems, and the rocket engines, are all used a number of times. The large external tank is discarded. The Orbiter has maneuvering capabilities when on orbit and can deliver and retrive payloads. When its mission of up to 30 days is complete, it re-enters the earth's atmosphere, becomes a high-performance aircraft, and lands on a runway. On the ground the Orbiter is refurbished by removing the returned payload, transporting the craft to its launch site, checking its several subsystems, installing a new payload, attaching solid booster rockets and a new external tank, fueling, and re-launching.

The crew of Orbiter consists of the commander and the pilot. In addition to these two essential crew members are mission specialists and payload specialists as required by the particular mission. These members will receive the training necessary to meet the requirements of the particular mission. Accommodations for 28 man days of crew equipment and expendables are provided by the Orbiter. Thus, the requirements of a 4-man crew on a 7-day mission are met. Additional man days can be provided, but the provisions are payload chargeable.

With a gross mass of 950 metric tons, the Space Shuttle system is capable of lifting payloads of up to 29,500 kg (65,000 lbs) and returning with a maximum of 14,500 kg (32,000 lbs). The weights and dimensions of Shuttle and its components are shown in Table 1. The Orbiter provides many facilities for payloads. There are 13 structural points for attaching payloads to the Orbiter. A remote manipulator system, with a light and a TV camera mounted on the arm, allow payloads to be manipulated and inspected. Up to 50 kilowatt-hours of electric power are provided to the payload from the Orbiter. The avionics supply course pointing, communications, data transmission and reception, TV transmission, and onboard digital computations.

Within the Orbiter is Spacelab, the system providing support for experiments performed on-orbit. This system includes a number of elements and services necessary to the success of a payload. Briefly, Spacelab provides electrical interfaces and additional power. It provides data communications systems from experiment to the Payload Specialist Station, to the onboard computer, and to the Payload Operation Control Center. The Payload Specialist Station allows

Table 1
Space Shuttle System
April 1974

Parameter	Metric value	English value
Overall Space Shuttle system		
Length	55.2 m	185 ft
Height	23.2 m	76 ft
Weight at launch	~1 860 000 kg	~ 4 100 000 lb
Payload weight into orbit		
Inclination (lowest), 28.5°	29 500 kg	65 000 lb
Inclination (highest), 104°	14 500 kg	32 000 lb
Solid-rocket booster		
Diameter	3.6 m	11.8 ft
Length	44.2 m	145.1 ft
Weight		
Launch	527 800 kg	1 163 500 lb
Inert	70 000 kg	154 300 lb
Thrust at launch, each	11 210 000 N	2 500 000 lb
External tank		
Diameter	8.4 m	27.5 ft
Length	46.9 m	153.9 ft
Weight		
Launch	739 800 kg	1 631 000 lb
Dry	31 900 kg	70 400 lb
Orbiter		
Length	37.5 m	123 ft
Wing span	23.8 m	78 ft
Height to extended landing gear	17.4 m	57 ft
Payload bay		
Diameter	4.8 m	15 ft
Length	18.3 m	60 ft
Cross range	2 038 km	1 100 n. mi.
Main engines (3)		
Vacuum thrust, each	2 090 700 N	470 000 lb
Orbital maneuvering subsystem engineers (2)		
Vacuum thrust, each	26 700 N	6 000 lb

Table 1 (Continued)

Parameter	Metric value	English value
Reaction control system		
Engines (40)		
Thrust, each	4 003.4 N	900 lb
Vernier engines (6)		
Vacuum thrust, each	111.2 N	25 lb
Weight		
Dry	68 000 kg	150 000 lb
Landing	~82 000 kg	~180 000 lb

for a man-in-the-loop mode. Other systems and services of Spacelab include thermal control of equipment, pointing systems, mechanical mounting systems (pallets), and command and data management. The payload specialist's role includes setting-up, preparing and stowing all payload equipment. He may align, calibrate, and adjust instruments or point instruments at targets in the appropriate sequence. He will have responsibility in data management, determining whether data should be stored or used in real time. The specialist may also play a role in maintenance and repair, but the extent to which these functions will be performed are yet to be determined.

It is important to point out that physical systems are being constructed currently. The several parts of the Shuttle system are being designed and constructed by various contractors. Figure 1 shows the major parts of Space Shuttle and who is building them. Figure 2 illustrates the general design concept for Spacelab. The specific subsystems for support of UV-Optical-IR astronomy are discussed in detail later.

ASTRONOMY PAYLOADS

The eight science presentations provided the central focus of the Workshop. Without active participation by the experimenters who are currently flying astronomy payloads, the subsystems development could be incomplete and without long-term direction. The Workshop was well attended and enthusiasm for additional meetings on a yearly basis was expressed. The only invitees, not attending, were either in the hospital or in the field launching payloads.

The astronomers were asked to propose payloads for Spacelab in the spirit of the rocket program, where costs and paperwork are minimized, short lead time and rapid turnaround are emphasized, and some degree of risk is accepted for each individual launch. The presentations by the astronomers are their

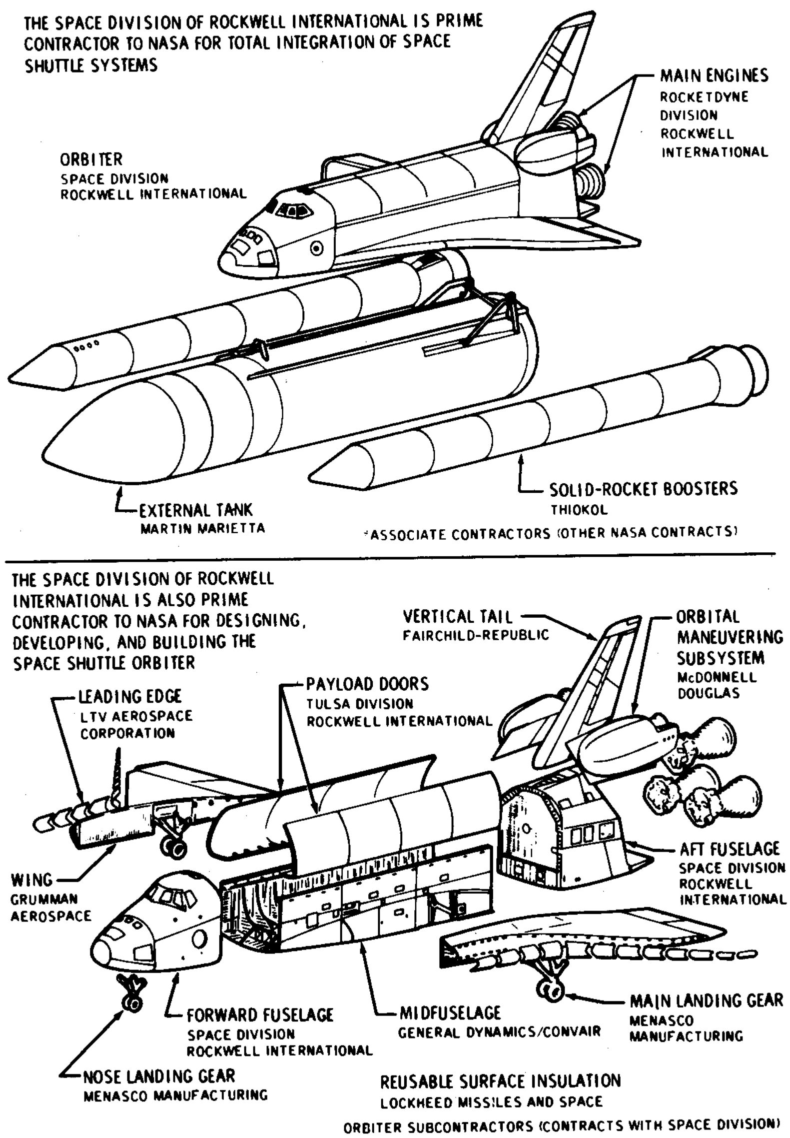


Figure 1. Status of Space Shuttle Contracting

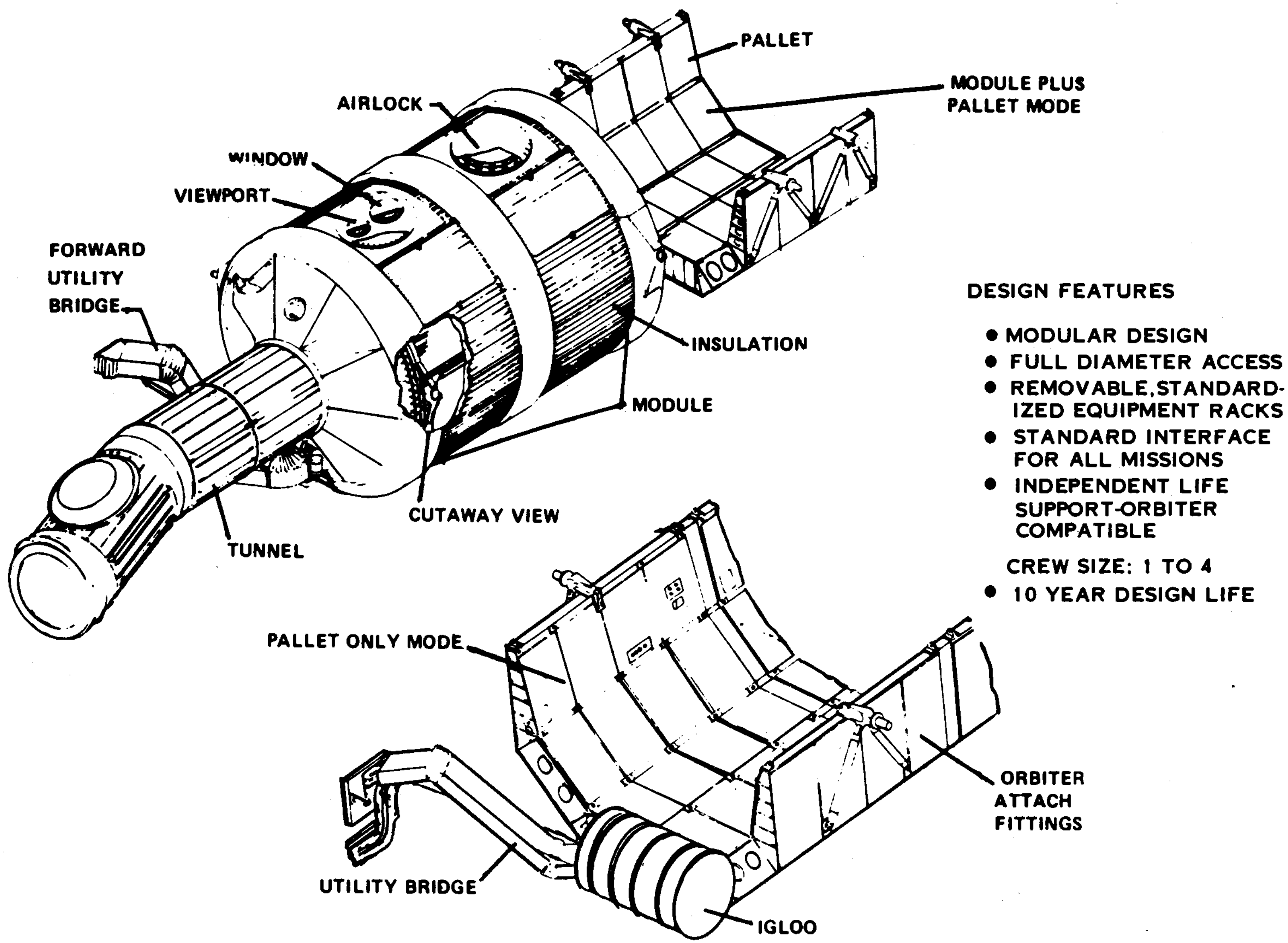


Figure 2. Spacelab Design Concept

interpretation of these guidelines. The following two tables summarize some of the important parameters for the payloads discussed by the eight different groups.

Small UV-Optical Payloads – Summary of Requirements

	Dimensions (cm)	Mass (kg)	Power (W)	Temp (°C)	Spectral Range (Å)	Resolution (Å)	Limit Mag.	Pointing Abs. ($\widehat{min}$)	Pointing Stab. ($\widehat{sec}$)	Data Rate (Kbps)	Field Diam. (deg)	Non-standard Requirement
Princeton												
High Resol.	15 m bay	<50	small	TBD	912-1100	0.003	~5	TBD	180	750	TBD	Dedicated Pointing 15 m light path
NRL												
Schmidt 1	30 X 55 X 115	80	25	20 ±15	1250-2000	Con	18	60	10	Film	11	RCS and gas Venting inhibited Has pointing mount. (Schmidt 1 and 2)
Schmidt 2	30 X 55 X 115	80	25	20 ±15	1050-1600	Con	18	60	10	Film	11	
USC												
UV-Tel.	100 X 100 X 250	400	500	Con	2000-3400	0.1	8	Con	1-Con	48	TBD	
Sky Survey	120 X 200 X 220	700	1000	10 ±10	UV-Vis	TBD	24	6	0.1-Con	Film	5	Large mass and size. 2.5 $\widehat{sec}$ roll stability.
Echelle	100 X 100 X 200	300	TBD	TBD	TBD	0.05	TBD	0.02	0.3	Film	TBD	Pointing
AFCRL												
IR-Tel.	51D X 137	170	150	7 ±30	4-30 X 10^4	Con	–	1	20	28	TBD	Scan mode LHe on gimbal
Berkeley												
EUV-Image.	44D X 250	150	12	24 ±19	100-1000	Con	TBD	60	3600	20	TBD	No SIPS needed
EUV-Spect.	18 X 27 X 65	16	10	7 ±47	250-1200	TBD	TBD	120	7200	40	TBD	Scan mode
X-Ray	43D X 180	160	40	12 ±30	3-100	TBD	–	60	3600	200	1-2	Gas flow detector
Wisconsin												
Photom.	38D X 200	91	100	30 ±70	925-3400	50	TBD	2	5	1	0.5	New Moon
GSFC												
Schwartz.	38D X 200	162	100	20 ±15	1200-3000	2	–	21	2	Film	11	Side looker 15 $\widehat{sec}$ stab-3rd axis

	Dimensions (cm)	Mass (kg)	Power (W)	Temp (°C)	Spectral Range (Å)	Resolution (Å)	Limit Mag.	Pointing Abs. (min)	Pointing Stab. (sec)	Data Rate (Kbps)	Field Diam. (deg)	Non-standard Requirement
Colorado												
Microch.	16 X 27 X 107	17	30	20 ±40	450-3100	2.5	13	1	30	400	0.1	
Polarim.	19D X 34	3	2	20 ±40	1050-7000	200	19	1	60	0.1	Con	
High Resol.	38D X 200	TBD	10	20 ±20	1050-3100	0.05	11	0.02	1	Film	0.001	Absolute Pointing

Notes: D – Diameter
TBD – To be determined
Con – Controlled by experimenter.

Cost and Delivery

	Cost Guestimate (thousands of 1975 dollars)	Lead Time (years)
Princeton		
High Resolution Spectrometer	300	2
NRL		
2 Schmidt Cameras	100	1.5-2
JSC		
UV Telescope (modify)	490	3
UV Telescope (copy)	1030	3
Sky Survey	2000	3
Echelle	500-1000	3-4
AFCRL		
IR-Telescope	1900	2.5
Berkeley		
EUV Imaging Telescope	40	0.25
EUV Spectrometer	125	3
X-Ray	45	0.25
Wisconsin		
UV Photometer	300	1
GSFC		
Schwarzschild Camera	200	1.5
Colorado		
Microchannel Spectrometer	150	0.7
UV Polarimeter	200	1.5
High Resolution Spectrograph	200 + telescope	1.5

The cost figures are only educated guesses and, in many cases, are not broken down or itemized in any way. The relative costs are also unreliable, because such things as travel, manpower support, and number of flights are not treated uniformly. The lead time is defined as the time between funding and the beginning of test and evaluation at Goddard.

1. A VERY HIGH RESOLUTION UV SPECTROGRAPH FOR INTERSTELLAR MATTER RESEARCH

E. Jenkins and D. York, Princeton University Observatory

Objectives

In 1959 prior to the development of space astronomy, Spitzer and Zabriskie predicted that the study of absorption features appearing in the far ultraviolet spectra of hot stars would afford us a very powerful means to analyze the composition and physical state of the interstellar gas. The foundations of that prediction even understated the enormous wealth of material and the growth in our understanding which has been precipitated by the observations from the Copernicus (OAO-3) satellite. We may anticipate that the International Ultraviolet Explorer (IUE) and Large Space Telescope (LST) should significantly widen the scope of ultraviolet observations by collecting spectral information at a much faster rate and with greater sensitivity. These two instruments, plus the proposed Spacelab 1-meter telescope facility, should be able to execute a comprehensive ultraviolet observing program leading to data not only on interstellar matter, but also on the actual targets observed - stars, galaxies, solar system objects, etc.

Worthwhile objectives for more specialized, new instruments for Spacelab include classes of observations which are outside the grasp of the relatively powerful, general purpose instruments just mentioned. One such program is the recording at substantially higher wavelength resolution the spectra of relatively bright stars. An increase by a factor of ten in resolving power to $\lambda / \Delta\lambda = 3 \times 10^5$, which corresponds to 1 km s^{-1} in radial velocity, permits us to address the following crucial problems in interstellar matter research.

a. Kinetic Temperature of the Diffuse Gas Intercloud Medium

While there are several approaches to learning about the temperature within dense accumulations of gas, such as observing 21-cm emission and absorption, H_2 rotation temperatures, and C I fine structure populations, temperature measurements for the more tenuous un-ionized material have been elusive. Comparisons of emission and absorption by broad velocity components at 21 cm seem to indicate temperatures ranging from 600 to 9000°K, but the interpretation of the results is somewhat controversial. High resolution measurements of widths for weak absorptions in the ultraviolet should show the thermal motion of the atoms. A dispersion in radial velocity produced by either turbulence or gradients in bulk velocities can be separated from thermal broadening by observing constituents of different mass. For instance, a temperature as low as 100°K will produce unsaturated absorptions by atomic hydrogen whose apparent widths are at least 44% wider than those from elements heavier than carbon, if the non-thermal broadening is no larger than 1 km s^{-1} and the half-width of the instrumental profile is 1 km s^{-1} . The measured temperatures of H I at relatively low densities bear directly on our theoretical understanding of the heat balance in the gas, as well as on the nature of thermal instabilities and phase operations.

b. Velocity Separation of Absorption Components From H I and H II Regions

Many atomic and ionic species arise from both H I and H II regions, and at low resolution the components are blended. The ability to separately consider contributions from the different regions has obvious advantages in the interpretations of abundances and physical conditions. For example, absorptions from H I regions caused by ions requiring more than 13.6 eV ionization energy for their production could be isolated. Experience with Copernicus data suggest H I and H II region velocities can have typical separations of 6 to 10 km s^{-1} for nearby stars - a velocity difference barely resolved by Copernicus but easily separated at the proposed 3×10^5 resolving power.

c. Separation of Velocity Components of H_2 with High and Low Rotation Temperatures

Early studies of H_2 absorptions suggested an increase in velocity dispersion for absorptions by H_2 in relatively high levels of rotational excitation ($J \geqslant 4$ or 5). More precise observations by Spitzer and Morton revealed that the apparent increase was due to a superposition of components at different velocities, rather than a symmetrical increase in the velocity spread of a single component. The ability to unravel these contributions would clarify our understanding of the rates of formation, destruction, and rotational excitation of interstellar H_2 under substantially diverse conditions.

d. Gas in the Solar Vicinity

Most O and B stars are on the order of 100 or more pc away, however a number of bright M and K giants are much closer. In the ultraviolet these stars exhibit strong chromospheric emission lines which may show narrow interstellar features in absorption. For instance, observations of the Lα absorption to nearby stars by Copernicus has revealed that the local neutral hydrogen density is only around 0.5 atoms cm^{-3} , considerably lower than average for our galaxy. Our confidence in the accuracy of this technique for measuring hydrogen can be significantly enhanced by going to higher resolution, since our present inability to see the precise shape of the emission is a principal source of uncertainty. Even more gain may be realized for elements other than hydrogen, where the emission lines and matching interstellar absorptions are much narrower.

The specific research possibilities listed above are in themselves strong justification forobservations at high resolution. In addition, the principal uncertainties in column densities derived from moderately (but not fully) saturated lines can be virtually eliminated by directly integrating optical depths over velocity instead of applying curve of growth techniques. In short, the value of high resolution profiles becomes obvious by reviewing the detail exhibited by lines in the visible spectrum recorded by Hobbs at a resolution of ~ 1 km s^{-1} .

Instrumentation

Simultaneous detection of the many adjacent wavelength bins is almost imperative, especially at high resolution, since the observing time on a shuttle mission is limited. This introduces an imaging detector as a necessary component of the system. Photoelectric devices capable of imagery have limited spatial resolution, however, which imposes the severest constraint on instrument design concepts when one requires high wavelength resolution.

A grating spectrograph with a focal length ℓ will have a resolving power given by $\lambda/\Delta\lambda = \ell$ (sec r) (sin i + sin r)/Δx where i and r are the angles of incidence and reflectance, respectively, and Δx is the width of a resolution element of the detector. Although high resolution can be achieved by having r approach 90°, blaze efficiency or effective beam collecting area of the grating is sacrificed. Another approach, which is the choice we adopt here, is to increase ℓ to a very large value. One can magnify or fold the dispersed beam to limit the physical dimensions of the configuration, but this is undesirable since the attenuation of the light flux is large, owing to the poor efficiency of optical elements in the far ultraviolet. On the other hand, we can capitalize on the generous length of the shuttle payload bay and have an uninterrupted beam from the grating at one end focused on the detector at the opposite end. If ℓ is as large as 15 m, the length of the Spacelab pallet assembly, and Δ x is 50μ (a realistic value), we can achieve $\lambda/\Delta\lambda = 3\ 10^5$ if the combined trigonometric terms in the equation are about unity (which gives reasonable angles). An additional benefit of a long focal length is the reduction of high order optical aberrations. For efficiency and simplicity, a concave grating used in a Wadsworth configuration seems most desirable.

A conventional approach for recording a spectrum is to allow the imaging device to accumulate and store the photon counts over the time of integration. While this has obvious advantages for economical data management, it requires elaborate and very precise compensation precedures over the whole integration time to eliminate drifts in wavelength caused by (1) guidance errors, (2) flexure of the shuttle or instrument and (3) variations in projected orbital velocity. To avoid these complications, we prefer to allow the spectrum to move and use very short integration times. The detectors will be operated in a photon counting mode, and the position of each photoevent will be recorded. Position offsets will be recorded using an image disector which senses the star's flux from a mirror rigidly attached (but with a small tilt) to the grating cell. The subsequent analysis of the data to produce a spectrum will compensate for the different forms of drift. The shortcoming of this method, of course, is the wide bandpass of about one mega Hz needed to record the rapid flow of photoevent coordinates.

Pointing and Other Spacelab Requirements

The entire shuttle vehicle must be oriented properly for each target star. No drift greater than about 0.1° is acceptable during periods of a half to one hour. The availability of control moment gyros may be essential for this experiment, because contaminants with column densities as low as 10^9 cm^{-2} are detectable and begin to interfere with observations of interstellar lines. The worst contaminant is H_2 and other bad species include OH, CO, H_2O, O_2 and N_2. Another solution would be to gate the experiment off during gas firings, if the column densities are large only for a small fraction of the time. The need for dedicated shuttle pointing will impact mission operations and sacrifices in observing efficiency for this or other experiments may result from conflicts. A limited capability for independent pointing could be acquired by allowing the grating to articulate along two axes, but the increased complexity and changing instrument characteristics would make this choice somewhat undesirable.

In several respects the proposed payload is essentially of the "sounding rocket class" in that it is lightweight, inexpensive, conceptually simple and is designed to accomplish a special class of observations outside the capability of a general telescope facility. In one other respect, however, it differs from normal small instruments: it is far from being compact, because the light beam traverses almost the entire length of the shuttle bay. Somewhere within the bay we must have an unobstructed line of sight for the light beam traveling between the grating and the detector. How difficult a problem this will be is unclear until it is known what the dimensions of other systems sharing the flight will be. In all likelihood some unobstructed path will exist, or alternatively, compromises could be made. (For instance, for a few of the pointing directions of SIPS, conflict may occur and the high resolution observations would occasionally be interrupted.) If serious interference with other payloads seems inevitable, then it may be preferable to operate this system on a mission carrying free-flyer satellites for which an empty payload bay would be available after release.

2. SCHMIDT CAMERA/SPECTROGRAPH FOR FAR-ULTRAVIOLET SKY SURVEY

G. Carruthers and C. Opal, NRL

Objectives

The primary objectives of the proposed experiment are to obtain far-ultraviolet imagery and intermediate-resolution spectra, in the 1050-2000 Å wavelength range, of stars and stellar objects (early type Pop. I stars, and Pop. II objects such as the faint blue stars at high galactic latitudes), emission and reflection nebulosities, planetary nebulae, relatively nearby external galaxies, and the brighter Seyfert galaxies and quasars. The stellar spectra will also provide information on the distributions of interstellar dust, atomic hydrogen, molecular hydrogen, and (for the most distant and/or reddened stars) atomic oxygen, nitrogen, and carbon.

It is desired to cover as much of the sky as possible, to the faintest possible limiting magnitudes with high photometric quality. The ultimate goal is a complete sky survey, reaching (in 20-minute exposures) unreddened B0 stars (or equivalent) as faint as $m_V = 18$ in direct imagery, and as faint as $m_V = 11$ in the objective-spectrograph mode (2Å resolution) or $m_V = 9.5$ (0.5Å resolution). The limiting magnitude for direct imagery is 8 magnitudes fainter than reached by the Celescope experiment on OAO-2. Thus, the proposed experiment will serve to lay the groundwork for observations with larger instruments such as the Large Space Telescope and the 1-meter Spacelab Optical/UV telescope.

Instrumentation

The proposed Schmidt camera/spectrograph unit is shown in Figure 1. It is a 15-cm aperture, f/2 system using electrographic recording and is similar to, but somewhat larger than, devices flown on NRL sounding rockets, on Apollo 16, and Skylab 4. The 15-cm camera is also very similar to a 10-cm aperture, f/1.5 camera/spectrograph unit constructed in 1967 for the Marshall-developed ST-100 platform, intended for a possible second Skylab. An important advantage of electrographic recording is the high quantum efficiency and long-wavelength rejection achieved by the use of front-surface (opaque) alkali-halide photocathodes. Thus, despite the relatively small aperture, the electrographic Schmidt camera has a high overall detection efficiency, plus linearity of response and wide dynamic range.

It is proposed to fly two camera/spectrograph units covering, respectively, the wavelength ranges 1050-1600 Å and 1250-2000 Å (see Table).

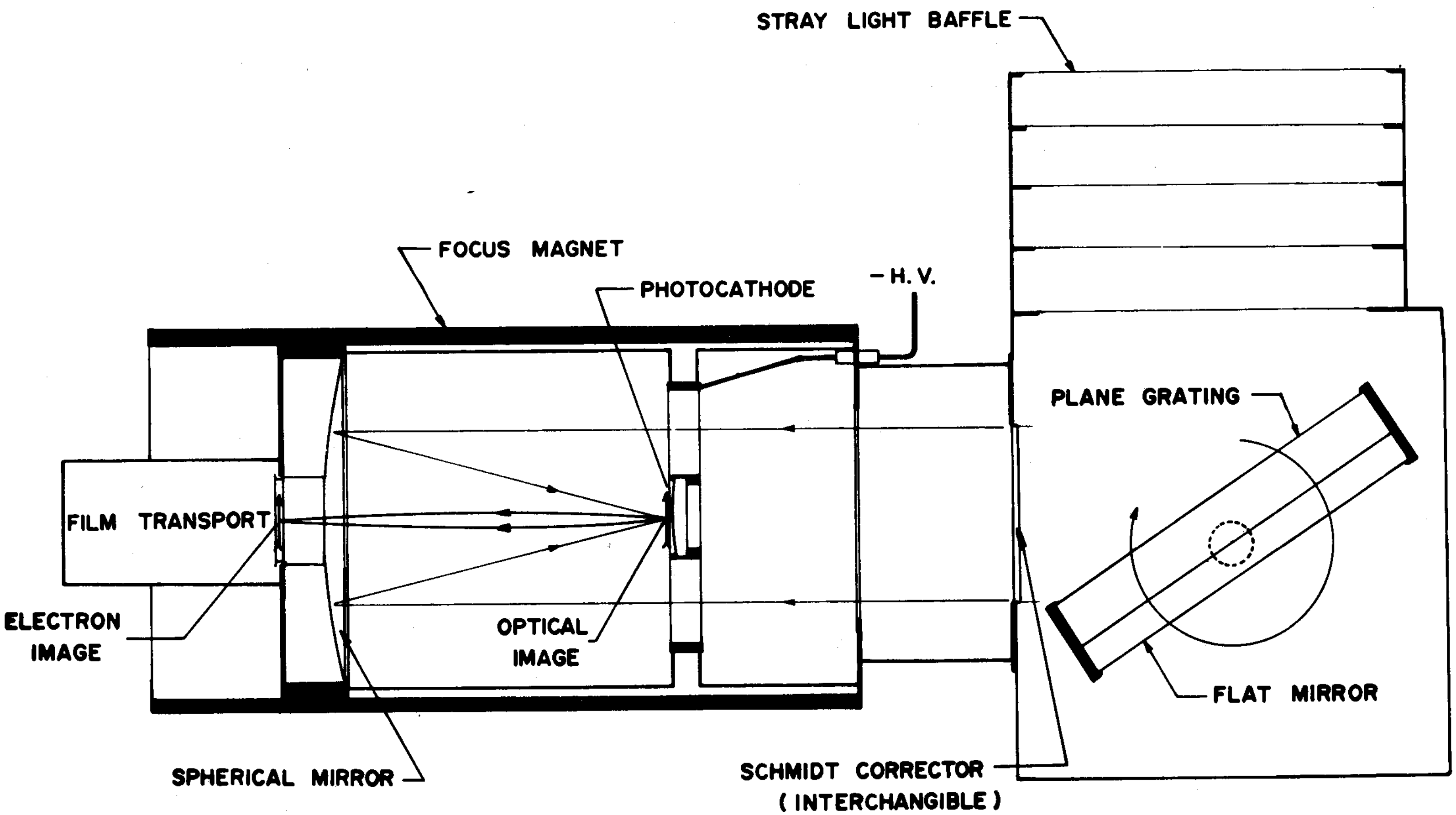


Figure 1. Diagram of the Schmidt Camera/Spectrograph

	Camera 1	Camera 2
Photocathode	CsI	KBr
Correctors	CaF_2, BaF_2, Al_2O_3	LiF, CaF_2
Imagery	1250-2000 Å	1050-1600 Å
	1350-2000 Å	1250-1600 Å
	1450-2000 Å	
Spectra	1250-2000 Å	1050-1600 Å
Fields of View	11° Circular	
Resolution (spatial)	20 arc sec	
(spectral	2 Å (300 lines/mm)	
	0.5 Å (1200 lines/mm)	

These units would operate simultaneously, while viewing the same region of the sky. Each unit would have an 11° diameter field of view, 20 arcsec resolution (0.5 to 2 Å spectral resolution, depending on choice of grating), and would record images on 70 mm electron-sensitive film (a 150-ft. roll in each unit would last a 7-day mission). For sky mapping, the effective field is a 7° square, and 842 different pointings are needed for complete sky coverage. Therefore, with 30-min. exposure sequences and all modes of operation for each starfield, complete coverage would require the night portion of 4200 orbits. Since the instrument is currently under construction, there would be no difficulty in being ready to fly on the early Shuttle flights. However, the proposed instrument has significantly greater capability than similar ones presently in use in sounding rocket flights and would not be obsolete by 1979.

Pointing and Other Spacelab Requirements

The pointing accuracy required is ±1° (desired ±0.5°), which is within the capabilities of the basic Shuttle RCS. However, the pointing stability required is ±10 arcsec over a 20-minute exposure time, which requires an additional fine-pointing system. Since the fine-pointing requirement is not so severe as for several other proposed instruments, and the sky-survey type of observing program is generally incompatible with the use of startrackers for fine pointing, we propose a special-purpose platform using rate-integrating gyros for fine pointing (see Figure 2).

Coarse pointing is achieved using the shuttle RCS, with the guidance of the shuttle IMU and the closed-circuit TV starfield camera. During these maneuvers, the platform gimbals and RIG's are caged, with the instruments pointing vertically out of the payload bay. Then, the platform gimbals and RIG's are uncaged, so as to hold the pointing to the required high stability. The platform gimbals and

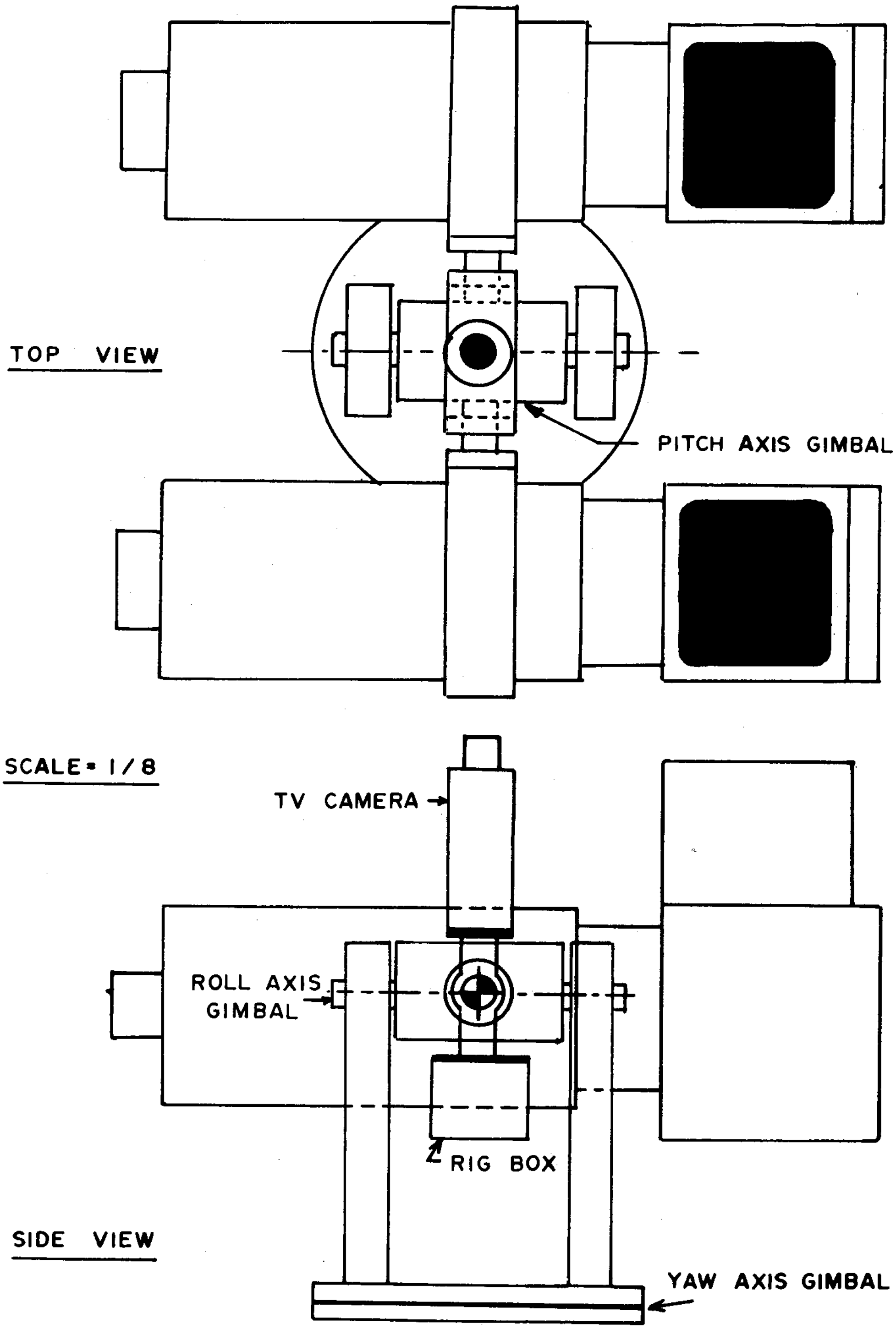


Figure 2. Conceptual view of an instrument package consisting of two Schmidt camera/spectrograph units mounted on a fine stabilized pointing platform. This package is mounted in the Shuttle payload bay and is controlled from the shuttle cabin or pressurized Spacelab cabin.

RIG's are then recaged before moving to the next target. Alternately, if successive pointings are close together in direction (as for sky mapping), the coarse slew can be done with torque motors on the platform gimbals, with the RIG's only being caged for the slew.

The ambient gas pressure in the payload bay must not exceed 10^{-5} torr during operations. Thus, RCS jets and overboard venting must be inhibited during exposures. The payload must be kept in dry nitrogen at all times after shipment from NRL. The experiment should be sealed and kept dry during re-entry. Tentative control and monitoring functions evisaged for the Payload Specialist control panel are the following:

High Voltage On/Off

Exposure Sequence Initiate (predetermined automatic sequence)

Manual Film Advance

Manual Selects: Corrector Plate, Mirror/Grating

Film Advance Monitor (flashing light)

High Voltage Monitor (meter)

Closed Circuit TV (pointing monitor)

Gimbal Cage/Uncage

Platform Cage (for launch and reentry)

3. UV TELESCOPE WITH ECHELLE SPECTROMETER

Y. Kondo and C. Wells, JSC

Objectives

The primary scientific objectives of this experiment are investigations of stellar chromospheres, dynamics of extended atmospheres of supergiants and WR stars, mass transfer in close binaries including X-ray binaries, chemical abundance in stellar atmospheres, and chemical abundance and electron temperature of the interstellar medium. We are currently conducting a multi-year program of spectrophotometry of astronomical objects in the mid-ultraviolet through use of JSC's balloon-borne Ultraviolet Stellar Spectrometer (BUSS). This project of payload development includes the flight-tested JSC BUSS payload and the JSC/SRL BUSS payload (SRL stands for Space Research Laboratory at Utrecht, The Netherlands). The JSC/SRL BUSS payload with adaptations constitutes the JSC/SRL Telescope Spectrometer for Spacelab and is scheduled for a balloon flight in October 1975.

Instrumentation

The proposed system consists of the BUSS telescope and star tracking system, supplemented with a high-resolution echelle spectrograph and SEC vidicon detector supplied by SRL. The instrument is shown schematically in Figure 1. Total weight is less than 400 kg, including star trackers and a gimbaled mounting platform. The telescope is an f/7.5 tilted-aplanatic design, which has been used successfully in previous BUSS mission. The telescope focal length is 3 meter, its aperture 40 cm. The star tracker shown in the figure allows coarse pointing of the entire telescope to one arc minute towards the target star, while a further refinement of the pointing is accomplished by an image motion compensation system with one arcsec stability even if the shuttle attitude changes at 1°/sec.

The spectrograph is of the echelle type, allowing the entire spectral region of 2000-3400 Å to be observed simultaneously by means of the SEC vidicon detector. This is the fundamental difference in this instrument as compared with, for instance, S59, BUSS, or OAO-3, where the spectrum is scanned step-by-step. The UV light from the telescope is reflected by means of a dichroic multilayer mirror into the spectrograph, while the transmitted visible light of the star image is used for the image position sensor. The main dispersing element of the spectrograph is an echelle, with a blaze angle of 63°.5 and a groove density of 79 lines/mm. The ruled area of the echelle is 102 × 206 mm, which is illuminated by means of a 500 mm focal length collimator. This design allows a spectral resolution at 2800 Å of better than 0.1 Å even if the convolution of the telescope blur circle and fine pointing errors of the telescope amounts to 3 arc seconds FWHM. The limiting magnitude is about $V = 8^m$. The spectral range of 2000-3400 Å is displayed in the spectrogram from the 112th order at 2000 Å up to the 66th order at 3400 Å. Reciprocal dispersions range from 1.21 Å/mm at 2000 Å up to 2.05 Å/mm at 3400 Å. The orders are separated spatially from each other by means of a quartz predispersing wedge in such a way that the whole spectrogram is fitted optimally to the 25 × 25 mm target of the SEC vidicon tube. The spectrograph will be equipped with a wavelength reference source in order to allow in-flight wavelength calibrations. The photometric response of the instrument will be determined by means of pre-flight and post-flight calibrations in the laboratory. Later improvements of the instrument include upgrading the spectral resolution to 0.03 Å, extension of the wavelength coverage to the 1150 to 3400 Å, range and using the echelle spectrometer with a one meter telescope.

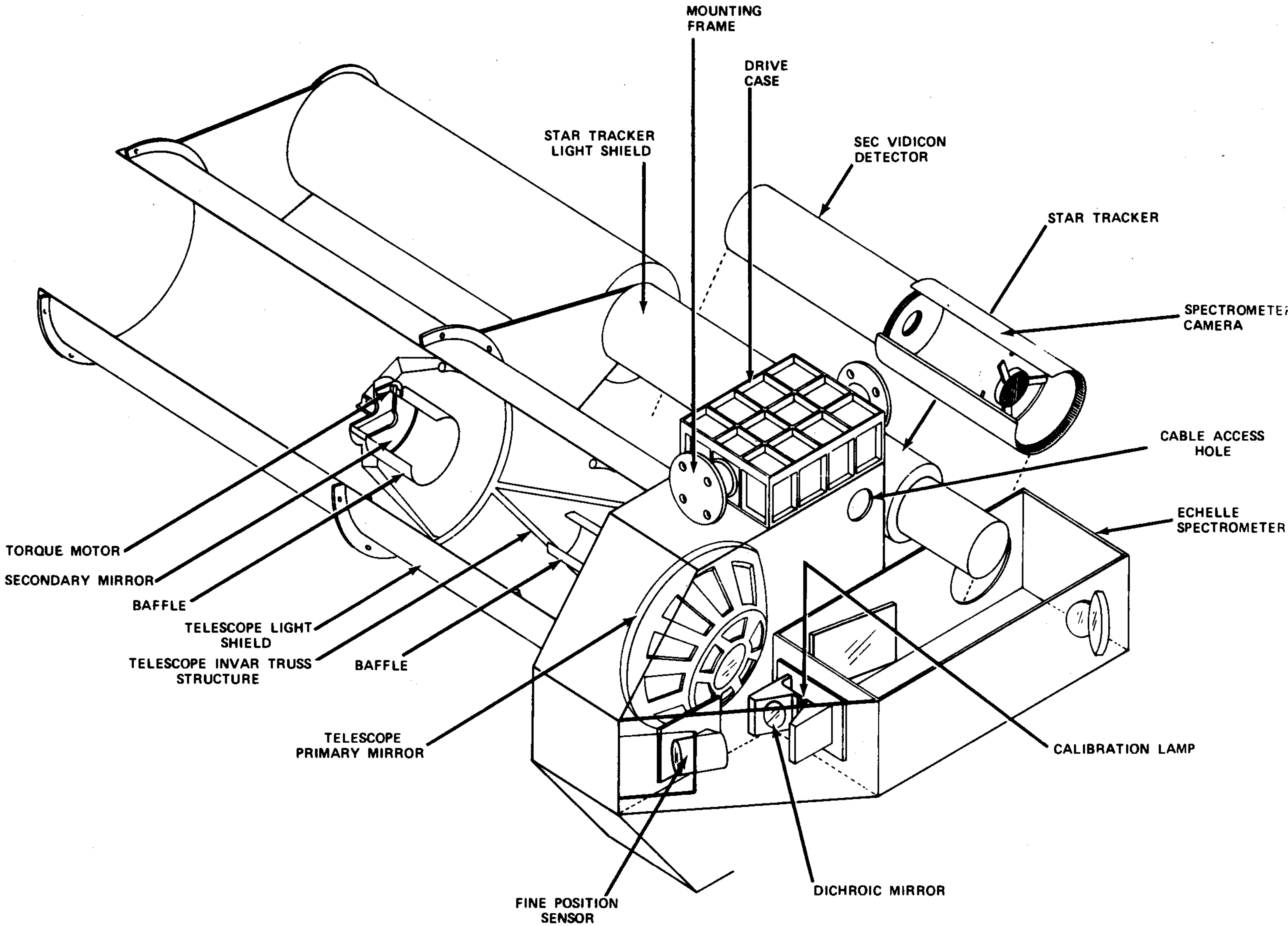


Figure 1. JSC SRL-BUSS System Cutaway

Pointing and Other Spacelab Requirements

The pointing requirements are compatable with the requirements for SIPS, but the complete pointing system of the BUSS makes it an attractive candidate particularly for early shuttle flights, when SIPS may not be fully operational.

The scientific data of the instrument will be stored on board on magnetic tape. Housekeeping data analysis should be done preferably on board, but could also take place on ground. Both housekeeping and scientific data can be handled by the existing computer facilities in Spacelab, or by a separate minicomputer with 16 K of 16 bit words. Every orbit an average of ten television frames of 8 Mbit each plus 1 Mbit of housekeeping data have to be stored on magnetic tape. Housekeeping data will, together with quick-look scientific data, be transmitted to the ground in parallel at a bit rate of 48 kilobits/sec in lieu of a specialist. Tasks of the payload specialist would be:

a. To start automatic star acquisition software program (once per orbit).

b. To start the measurement sequences software (once per orbit).

c. To ensure proper data storage (changing tapes, etc., regularly).

d. To take action in case of anomalies.

As a backup all commands can be generated also from the ground.

Additional Payloads

Two other instruments from JSC were discussed at the workshop that exceed the guidelines for small payloads in weight, size, or pointing requirements. The first was a 30-inch Schmidt telescope with a package size of 1.2 × 2.2 × 2.0 m and a mass of 700 kg. The absolute pointing accuracy needed was only 6 arc min and internal stability is provided to 0.1 arcsec but a roll stability of 2.5 arcsec is required. The second payload was an Echelle Nebular Spectrograph with 1 × 1 × 2 m exterior dimensions and a 300 kg mass. Pointing accurate to 1 arcsec is needed with 0.3 arcsec stability.

4. SMALL INFRARED CRYOGENIC TELESCOPE

R. Walker, AFCRL

Objectives

The objective of this work is to obtain observational data characterizing the spectral energy distribution of celestial objects in the intermediate infrared, 4 to 30 microns. Specifically two classes of observations would be performed.

A. Measurements of diffuse sources of large angular extent:

a) Thermal emission from interplanetary particles (zodiacal emission) - A low resolution spectral and spatial map of zodiacal emission would permit identification of compositional classes (silicate, iron, etc.) of the emitting particles and compositional variations with distance from the sun.

b) Cosmic background radiation due to the aggregate of unresolved galaxies - Definition of the spectrum of the cosmic background in the middle infrared will provide much selectivity in choices between steady-state and evolutionary models of the universe, and provide needed data on the mean density of matter in the universe.

c) Survey of galactic plane for extended regions of nonthermal emission - A great variety of atomic and molecular emission lines have been predicted for regions where dust and gas are interacting, for example:

H_2 at 4.4, 5.0, 6.1, 8.0, 12 and 28 microns; Ne at 12.8, 15.4, and 14.3 microns; Fe^+ at 26 microns.

A survey defining positions and intensity of these regions would serve as a basis for a great many detailed ground observations, and provide integrated fluxes for the larger objects difficult to observe from the ground.

B. Measurement of sources of small angular extent:

a) Selected Areas Survey - The present point-source IR survey of AFCRL is complete to M(4) = 1.5, M(11) = 1, M(20) = -3 magnitudes for 80% of the sky and will add significantly to our understanding of galactic structure. The longer integration times available on orbit permits observation of small regions, such as the Kapteyn Areas, to a statistical limit 3 magnitudes fainter.

b) Extragalactic Objects - Forty-four galaxies were observed in the AFCRL sky survey. These observations indicate that with the longer integration time available on orbit, it will be possible to perform a detailed survey of the Virgo cluster.

Instrumentation

The telescope (less gimbals) will fit within a cylinder 51 cm diameter by 137 cm long. The telescope should be free to view in all directions, except that the optical axis of the telescope must not approach closer than 30° to any spacecraft structure, the sun, the moon or the Earth limb. The telescope will have a vacuum cover which must be removed when in space. This will be by remote command (operator), and the cover will be retained on the telescope or pallet for reinstallation at the completion of the mission.

The basic HI STAR rocket telescope would be modified by the addition of an extended "sun shade" and by increasing the capacity of the LHe dewar. The resulting cryogenic telescope would be mounted in a fine-pointing two-axis gimbal to the spacelab pallet. Two modes of operation are envisaged. In the first, the telescope would be pointed to pre-selected celestial coordinates and remain at that position for a predetermined length of time. In this mode the internal chopper of the system would perform total modulation to permit measurement of the absolute sky radiance. Spectral data would be obtained by a multi-element detector array with a "wedge" filter providing narrow wavelength band isolation. In the second mode, the telescope would be pointed at preselected coordinates and a reciprocating scan would be generated by the gimbals. Point objects would be detected as they transit the detector elements. Multi-band interference filters would isolate selected spectral regions. In this mode surveys of the objects in selected areas would be accomplished. Both modes of operation could be employed on a single orbital mission, if desired.

Data from the multi-element array would be conditioned and preprocessed by the "on-gimbal" telescope electronics. Data would thus be transmitted to spacelab for further processing, recording and transmission to the ground.

Pointing and Other Spacelab Requirements

A special gimbal mount is required to point the telescope to within 1 arc minute of the desired celestial coordinate and maintain that line of sight with a stability of 20 arc seconds, peak to peak. In addition, the gimbal should be able to scan at rates on the order of several degrees/sec with a constancy of 1% of the scan rate. Scan amplitudes should be adjustable in the range 1 to 30°. Positional readout during scan should be accurate to ±20 arc seconds.

Scan mode will require a special purpose memory unit with 16 bit word size capable of co-adding 30 input channels at the rate of 2000 words per second per input channel. Input words would be 14 bit length, (60K, 16 bit memory). Computer memory would be dumped at completion of area scan, and stored information further processed by on board computer to produce coordinates and amplitudes of sources detected. This can be easily accomplished with a computation rate of 2000 per second and a memory of 10K. Total data to be "dumped" to ground in one day is determined by number of sources detected. Total is estimated at 10^5, 10 bit words/day = 10^6 bits/day (max.).

For all the observations desired, the orbit should be above 400 km altitude. A variety of orbital inclinations and launch times is desired, depending upon the main objectives of the flight. For example: an inclination of 28° would optimize observation of the regions near the galactic poles, while a sun-synchronous polar orbit would provide the best environment for scanning selected areas.

The telescope would consume 18 kgs. of stored liquid helium during a seven day mission. The LHe would be stored in the telescope dewar at a pressure of 3 atm. The boil-off gases could be exhausted into the local environment if this would not compromise other payloads on the mission.

Manned support would be required to operate the telescope and gimbals. It is assumed that pointing would be through interface with the spacelab computer and aspect reference system.

Of special concern to the infrared experiment is the cleanliness of the local environment. Class 5000 should be maintained in the unpressurized section. Effects of reaction jets is not known at this time; however, it is estimated that emission rates for particles 10-25 microns in diameter should be kept below 15/minute, if possible, and the H_2O vapor column density should not exceed about 10^{14} /cm^2.

Space chamber tests of the first system would be highly desirable. The chamber should have an internal cold liner at $T \leq 20°K$.

5. TWO EUV EXPERIMENTS

S. Bowyer, University of California at Berkeley

A. EUV Imaging Telescope

A number of classes of galactic objects have been predicted to emit the bulk of their radiation in the EUV band between 100 and 1000 Å. This instrument will be capable of detecting such sources and locating their positions to within 10 arc minutes. If any extended EUV sources are discovered, this experiment can map them by simple pointing maneuvers. In addition, the spectral bandpass may be changed by placing different filters in front of the detector.

The great strength of this experiment lies in its imaging ability. In the EUV, the largest source of background is the resonant fluorescence of solar photons with the gases of the Earth's atmosphere. Thus, this radiation is diffuse, and appears distributed over the image plane. A point source, however, remains confined to one resolution element on the image plane. The net result is that the signal to noise ratio rises by the number of resolution elements, which is typically 1000.

The experiment shown in Figure 1 consists of a grazing incidence imaging telescope which looks out the nose of the rocket payload and focuses the incoming rays onto a RANICON detector. The RANICON is composed of a microchannel array plate in front of a square resistive anode with signal outputs at each corner. When a photon strikes the plate, it emits a pulse of electrons which then strikes the anode. By weighting the relative strengths of the signals in the four pickups, one can tell where the photon struck the plate. Mounted directly in front of the RANICON is a thin filter designed to restrict the photon bandpass to a desired range of energies. Through the center of the mirror runs a baffle which eliminates rays that can strike the detector without being imaged. At the front of the mirror is a magnetic collimater which rejects electrons of energy up to 25 keV.

The telescope must be pointed and held to ±1°. Each target must be observed over a total time ranging from 1 minute to 5 hours, though the observation need not be uninterrupted. The experiment should not be pointed closer than 30° to the Sun.

The experiment needs a bit rate of 20 kbps when operating. Either direct telementry or on board storage is acceptable. A record of the spacecraft aspect is required; 30' accuracy is required, 5' accuracy is desirable. Note that this is only a recording requirement and is not a pointing requirement. There will be a door on the side of the shell to allow access to electronics. This will be shut and not used during flight.

Four analogue outputs should be monitored intermittently either on board or on the ground. These outputs are:

i) Total Counting Rate

ii) RANICON voltage

iii) Pressure

iv) Current

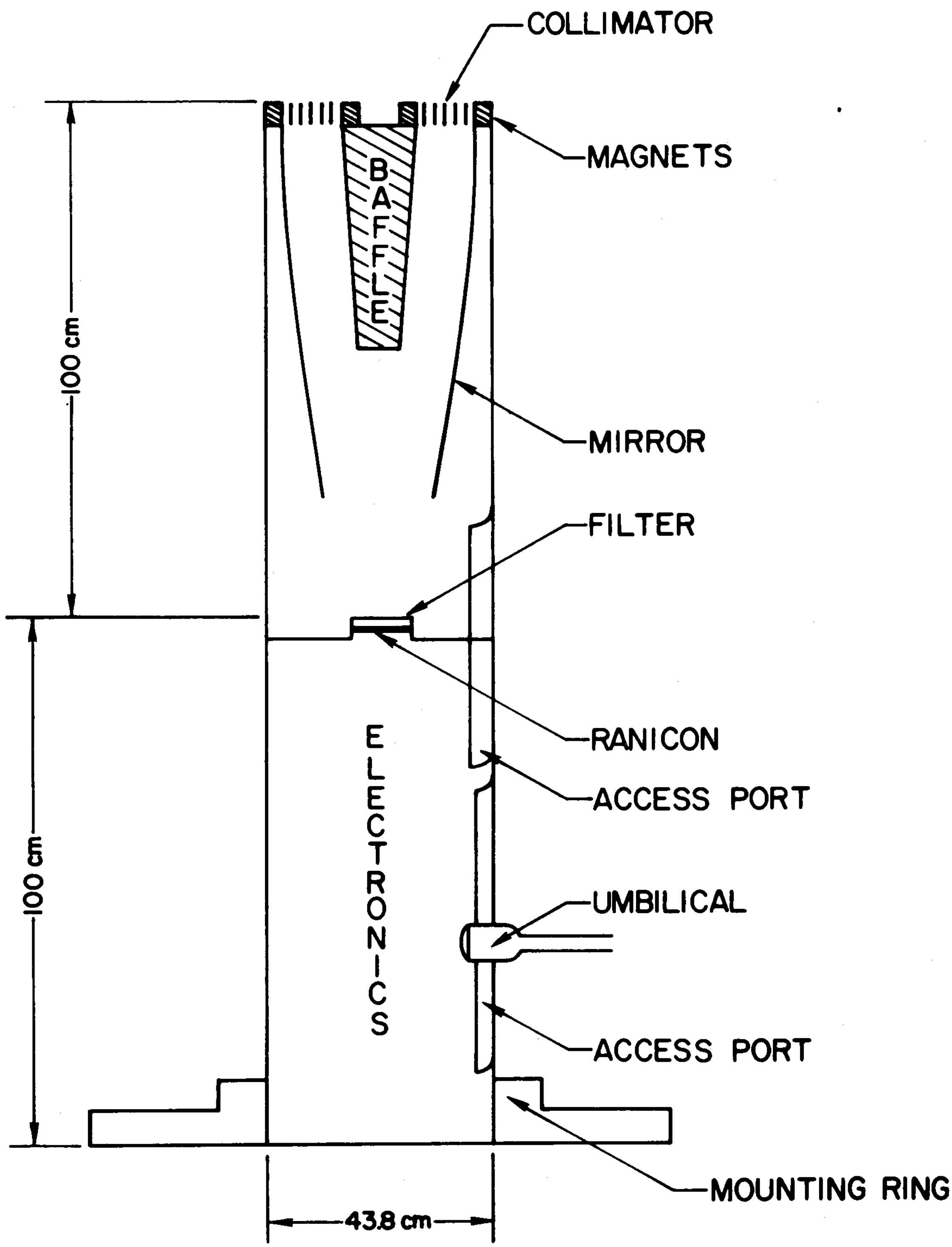


Figure 1. Schematic of EUV Telescope

B. EUV Spectrometer

The primary scientific goals of the EUV Spectrometer are summarized in the following four areas.

a) Geocoronal Airglow

The total existing data on both the atmospheric dayglow and nightglow in the range from 300 to 1050 Å is limited to a small number of measurements made with broadband photometers ($\Delta\lambda \sim 300$ Å) made with sounding rockets. The interpretation of these data is by necessity restricted, as it is based on assumptions as to the wavelengths of the radiation being observed. No moderate or high resolution studies have been made at these wavelengths and no spatial or temporal studies have been carried out. Extreme ultraviolet airglow measurements which should be carried out with the instrumentation include an exploratory search of the EUV band of the spectrum (300 to 1050 Å) to direct with high sensitivity all resonantly scattered and collisionally excited radiation and search for locally enhanced regions produced as a result of specific sources of collisional excitation.

b) Aurora

The need of remote sensing of auroral phenomena becomes evident when one considers the vast scale, in both time and space, of the necessary measurements. Without considering details, it is obvious that adequate coverage of the aurora using only in situ observations is nearly impossible even with a relatively large number of satellites and rockets. Fortunately, the aurora by its very nature is amenable to study by remote sensing techniques. This characteristic contributes to the fact that the aurora is probably the most useful phenomenon for use in efforts to experimentally explore both the magnetosphere and the ionosphere. Currently no auroral EUV spectrum exists.

c) Plasmasphere

The HeII 304 Å line is optically thin at Shuttle altitudes and plays a unique role as a tracer for the plasmasphere. A study of this radiation will facilitate our understanding of the nature of this region and its interaction with the magnetosphere.

Observations of this line will permit detailed evaluations of competing models of the plasmasphere as was carried out by Paresce, Bowyer and Kumar (J.G.R., 79, 174, 1974). Number densities of ionized helium derived from this data may be more reliable than number densities derived from mass spectrometer data because of various experimental difficulties inherent in measurements with in situ detectors.

d) Local Interstellar Medium

It is now well established that the study of resonantly scattered 584 Å radiation from neutral helium will be central in our developing knowledge of the interaction of the local interstellar medium with the solar system. By the time of the Shuttle these studies should have delineated many of the parameters of this interaction, but it is likely that some effects such as changes with solar cycle and trace element measurements will not be fully explored. Studies of 584 Å HeII and 1025 Å H I radiation will delineate these interactions and studies of other EUV lines such as predicted by Blum, Fahr, Axford, and others will define the trace element interactions.

Brief Description of Instrument

An optical layout of a possible EUV spectrometer configuration is shown schematically in Figure 2. The incident light first passes through a baffle to eliminate off-axis radiation. After passing through the entrance slit the light impinges on a platinum coated concave diffraction grating at an angle of incidence of ~10°. The grating is an off the shelf Bausch and Lomb replica ruled at 2400 lines/mm, blazed at 1000 Å and having a radius of 400.7 mm.

The diffracted radiation is focused by the grating onto a RANICON situated on the Rowland circle. The inside order spectrum is used for packaging convenience. The RANICON serves as an efficient position sensitive EUV photon counter and consists of a 75 mm diameter channel electron multiplier array followed by a resistive anode. The front face of the CEM array is the photocathode, where photoelectrons are generated; an individual electron is multiplied about 10^7 times in traveling the length of a channel. The close spacing of adjacent channels permits good spatial resolution of an EUV spectral image. Each electron pulse produced by the CEM array is proximity focused onto the resistive anode. This anode is connected to low noise charge sensitive amplifiers, whose relative output pulse amplitudes give the location of the detected photon. The image is accumulated in a small random access memory for periodic readout.

The pointing requirements depend on the scientific objective.

a) Geocoronal airglow: random or programmed sweeps of overhead sky (1 to 5°/second) to accuracy of ±10°.

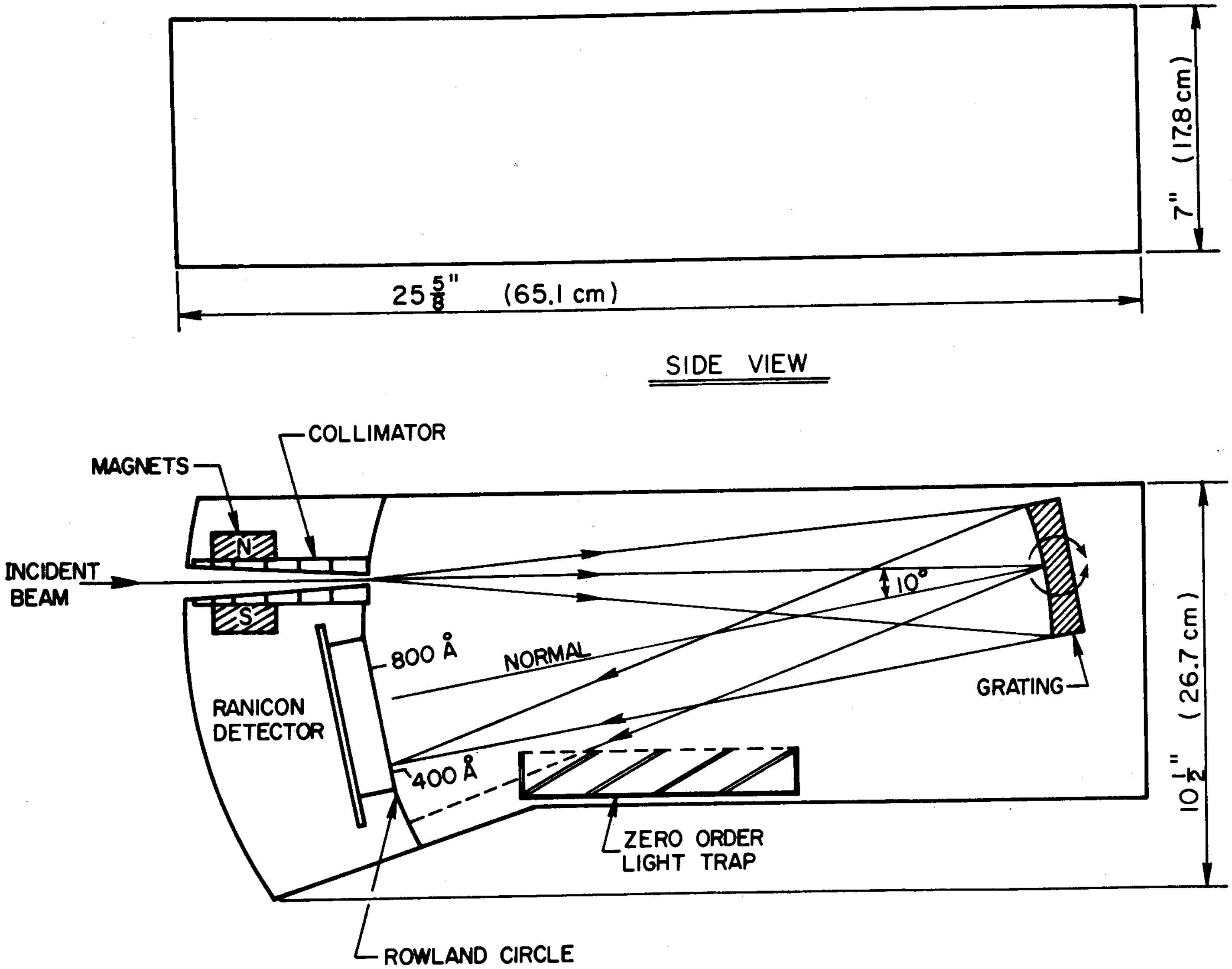


Figure 2. EUV Spectrometer

b) Aurora: programmed sweeps of auroral arcs (1° to 5°/second); pointing at one geographical point (±2°) for duration of overhead pass.

c) Plasmasphere: programmed scans (1 to 5°/second) to accuracy of ±5°.

d) Interstellar medium: random pointing or programmed sweeps of sky within ±40° of zenith.

A record of the aspect is required with 1° accuracy. A maximum data rate of 40 k bps for intervals of 5 minutes is required for auroral observations. At other times, a maximum of 10 k bps is needed. The experiment must be purged with dry nitrogen until shortly before launch (typical flow rate: 1 cubic foot per hour).

C. X-Ray Payload

A high-time resolution X-ray experiment was also discussed. The Spacelab requirements for pointing and power were similar to those of the EUV payloads. A data rate of 200 k bps, 3 deploying doors, and gas supply bottles are included as special needs.

6. ULTRAVIOLET PHOTOMETER

A. Code and R. Bless, University of Wisconsin

Objectives

The purpose of this experiment is to establish the absolute energy calibration for a net of about 40 early-type stars in the spectral interval 925 to 3400 Å. Any member of this group of carefully measured stars would serve as a secondary standard of absolute flux for other UV telescopes in orbit.

Instrumentation

This payload is essentially identical to that flown on Aerobee rockets. It includes a spectrograph feeding 7 detectors sensitive between 900 Å and 1700 Å, each with about 50 Å bandwidths, along with four individual filter photometers sensitive to radiation from about 1900 to 3400 Å with bandpasses ranging from 50 Å to about 200 Å (see Figure 1.)

The spectrograph consists of an 8-inch spherical mirror (whose field of view is limited to about 2 by 30 arc minutes), which illuminates a 600 line/mm plane diffraction grating blazed at 1200 Å. The resulting spectrum, with a dispersion of about 17 Å/mm, is focussed on Bendix windowless channeltrons fixed in the focal plane. These detectors are operated in a pulse counting mode. The payload is evacuated before flight to minimize out-gassing problems.

The second group of four photometers mentioned above are of a type we have flown many times before — two-inch quartz refractors with six-layer MgF_2-Al interference filters to shape the ultraviolet pass bands — and EMI 6256b photomultipliers operating in a pulse counting mode. The zero-order alignment detector used on the Aerobee will be permanently mounted on the shuttle payload.

Pointing and Other Spacelab Requirements

The instrument requires an absolute pointing accuracy of 2 arc min and a stability of 5 arcsec during an observation of 20 minutes. After orbital insertion the mission specialist will command small slew steps of about 10 arcsec and read the output from a zero-order detector in order to measure the absolute pointing offset between the telescope and SIPS mount. After on-orbit calibration of the pointing platform errors, the absolute pointing errors should be only ±15 arcsec. In zero gravity, only thermal changes should affect the ability to maintain a 15 arcsec absolute pointing. Over 1 week mission we want to observe bright stars spaced over 1 hemisphere of the sky twice. Do not observe in sunlight; close shutter when when near sun. Strict cleanliness precautions are necessary for calibration payloads and dry nitrogen will probably be required for purging during launch and re-entry.

Data is recorded by an on-board computer and transmitted via TDRS whenever possible. Check-out phase (1-3 orbital nights): payload commanded by mission specialist must have voice contact during this period; otherwise, we must have real-time data link. During the first day we should have several data dumps to control center. After the first day, one dump per day is sufficient.

After check-out the payload can be operated automatically from preprogrammed commands. These should be capable of quick revision. Since there are no movable mechanisms in this particular spacelab payload, control of the experiment can be relatively simple namely: turn on/off experiment low voltage, turn on/off experiment high voltage, turn on/off calibration lamp. Total lines needed: 3.

However, to take advantage of the power of spacelab's command ability a more flexible and safer (in the event of a payload subsystem failure) command sequence can be used with only a small increase in hardware. Each of the 12 detectors, counting the zero order detector, can be individually enabled or disabled through redundant payload hardware. Each detector would require 2 command lines, i.e., enable/disable detector LV and enable/disable detector HV. Additional command lines would be needed to provide LV to housekeeping circuitry, calibration lamp power supply and shutter open/close, zero-order detector field stop, and nitrogen purge on/off. Total command lines required: 30.

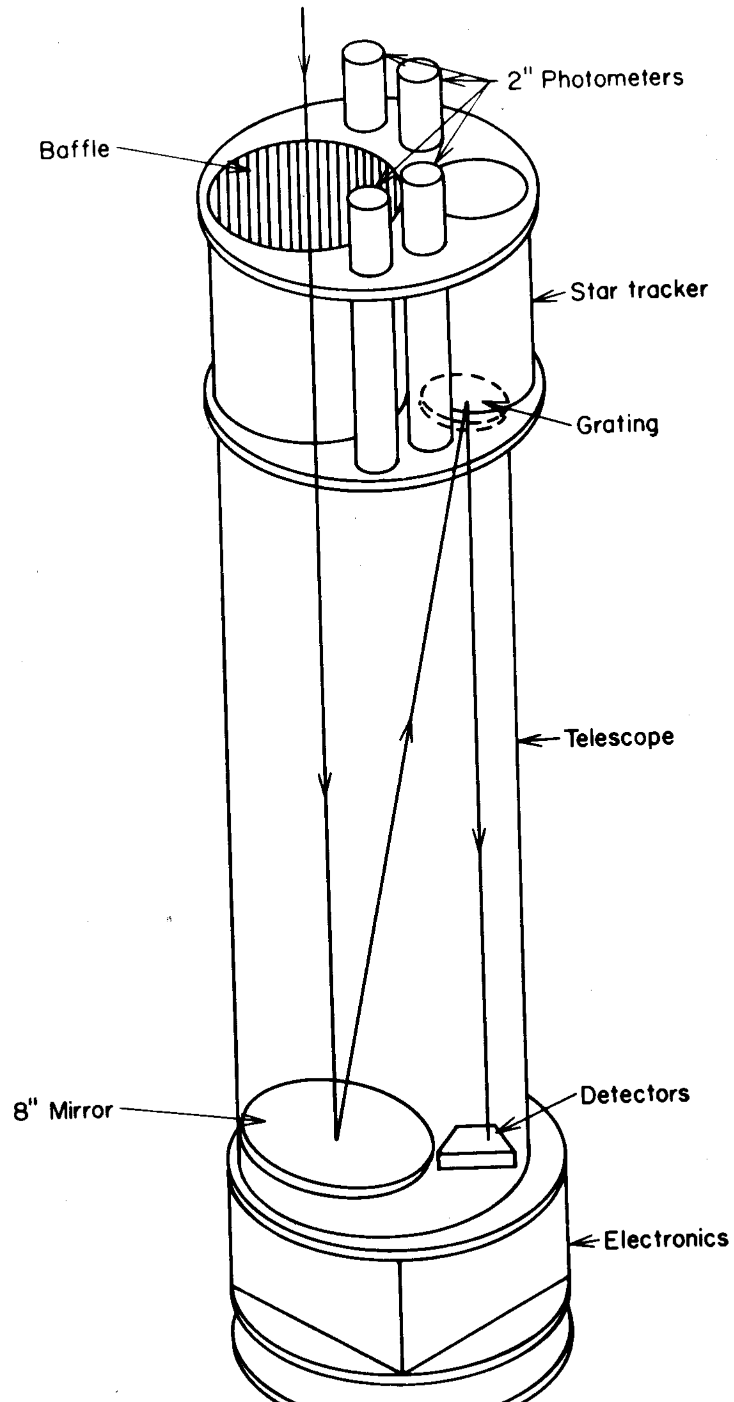


Figure 1. Wisconsin far UV spectrometer payload including four broadband photometers

We would like about one month as close to flight as possible to recalibrate payload.

The following table summarizes our thoughts on some of the important parameters of a Spacelab flight. In order to maintain the basic philosophy of the sounding rocket program which has been quite successful over the years, the Spacelab support systems should be designed to satisfy the goals listed in the final column.

Comparison of Rocket, Satellite and Spacelab Missions for Optical Astronomy

	ROCKET	SATELLITE	SHUTTLE SORTIE
Scientific Objective	Specific measurement	Variety of invest. possible	Variety of invest.
Observing Time	Minutes	Months	Days
Lead Time	6 Months	2 - 3 Years	1 Year
Integration Time	Month	6 Months	Months (?)
Turn-Around Time	6 Months - 1 Year	Years	6 Months - 1 Year
Payload Weight Volume Aperture Qual. testing	~ 100 - 200 lbs $1 - 2 \times 10^5$ cm^3 up to 10"-12" telescope fairly extensive	100 lb - 2000 lb $4 \times 10^5 - 5 \times 10^6$ cm^3 up to 1 m very extensive	large like satellite like satellite relaxed (off shelf?)
Cost (Experiment)	$.3 M	~ $5 - 10 M	~ $.5 M
Experiment $/ Observing Time	~ $1000/sec	~ $10/sec	~ $5/sec
Maximum Opportunity	2/year	1/5 years	up to 2/year
Data Analysis	Moderate effort	Large effort	Moderate effort
Interface Requirement	Minimal	Extensive	?
Man Interface	None	Unlikely	Possible (intended)
Training and Simulation	Little required	Extensive	Perhaps 3 months (?)
Pre-flight Calibration	Relatively simple, within weeks or days	Year lead time	Could be same as rocket
In-flight Calibration	Possible	Possible	Possible
Post-flight Calibration	Possible	Not Possible	Possible
In-house Organization Required	Small	Large	Small
Quick Reaction to new research or targets of opportunity	Possible	Only accidently	Possible

7. SCHWARZSCHILD CAMERA

A. Smith, GSFC

Objectives

The experiment is designed to measure faint surface brightness such as that associated with supernova remnants, planetary nebulae, emission and reflection nebulae, and galaxies. Most of the high excitation forbidden lines of O II, O III, Ne III, Ne IV, and Ne V from which temperatures and densities can be derived will be observable. In order to record ultraviolet surface brightness of galaxies equivalent to 19th visual magnitudes per square arcsecond, exposure times will be on the order of 20 minutes.

Instrumentation

The camera has a low focal ratio and utilizes only two reflecting surfaces to achieve diffraction limited performance. Some of its characteristics are listed in the following table.

SCHWARZSCHILD CAMERA CHARACTERISTICS

	Camera 1	Camera 2
Aperture	141 mm	141 mm
Focal length	200 mm	176 mm
Effective Focal Ratio	f/1.7	f/1.4
Field of view	0.2 radians	0.2 radians
Focal plane diameter	40 mm	40 mm
Resolution	37 arcsec	12 arcsec (diffraction limited)
Vignetting	50% at edge of field	60% at edge of field

In the column labeled "Camera 1" are listed values which can be attributed to an existing Aerobee rocket payload. The characteristics of "Camera 2," an improved version of camera 1, are based on ray trace designs and diffraction analysis.

An optical schematic is shown in Figure 1. The secondary mirror is larger than the primary. The reflected light is imaged through a central hole in the primary mirror to a nearly flat focal plane which permits the use of different kinds of detectors. A circular baffle must be placed between the secondary and the primary mirrors to prevent direct illumination of the focal plane. When diffraction limited performance at 2 arcsec or worse is desired the Schwarzschild design possesses some obvious advantages. There are only two axially symmetric surfaces to manufacture, albeit they are general aspheres, and the focal plane is both flat and accessible. The major drawback is the large vignetting as indicated in the table. However, at the edge of the central 3 degrees of the field of view the vignetting is approximately 16% for camera 2.

The camera can be used by itself to obtain images of various kinds of nebulae and galaxies; in which case, broad band filters can be inserted in the light path preferably before the entrance aperture. Alternatively, an objective grating can be used to diffract the light from, say, well defined supernova filaments, before the light enters the camera. Figure 2 is an isometric drawing of the existing rocket payload which operates in the objective grating mode. As a indication of the system's sensitivity when using a microchannel plate (MCP) image intensifier and 2537 Å light, a suitable image is recorded in 8 seconds if the surface brightness of the source is 2.3×10^8 photons cm^{-2} s^{-2} $ster^{-1}$ or 2.9×10^3 Rayleighs. The resolution of MCP intensifiers cannot approach the resolution of the optics so that the more conventional magnetically focused image intensifiers or electrographic detectors would be a better selection for Shuttle use. These detectors may may not provide the luminous gain of the MCP detectors, but the increase in observing time will much more than compensate for this minor deficiency.

Pointing and Other Spacelab Requirements

The attitude control system is of crucial importance to most optical astronomical experiments. While the SIPS, as presently conceived, adequately points instruments with optical axes parallel to the symmetry axes, it cannot handle "side lookers." For this reason, modifications to the Ball Brothers SIPS or an altogether new design should be undertaken.

Sometimes the signal for controlling the stability can be supplied by the user, but this is not always the case. Startrackers used for this purpose on sounding rocket payloads are now routinely provided by the Sounding Rocket Division of GSFC and this service should be provided to the user of Spacelab. Often, as in the case of the Schwarzschild Camera observations, there is no star in the field bright enough to provide adequate signal for guidance purposes. In these cases two possible guidance methods come to mind. The first utilizes a single star tracker and exceedingly good low drift gyros, i.e. with drift rates ~0.001 degree/hour. In this case, the startracker is used to update the gyros while the gyros themselves

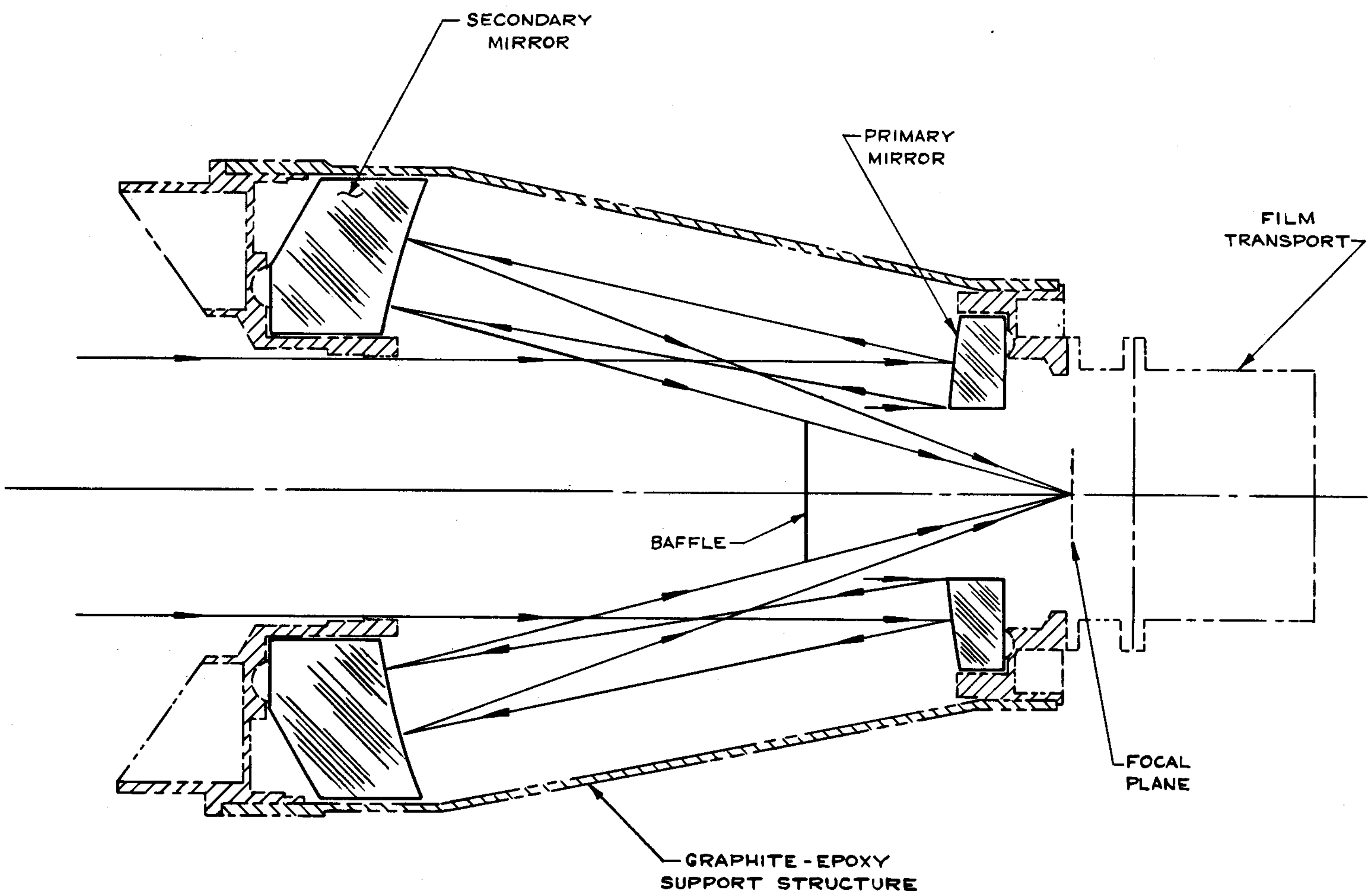


Figure 1. Schwarzschild Camera

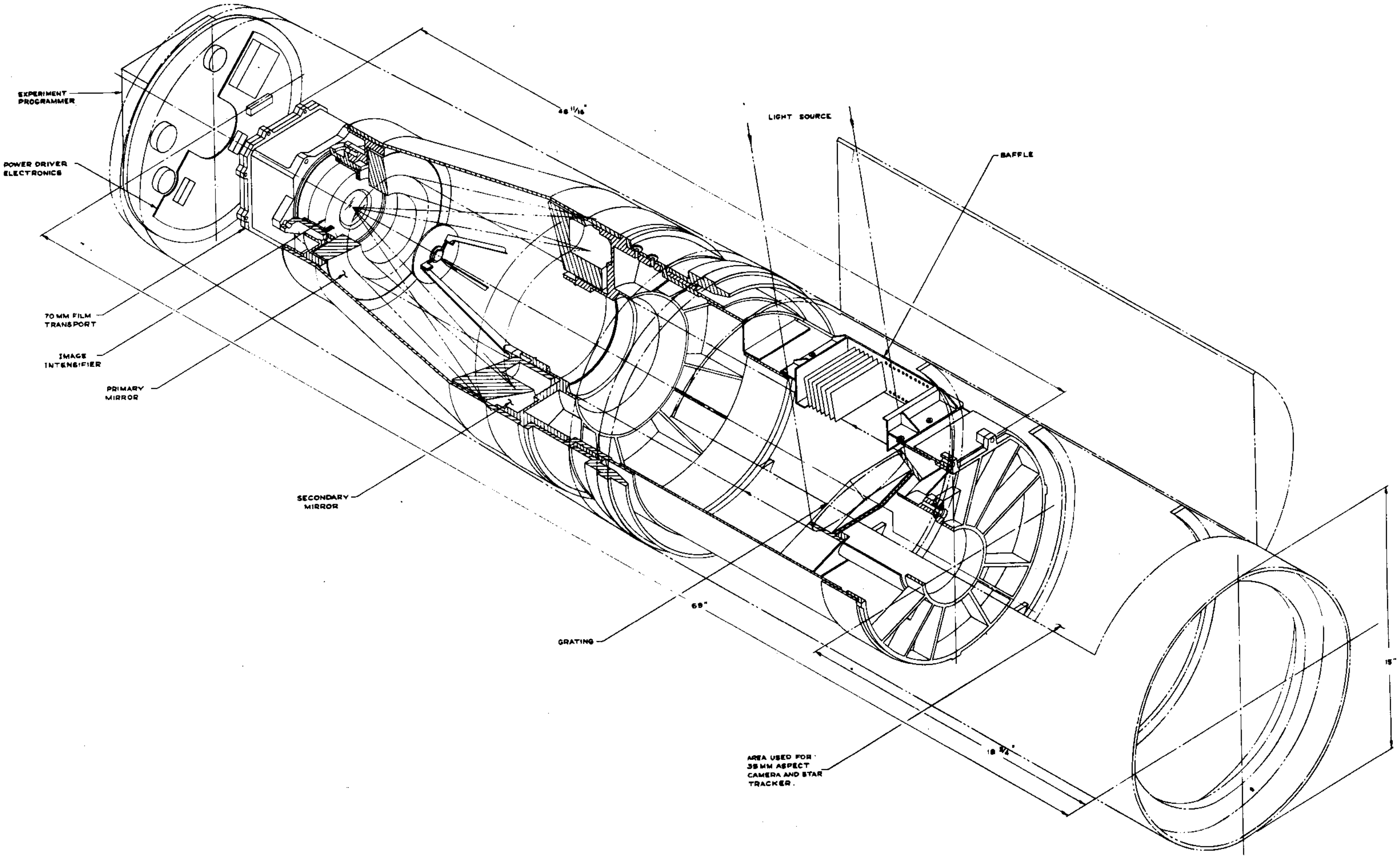


Figure 2. Schwarzschild Payload

provide error signals which are used to correct for short term pointing fluctuations. The second method would use two gimbaled star trackers, which when programmed to point at two acceptably bright stars would point the experiment optical axis in the desired direction. Ideally, the star trackers would prevent any significant drift and provide on the order of ±15" stability about all three orthogonal pointing axis. To narrow the limit cycle to ±1 arcsec, rate integrating gyros could be used with periodic updates from the star trackers to minimize drift.

Since we are attempting to detect faint surface brightnesses we will want to observe in orbital night. Thus, we want to be pointed before entering orbital night and remain pointed throughout the duration of orbital night.

The detector used in the initial flights will very likely be an image intensifier plus film. An on-board computer could control the film advance, shutter and high voltage functions using inputs made by a payload specialist. However, the input could be made from the ground if the on-board computer had enough memory capacity to control the experiment during the times when there is no contact with a ground station.

If real time contact can be maintained, then in the case where an image tube such as a SEC vidicon is used, a quick look data reduction program and CRT display should be available at Goddard. If real time contact cannot be maintained, then a CRT display plus a minimized data reduction capacity should be available at a payload specialist station. We can envisage situations, particularly when orbit to orbit ground contact is not possible, when a payload specialist will be necessary to maintain the most efficient use of observing time. Thus, modifications to the observing program and evaluation of data provided in the quick look mode can be handled best on an orbit to orbit basis by a payload specialist.

In the case where film is used as the recording device we need to prevent "backheating" of the film after re-entry, or the capacity to bring the film into the Shuttle cabin before re-entry. We need the opportunity to evacuate and backfill our payload when it is mounted in the Spacelab. The maximum temperature gradients permitted in the optics section are about 0.2°C/cm, which implies a temperature differential across the diameter of less than 8°C.

8. THREE ROCKET-CLASS PAYLOADS FOR SPACELAB

C. Lillie, University of Colorado

A. Microchannel Spectrometer

The Microchannel Spectrometer, shown in Figure 1, has been described by Lawrence and Stone (1975 in Rev. Sci. Instr.). It was flown on Aerobee 26.024 in January 1974 to observe Comet Kohoutek. The flight of the payload is scheduled in October 1975 to observe Venus, Mars, and (perhaps) Capella. The instrument consists of an exponential baffling system which provides an 8' × 8' field of view; a concave grating with a one meter radius of curvature, and two Varian, Model 8964 microchannel plate (MCP) detectors in a chevron configuration with two resistive strip anodes. The MCP's are 3 cm diameter with 50μ channel spacing, and have a CsI cathode coated onto the input side of the detector. A trap door is provided to seal the instrument when not in use, and an ion pump maintains an internal pressure of 10^{-5} torr. The location (or wavelength) of each photoelectron pulse on the anode is determined by a charge division method. The electron pulse at the output of the MCP's forms charge pulses A and B at the input of two DC coupled, charge sensitive amplifiers. In the second stage we form two pulses of amplitude A and A + B. The divider then forms the signal 10A/(A + B) which is proportional to the distance along the resistor where the original pulse occured.

The flight instrument covers two spectral ranges: 500-950Å, and 1210-1660Å with a resolution of ~ 2.5Å for point sources, and an effective aperture of 2 cm^2 out of a geometric area of 50 cm^2. For use on Spacelab the spectral range of the instrument would probably be ~900 to 1800Å. For additional wavelength coverage a second instrument could be flown to cover the 1750 to 3100Å region. A third resistive strip anode could be included to cover the 450 to 900Å region to observe nearby white dwarf stars and chromospheric and coronal emission features of late type stars.

In its present configuration, with a 1 hour integration the microchannel spectrometer can observe unreddened OB stars of V ~ 13^m with 3% photometric accuracy, and with 2.5Å resolution. This sensitivity will permit the observation of nearby white dwarf stars, planetary nebulae, the brighter galaxies, late type stars, heavily reddened OB stars, OB stars in other spiral arms and the Large Magellanic Cloud, the planets, and the emission from comets as faint as $m_1 \sim 8^m$. An improved version of this instrument with ~5 to 10× more sensitivity, and ~ 1Å resolution is planned for future rocket flights. The major disadvantage of this instrument is its limited dynamic range: with the present (commercially available) electronics, pulse pile-up begins at ~ 10^4 counts/sec, making the pulse location less precise. Thus the current instrument will saturate on an unreddened $6^m.9$ O star. This limitation can be overcome somewhat with improved

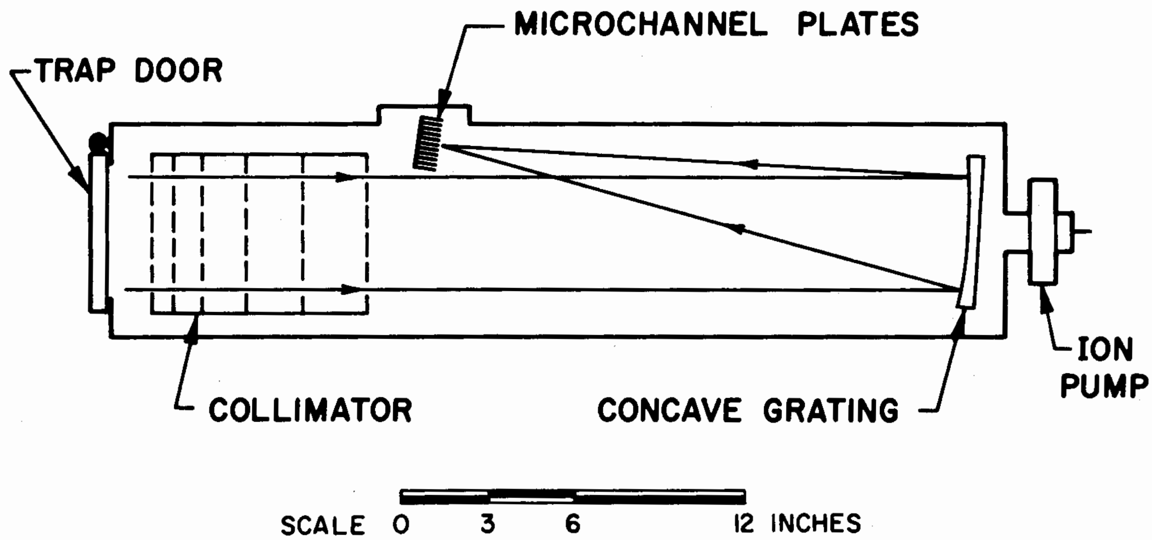


Figure 1. A Schematic Drawing of The Microchannel Spectrometer

electronics. Another solution would be a motor driven iris to vary the aperture size. This maximum allowable count rate means the minimum integration time for 10^3 counts/channel will be ~ 22 seconds.

The pointing requirements of this experiment are ±1 arc min absolute, ±30 arcsec jitter. It can observe during the day if no sunlight is incident on the instrument and no illuminated surface is within ~30° of its optical axis.

B. Ultraviolet Polarimeter

This payload which is scheduled for flight in the summer of 1975 consists of seven ultraviolet polarimeters which will be flown to measure the brightness and polarization of the zodiacal light, stars, airglow, and the Milky Way in the 1500 to 4100Å region. The instrument (Figure 2) consists of a 15 cm, f/1.4 cassegrain telescope, aperture, rotating analyzer, a filter, Fabrey lens, and photomultiplier tube. A motor rotates the analyzer at 10 rps. A shutter provides a dark signal. High and low voltage power supplies, a pulse-amplifier/discriminator unit and a logic unit complete the instrument. This rocket polarimeter is a derivative of our Mariner Jupiter/Saturn 1977 Photopolarimeter Experiment shown in Figure 3. This instrument has an eight position filter wheel and an analyzer wheel with four discrete positions per measurement cycle: no analyzer (open), and analyzers with 0°, 60°, and 120° orientations. A four position aperture plate provides fields of view with diameters of 4°, 1°, 1/4°, and 1/16°. The sensitivity of the instrument is such that a $V = 10^m$ AOV star can be observed with ~1% photometric accuracy in ~100 seconds integration time. For sky background observations with the 4° field of view we receive ~5000 counts per second per Rayleigh in the most

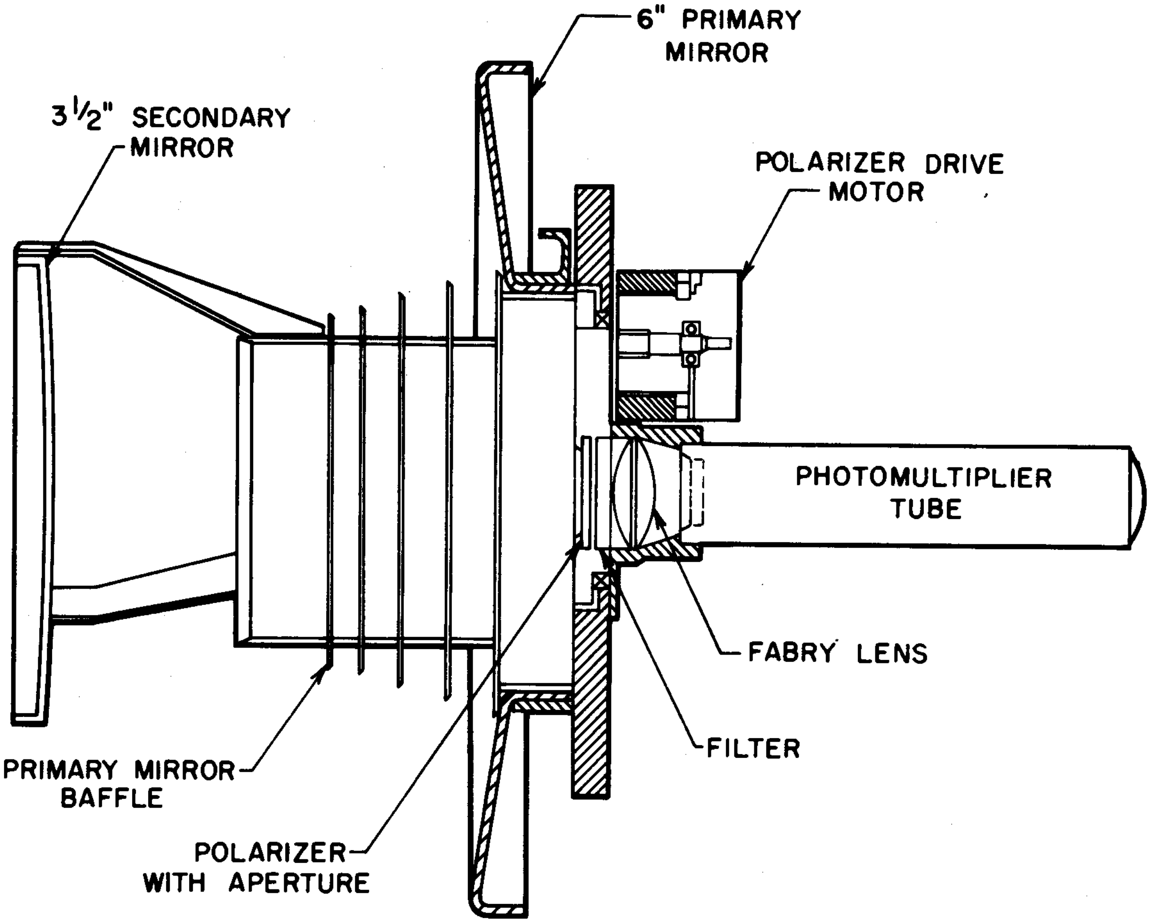


Figure 2. Zodiacal Light Photopolarimeter

sensitive bandpass. This means a surface brightness of $\sim 25^m$ per square second of arc can be measured with a signal-to-noise ratio of 10:1 and with long integration times, the threshold for detectability is about 5^m fainter. A modified version of this instrument on an early shuttle flight would observe stellar sources and the sky background and could determine the sky brightness due to outgassing from the spacelab and the shuttle. The overall dimensions of the MJS photopolarimeter experiment are 20 cm diameter by 34 cm long, plus a 71 cm shadow caster extension which permits observations to within 20° of the sun. In the sky brightness mode and for bright stars a pointing accuracy of ±0.5°K would be sufficient; for faint stars ±1' pointing is necessary.

C. High Resolution Spectrograph

The third payload shown in Figure 4, is a high resolution echelle spectrograph with a resolving power of $\sim 2 \times 10^4$ at Lyman-alpha. It has been proposed for

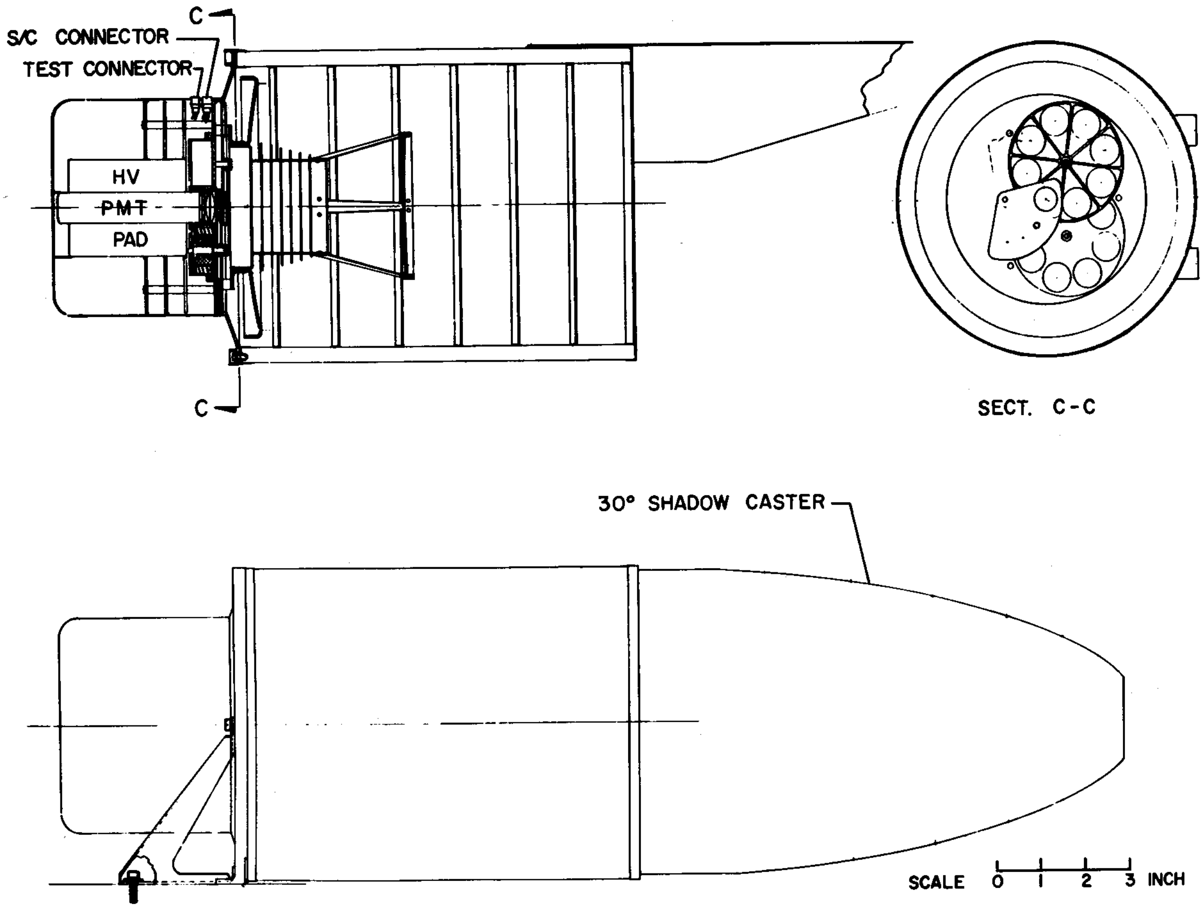


Figure 3. The Mariner Jupiter/Saturn 1977 Photopolarimeter Experiment

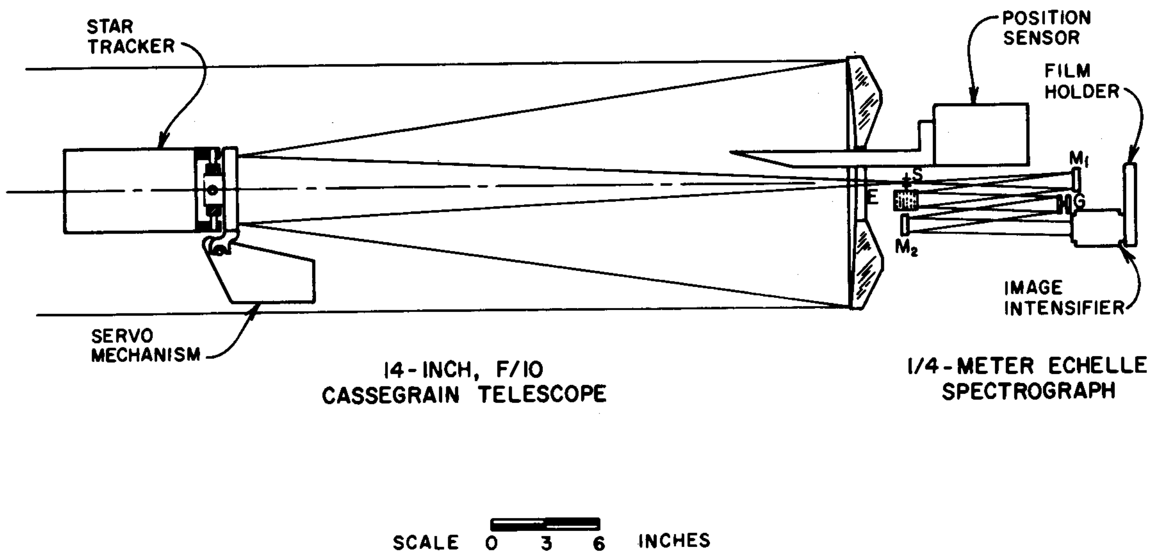


Figure 4. High Resolution Spectrograph Experiment

flight on an Aerobee rocket in FY '77 with a 36 cm telescope with a servo-controlled secondary similar to one developed at Johns Hopkins University. The most desirable detector system would seem to be the intensified film camera developed by Carruthers at NRL. On a sortie mission with a one hour exposure it should be possible to observe unreddened OB stars as faint as $V \sim 11^m$ with reasonable accuracy.

General Spacelab Requirements

The preferred mode of operation of these experiments would be with manned support by a payload specialist from our investigation team. We would provide an instrument with a control unit mounted in the spacelab. If possible, we would provide a dedicated mini-computer with A/C inputs, oscilloscope, and mass storage device to automate the instrument operation, collect and store data, and to provide a quick-look data analysis capability in orbit. This system would permit development of the hardware and software interfaces at the user's institution, and result in considerable savings in overall cost of operations.

We anticipate operating these experiments ~ 12 hr/day or ~ 7 orbits/day. The number of objects observed per orbit would vary from 1 or 2 during routine operations to 5 or 6 during peak periods. During a seven day mission 50 to 100 targets could be observed. The orbital operations would be supported by personnel on the ground, at both mission control and the user's home institution. Quick look analysis of the data (payloads A and B) between operating shifts would permit modifications in the observing sequence to optimize the data collection. The detailed data analysis would be performed after the flight.

9. ADDITIONAL PAYLOADS

Several astronomers have proposed experiments for Spacelab but did not make an oral presentation at the Workshop. The documentation for these payloads is generally less complete than for the first eight groups. A brief description of each instrument follows.

A. Cryogenically Cooled IR Telescope

P. Dyal, Ames Research Center

The telescope is a folded Gregorian cooled with supercritical LHe and operating at 20°K. The detector is cooled to 4°K. A combination of flexible lines and rotary cryogen transfer joints may permit locating the LHe in a tank separated from the telescope. The forward end of the telescope tube is covered with a vacuum tight door that is remotely removed in flight for conduct of observations and avoidance of contamination. To avoid contamination inhibition of main thrusters will most likely be required during the observing program. Attitude control by vernier thrusters with wide (±20°) deadbands is acceptable. Controlled, programmed dumping of excess H_2O and venting will be required. The telescope, exclusive of the LHe and its tank, is 0.5 m in diameter by 2 m in length and weighs 75 kg. The pointing requirements are 5 arcsec in pitch and yaw and 1° over ±90° range in roll (absolute) with a stability of 1 arcsec pitch and yaw and 1° roll. Two dimensional raster scan capability is desired. The data rate is 10 kbps.

B. Mariner Jupiter/Saturn Ultraviolet Spectrometer

A. L. Broadfoot, Kitt Peak National Observatory

The spectrometer is 12.5 × 14.5 × 43 cm and has a 2° × 10° field of view. The instrument would look at earth airglow with a stability requirement of 1 arcsec. Spectral coverage is from 400 to 1800Å using a micro-channel plate anode array for a detector. The mass is 3.5 kg and power needs are 2 watts.

C. IUE Spectrograph

A. Boggess, Goddard Space Flight Center

The telescope with echelle spectrometer is currently scheduled for launch on the IUE Spacecraft in 1977. With minor modifications to the optics and an updated detector system, a copy of the instrument would be a good experiment to fly on Spacelab. High resolution spectra would be obtained in the 1150 to 3000Å region. Operation on Spacelab would be from the IUE Mission Control Center located at GSFC. The package is 0.6 m in diameter and 3 m long with a mass of 107 kg. Pointing requirements are 1 arc min pitch and yaw and 1° roll (absolute) with a stability requirement of 0.25 arcsec in pitch and yaw from internally produced error signals. The experiment uses 185 W of power and has an SEC vidicon detector readout at 40kbps.

D. Ultraviolet Telescope-Spectrometer

H. W. Moos, R. C. Henry, and W. G. Fastie; Johns Hopkins University

The experiment consists of an Aerobee payload of 38 cm diameter by 178 cm long. The prime targets would be the weak ultraviolet emissions from planets and cool stars. The detector is a micro-channel plate overcoated with CsI and is readout electronically. Pointing accuracy and stability needed is 3 arcsec with additional image stabilization provided internally by moving the secondary mirror, while tracking bright stars or planets. Total mass is 91 kg. The data rate is 200 kbps, but could be greatly compressed by onboard processing.

E. Narrow-Field Objective Spectrograph

R. C. Bohlin and T. P. Stecher, Goddard Space Flight Center

The payload is an Aerobee rocket experiment with a mass of 70 kg and dimensions of 38 cm in diameter by 150 cm long. Targets include nebulae and faint stellar objects where there are no bright guide stars in the field. The detector is a micro-channel plate with a 35 mm film transport for recording the spectra between 1150 and 2900Å. The main modification for Spacelab would be to increase the film supply from the current 25 frames to around 250 frames. The field of view is 17 × 24 arc min requiring an absolute pointing accuracy of about 2 arc min to center the target on the detector. A stability of 2 arcsec during a 30 min exposure would be compatible with the resolution of the detector and optics. Ideally, the film temperature should not rise much above 20°C at any time.

F. Far-UV Wide-Field Telescope (Wynne Camera)

S. Bowyer and co-workers, Berkeley

The instrument consists of three parts: a Wynne camera which may be used for direct photography or with an objective prism, a micro-channel plate detector with a cesium iodide photocathode, and a film magazine and drive mechanism. The useful field diameter is 4.5 degrees. This instrument was designed in France and has flown on a French Veronique rocket. The complete package weighs 60 kg and is 57 cm in diameter by 146 cm in length. Pointing accuracy required is 3° with 6 arc min stability. If the detector is converted to electronic readout, a bit rate of 256 kbps would be needed. The power requirements go from 30 W for film to 100 W after conversion.

ASTRONOMY MISSION STUDIES

W. Scull, GSFC

As an initial effort in looking at system interfaces and the potential problems of flying a variety of instruments on Spacelab, GSFC conducted a quick mission/system study of several instruments from the disciplines of UV/optical astronomy, solar physics, and high energy astrophysics. These initial efforts were started with the possibility in mind that indeed the early missions might include payloads from a variety of disciplines as opposed to a dedicated discipline mission. The preliminary studies were aimed at determining the feasibility of flying mixed discipline payloads and at planning the mission operations. Clearly, if the observational requirements of a particular discipline required a major share of the observational time, it might be better to consider missions dedicated to that discipline.

Three missions were studied:

1. Combined Solar, UV and High Energy Astrophysics Missions
2. Facility Class Mission
3. Free-Flyer Delivery Mission with additional attached instruments.

Instruments

Instruments selected as candidates for these studies are listed in Table 1 together with their equipment characteristics and requirements. The Mission 1 instruments were selected to exclude facility class instruments. The Orbiter would be used for pointing and orientation in conjunction with a Small Instrument Pointing System (SIPS) being studied by GSFC. However, Mission 1 would not require use of the ESRO-studied Instrument Pointing System (IPS). Thus, for the first study mission, the Solar Physics instruments consisted of an Externally Occulated Coronograph, (SO-1), a Solar X-Ray Telescope (SO-2), and a Solid State Flare Detector (SO-3), mounted on a single pallet. High Energy Astrophysics instruments included in a Large Area X-Ray Detector (HE-1), mounted on a single pallet, and a large Cosmic Ray Detector (HE-3), mounted directly to the Orbiter. A general purpose IUE-class UV Telescope (UV-2) and a Schwartzschild Camera (UV-1) for astronomy, mounted on a single pallet, completed the payload shown in Figure 1.

For the second study mission, the UV pallet and its payload was replaced by a single pallet carrying the UV facility-class (1-meter) telescope mounted on the ESRO Instrument Pointing System (IPS). As a result of the volume occupied by this instrument, it was necessary to reduce the High Energy Astrophysics payload to a single instrument, HE-1, while still including the Solar Physics payload.

The third study mission, for studying the combination of a deployable free flyer and a pallet payload, included the UV Astronomy payload of two instruments plus a typical free flyer. The Solar Maximum Mission (SMM) was chosen as a representative deployable free flyer.

For pointing the smaller instruments that required more accurate pointing than that provided by the Orbiter, a Small Instrument Pointing System (SIPS) was included in the study. This device contains two individually controlled sets of gimbals mounted on a single pedestal as shown in the following presentation on SIPS.

Table 1

Equipment Characteristics And Requirements

INSTRUMENT	UNIT SIZE (M) W OR D	H	L	UNIT DRY WT (KG)	POWER (W) OPER	PEAK	PK DUR (HR)	AC OR DC	TEMP LIMITS (°K) OPER MIN	OPER MAX	NON-OPER MIN	NON-OPER MAX	REMARKS
CORONA-GRAPH	0.60	0.60	4.60	204	40	100	0.0111	AC	291	298	275	325	295 ± 10°K INTERNAL
SOLAR X-RAY	0.50	0.50	4.00	250	50	110	0.1	AC	288	300	277	305	295 ± 10°K INTERNAL
FLARE DETECTOR	0.50	0.50	0.50	90	20	20	N/A	AC	292	296	277	305	
LARGE AREA X-RAY	2	3	2	2000	150	150	N/A	DC	273	308	243	308	<5°C GRADIENT ACROSS GLASS GRID
COSMIC RAY DETECTOR B	2.20	2.20	3.00	3000	90	90	N/A	DC	273	308	253	338	
SCHWARZ-CHILD CAMERA	0.38	1.90	-	129.5	80	100	0.1	DC	280	310	250	310	MINIMIZE TRANSIENT ΔT
GENERAL PURPOSE UV TELESCOPE	0.76	1.27	-	45.4	30	50	.00007	DC	273	313	273	313	

Scientific Observational Targets

For operational flexibility of missions carrying instruments from different disciplines to exist, it was apparent that, while the Orbiter could be used for coarse pointing, simultaneous and independent observations with the various instruments would be necessary. Accordingly, a series of targets considered scientifically desirable for observations was developed by scientists in the three disciplines. These targets are shown in Figure 2, using an ecliptic coordinate system. Solar Physics requires solar viewing orientations, while the majority of the High Energy Astrophysics targets in this study resulted from requirements of the X-Ray experiment. It was desired to obtain 10^5 seconds of observations of the Andromeda Nebula (M-31), to scan the Vela remnant in a 6×6 scan matrix (36 individual matrix element observations of 23 minutes), and to scan the galactic plane in 1° steps, plus other targets as possible. Requirements of the Cosmic Ray Experiment were not as severe, it being desired that the instrument field of view not be occulted by any part of the Earth. UV Astronomy targets included 25 locations

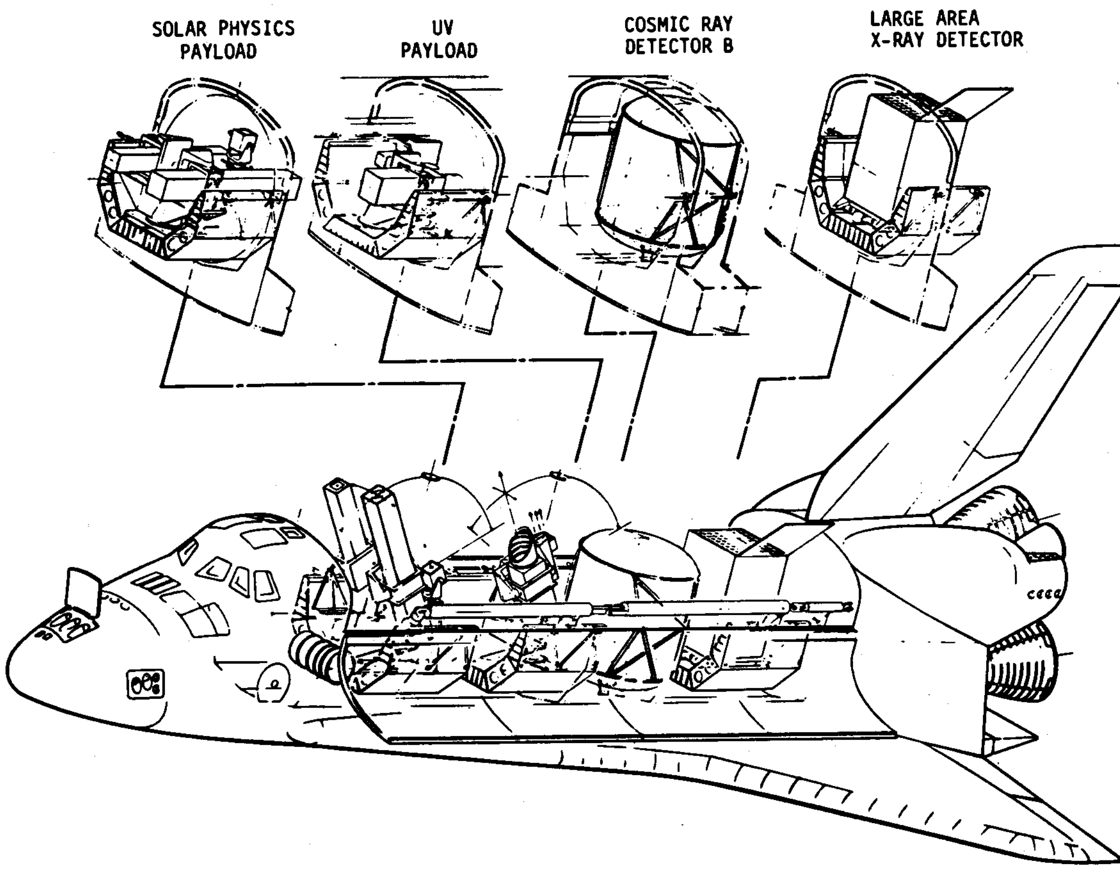


Figure 1. Combined Solar, UV, & High Energy Mission

distributed over the sky. Of these 25 targets, 5 were first priority, with the remainder as second priority targets.

Orbit

A 200 n mi circular orbit at 28.5° inclination, with the launch timed to minimize inclination of the orbit to the ecliptic and allow simultaneous Vela and sun viewing, was considered. To maximize scientific data acquisition, 24 hours/day operation was considered. A six man crew, including 3 Payload Specialists for continuous observations, was included. One revolution per day was set aside for housekeeping purposes. By selecting a basic orientation of the Orbiter X-axis (longitudinal-axis) perpendicular to the ecliptic plane (X-PEP); except when making observations with HE-1, the large X-Ray Detector, and observations of the UV polar sources, it was possible to observe most targets with periodic roll/pitch maneuvers requiring about 6 minutes.

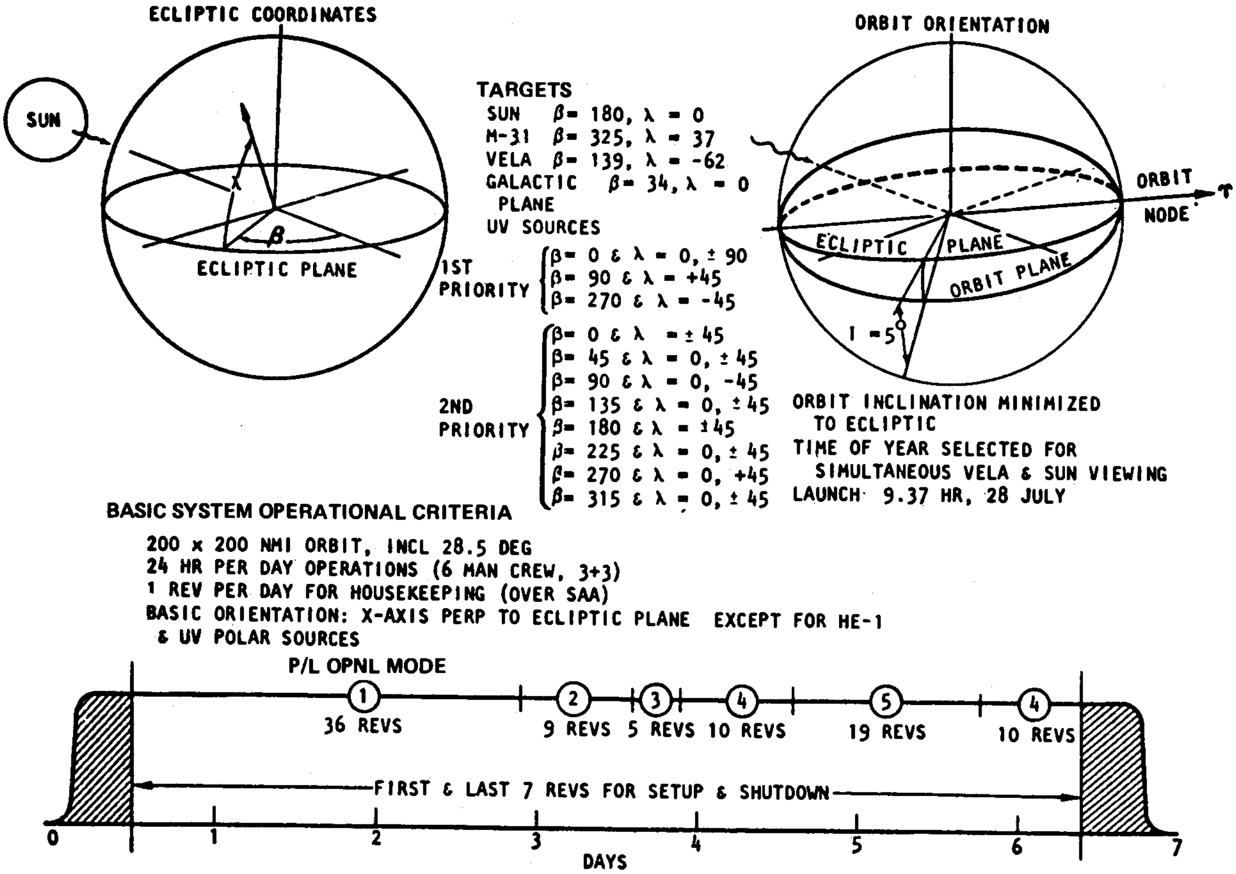


Figure 2. Mission Geometry and Summary Profile
Combined UV, Solar, High Energy Sortie Mission

Operational Time Lines

For the 7-day duration of Mission 1, a time line of 5 different modes was established for 6 operational days, the first half and last half mission days being set aside for setup and checkout after launch and stowage and descent preparations prior to return.

Mode 1, shown in Figure 3 for a 2 revolution duration, was performed to prioritize X-ray observations. Periods of Andromeda and Vela pointing and the maneuvering times to change targets are shown. For HE-1, the actual times when the Vela/Andromeda sources would fall in the instrument field of view are shown. Also shown are the times when the Orbiter-Z axis would coincide with the sun line-of-sight (LOS). Around these times are then shown the times within which Solar Physics instruments, SIPS-mounted, could track the sun or UV Astronomy instruments, also SIPS-mounted, could observe. Significant periods of solar and

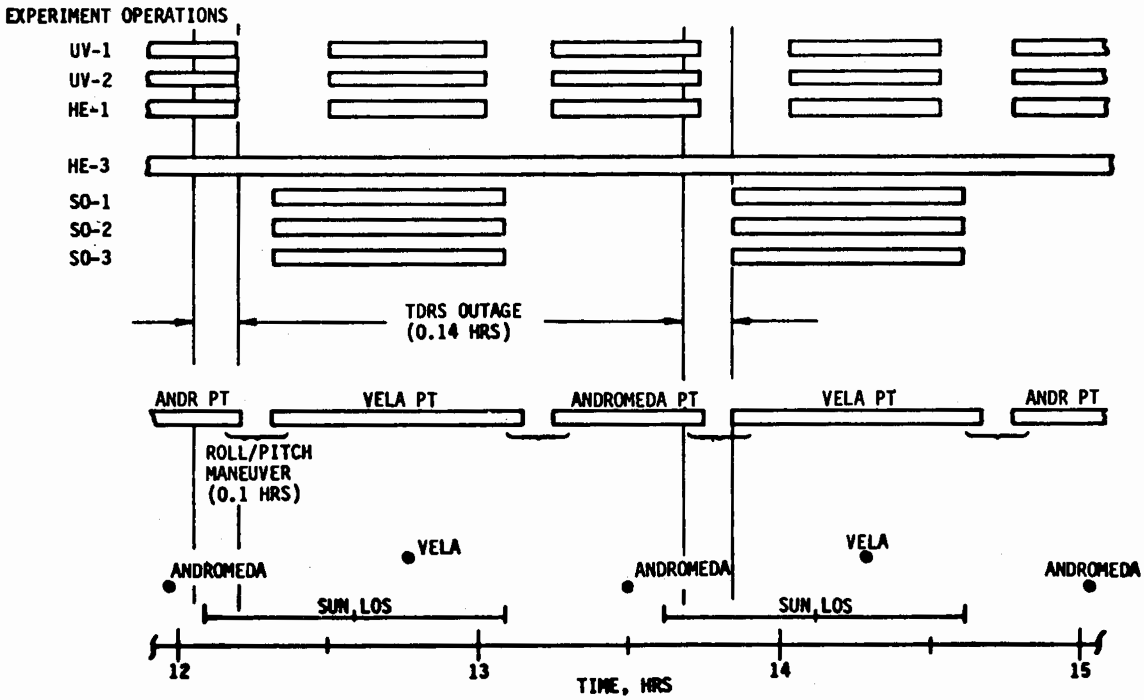


Figure 3. X-Ray Observations (Mode 1)

UV astronomy observations occur. In addition, since the Orbiter Z-axis is pointed away from the Earth during this time, cosmic ray observations are practically continuous. An estimated 10 percent outage of Tracking and Data Relay Satellite (TDRS) coverage per orbit is also shown.

Mode 2 was prioritized for 9 revolutions of observations of combined Solar Physics and first priority UV Astronomy targets. No observations with the X-ray detector are programmed, while again the cosmic ray experiment has continuous observations. Mode 3 prioritized cosmic ray observations for 5 revolutions, with a continuous 3.9°/minute roll rate about X-PEP. With the Z-axis maintained continuously away from the Earth, continuous cosmic ray observations are possible. Mode 4, prioritized for 20 revolutions of X-ray (galactic plane scanning) and solar pointing, includes significant coverage for all of the instruments. Mode 5, prioritized for 19 revolutions of X-ray and UV Astronomy observations, also includes significant coverage for all of the instruments.

A similar time line study was performed for Mission 2. The entire 6 day observational period was similar to Mode 1 of Mission 1 except that more accent was placed on priority observations with the UV Astronomy facility class telescope.

For Mission 3 the selected orbit was 332 n. mi. circular, with 30° inclination. Approximately 13 revolutions are used to check out and deploy the free flying SMM satellite and set up for UV observations, and 7 revolutions are used as in other analyses to prepare for descent. Once the free flyer is deployed, the entire observational time is available for UV observations, since no retrieval of a spacecraft is programmed.

Mission Performance Study

In summarizing mission performance for the available 6 day observational time, Mission 1 resulted in 158 UV Astronomy observations of at least 30 minutes duration each with all targets covered at least once. X-ray observations cover all requirements except for scanning only about half the galactic plane. Cosmic ray observations were possible more than 90% of the observational time with more than 50% of the observational time without any Earth occultations. Solar observations were possible about 60% of the available observational time. Mission 2, optimized for UV facility-telescope operations, include 178 observations, each of at least 30 minutes duration, with 15 observations of each of the five first priority targets. X-ray observations included a complete scan of the galactic plane and about 70% coverage of the Vela and Andromeda targets. Solar observing totalled about 65% of the available observational time. Mission 3, once SMM was deployed, of course resulted in excellent UV Astronomy coverage.

Reaction Control System (RCS) Operation

From the operational aspects of the Orbiter, propellant usage does not appear to be a problem for the missions studied. Mission 1 required approximately 4400 pounds of the available 6040 pounds of Shuttle propellant. For all these missions of 7 days, it should be noted that approximately 50% of the propellant was used for payload operations, the remainder for ascent/descent and setup/shutdown/housekeeping (See Table 2).

Mission Weight

Mission 1 weight (Table 3) included about 31,500 pounds, of which approximately 27,600 would be payload chargeable landing weight. With a 65,000 pounds up-weight capability, the mission does not appear weight limited. Mission 2 with an up-weight of about 24,700 pounds and approximately 21,100 pounds on landing appears volume limited rather than weight limited. For Mission 3 the total down-weight after deploying the SMM spacecraft and returning to Earth without recovering any free flyers would be about 12,600 pounds. This number results from the release of the SMM (3824 pounds) and the use of approximately 10,000 pounds of RCS propellant during the mission after a total lift-off payload weight of approximately 27,250 pounds.

Table 2

RCS Propellant Utilization

	RCS Propellant, Lbs.		
	Mission No. 1 (UV-HE-Solar Sortie)	Mission No. 2 (UV Facil, Solar/ X-Ray Sortie)	Mission No. 3 SMM Del, UV Sortie
Shuttle Ascent & Descent	1320	1320	1330
Payload Operations	2430	2080	1810
Setup House-keeping Shut-down	660	660	560
TOTAL	4410	4050	3700
RCS Tank Capacity = 6040 Lb			

Longitudinal Center of Gravity (CG)

In studying the placement of instruments in the cargo bay, the location of the center of gravity had to be considered in addition to instrument fields of view, pointing system coverage capabilities, etc. The CG's of the payloads for the three missions studied all fell within the longitudinal allowable CG envelope both wet and dry (propellant expended) and below the limits of take off and landing weights (Figure 4). Similar considerations of CG envelopes in the other two axes also indicated no problems. The significant shift forward (wet to dry) of the CG for Mission 3 is due to deployment of the SMM.

Orbiter Attitude Control

For controlling the attitude of the Orbiter, the primary reference is a navigation base located in the crew area. Part of this nav-base, an Inertial Measurement Unit (IMU) determines the attitude reference. Attitude control is by coarse (950 lbs. thrust) and fine (25 lbs. Thrust) bipropellant (monomethylhydrazine and nitrogen tetroxide) jets. Several modes of control — free drift, inertial hold, and source tracking of a fixed reference are available.

Table 3

Mission 1 Weight Summary

Equipment	Provided By: Orbiter (P/L Chargeable)	Spacelab	ASP
Experiments			12132 ● UV Array ● HE Array ● Solar Array
Structural	1302 ● Bridge Fittings ● Keel Fittings	4983 ● Basic Pallets ● Igloo	200 ● HE Supports
Elec. Power Syst.	1450 ● EPS Tankage ● EPS Reactant	122 ● Exper Inverter ● Subsyst. Inverter	--
Command & Data Handling Syst.	--	382 ● Recorders ● Computer	140 ● Formatters ● C&D Panel
Pointing & Stabilization	3090 ● RCS Propellant	--	6920 ● SIPS(3) ● Flare Det Mtg
Communications	263 ● TDRS Wide Band ANT	--	--
Crew & Provisions	481 ● Personnel (2) ● 14 M-D Provisions	--	--
TOTALS	6586	5487	19392

Mission Grand Total = 31465

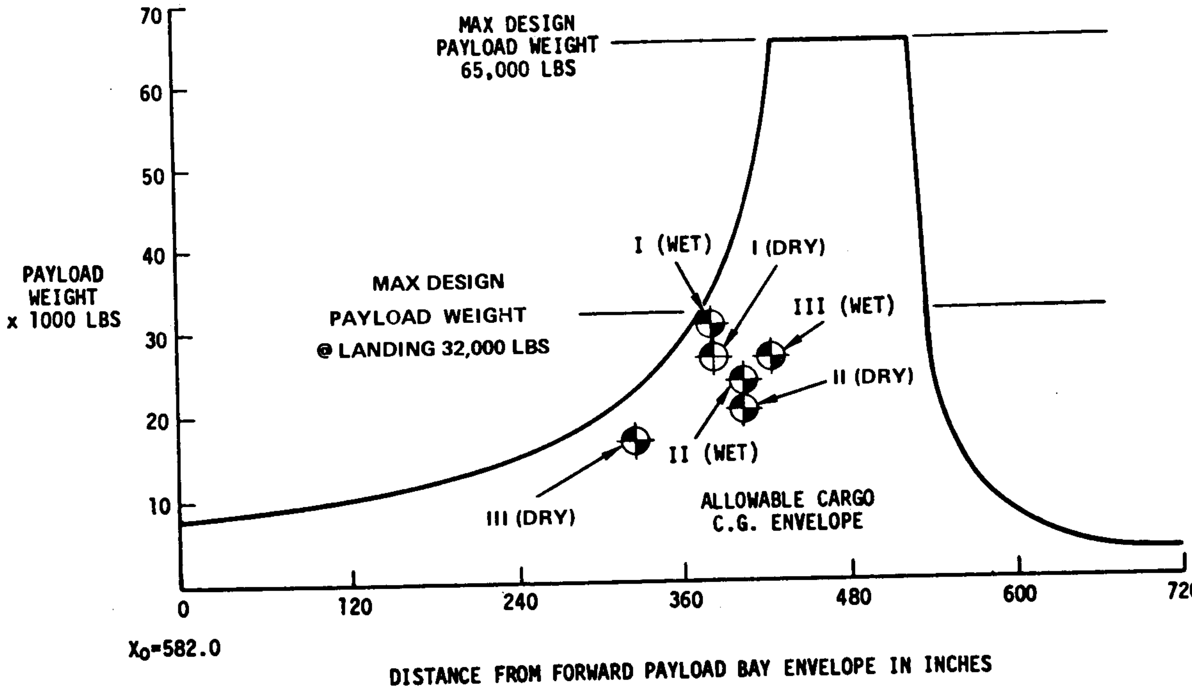


Figure 4. Cargo CG Limits (Along X-Axis)

Line of sight (LOS) attitude control may be from experiment mounted sensors in the cargo bay, with nominal LOS determination with respect to the nav-base. However, if nav-base references are used, a bias of 2-4 degrees between the nav-base location and the cargo bay due to structure deformations must be considered. Anticipated errors in the inertial mode can be ±0.5°, based upon ±0.1° misalignment of the IMU, ±0.25° error in the control system, and gyro drift of ±0.15° for one orbit. Realignment of the IMU approximately each 1.5 orbits would be required to compensate for gyro drift. In a source tracking mode, attitude errors could be ±0.35° since no gyros are required. This type of control could also be maintained for longer periods of time dependent upon RCS consumption, thermal requirements, etc.

The RCS thrusters located fore and aft on the fuselage, can maintain variable rates of 0.001 to 0.133°/sec or 0.25 to 1°/sec and accelerations of 0.025 to 0.035°/ sec^2 or 1 to 2.5°/sec^2 for the fine and coarse thrusters, respectively. Rates can be maintained to 0.1°/sec with any one vernier jet non-operational.

Command and Data Handling

For the Command and Data Handling Subsystem (CDH), the general rules and assumptions (Table 4), used in the study are basically that the payloads will use existing Spacelab hardware where possible. Data requirements were calculated for a 90 minute orbit and assuming only 60 percent TDRS coverage. This assumption includes the previously discussed 10 percent TDRS outage, plus coverage unavailabilities due to number or locations of Ku-band transmitting antennas on the Orbiter, availability of the Ku-band link, etc.

Table 4

Command and Data Handling Ground Rules and Assumptions

- Caution & Warning Must Have Redundant Sensors & Transmission - Preferably Using Different Techniques
- Payload Power On/Off Dedicated Control Panel
- Command & Control Of Experiment & Pallet Subsystem Using Data Bus (Multiplexing) Techniques
- The CDHS For Experiments Is Basically Independent Of Orbiter & Located In Igloos. Orbiter Computer Used As Backup
- Utilize Space Lab Equipment Whenever Possible Including Computer Software
- Data Rates Based On 90 Minute Orbit, 60% TDRS Coverage, 1K bps Per Instrument For Housekeeping, 10K bps For Space Lab Housekeeping
- Data Transmitted In Real Time Requires Use Of K Band Capabilities Of TDRS
- Scientific Observations Are Directed From The Ground Via Orbiter RF System. On-Board Operator Function Is Control Of Instrument Operations

Data capacity per orbit totals 3400 megabits; and with an estimated 40% outage of TDRS, storage of approximately 1400 megabits per orbit would be required. A comparison of the experiment requirements in terms of housekeeping telemetry rates, peak experiment data rates (real time), data storage and playback rates, and total storage capability indicates that the current Spacelab CDH system can handle the requirements of the payloads studied. A sample data rate profile for Mission 1 in Figure 5 is matched against the data handling capabilities in Table 5. Possible command/control functions and typical tasks that would be required to be actuated from/through the Orbiter are listed in Table 6. Although these functions and tasks are shown as actuated by the PSS or MSS (Mission Specialist) it is possible that many of these functions or tasks could be accomplished from the ground. These considerations are still under study.

Table 5

C&DH Requirement Capability Comparison

	Experiment Requirement	Capability Spacelab	Orbiter
Housekeeping Data Acquisition Rate	17 K bps	1 M bps (Data Bus)	Performance Monitor System
Peak Experiment Data Acquisition Rate	2.09 M bps	50 M bps (Dedicated Coax)	N/A
Command/Control Data Rate	TBD	1 M bps (Data Bus)	N/A
Recording Rate/Time	2.09 M bps Peak 1.09 M bps (Normal) For 36 Min (Max)	7.5/15/30 M bps 80/40/20 Min	Voice Rec., Loop Maint Rec.
Recorder Storage	1720 M Bits	360 M Bits	1 Channel (K Band) at 50 M bps
Orbiter to Ground Transmission Rate	1.08 M bps	N/A	1 Channel K Band at 1 M bps 2 Channels S Band at 64 K bps
Ground to Orbiter Transmission Rate	TBD	N/A	1 M bps K Band 2.4 K bps S Band
Command/Control Displays	Keyboard/Crt Exp Dedicated C & W	Keyboard/Crt	~3400 In^2 of Panel Area
Caution/Warning		Display/Audio	Display/Audio

Table 6

Command/Control Functions From Orbiter (PSS/MSS Stations)

Function	Typical Tasks
• Experiment Management	• Control of Instruments • Data-Record/Dump • Data Selection • Type Changes

Table 6 (Continued)

Function	Typical Tasks
• Performance Monitoring	• On/Off • Temperatures/Pressures • Data Stream Stability
• Instrument Pointing For Target Acquisition	• Control Gimbals To Point Instrument (3 Axis) • Axis Transformation
• Caution & Warning	• Instruments/Gimbals Locked/ Free • Instrument Position • Critical Temperatures, Pressures
• On-Board Checkout	• Functional Test Of Major Assembly As Indicated By Performance Monitoring On Ground

Electrical Power and Energy

Estimated average and peak power and total energy requirements for the mission studied are compared to the Spacelab/Orbiter capability in Table 7. As with the CDH system, the Electrical Power System (EPS), using one 840 KWH reactant kit, plus the 50 KWH furnished by the Orbiter, can readily handle the power/energy requirements for a 7-day mission.

Thermal Environment

For estimating the temperatures of the thermal environment, the orientations of the Orbiter were X-PEP (Position A) for 76 orbits or 52° from X-PEP (also Position A) for 36 orbits during the sunlit portions of the orbits with the sunlight illuminating the cargo bay. During eclipses, operational orientation was X-PEP with the cargo bay facing outward to space (Position B) as shown in Figure 6. Calculated payload bay liner temperatures vary from about 330°K during the sunlit portion of the orbit to approximately 100°K during eclipses. Orbital average temperatures are 210°K to 260°K.

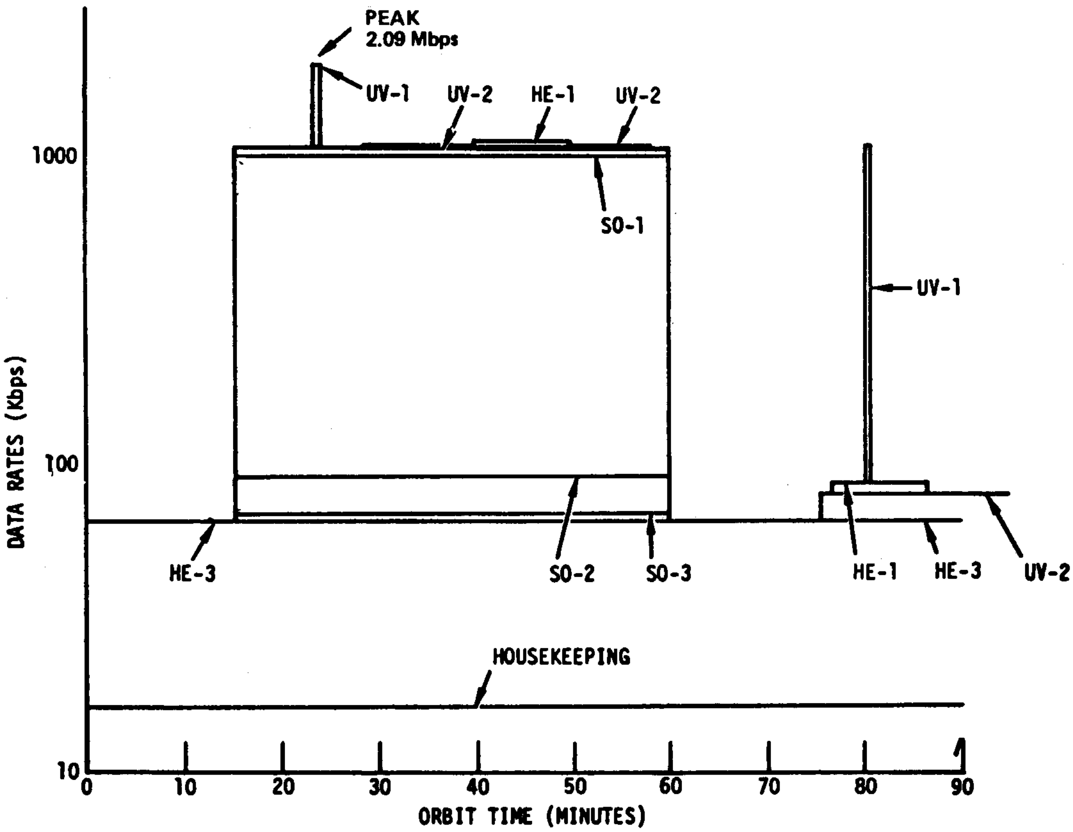


Figure 5. Typical Data Rate Profile

Table 7

EPS Requirements/Capabilities Comparison

Function	Req't	Spacelab/Orbiter Capability
Mission Energy	521 KWH	890 KWH
28 VDC Unreg Power - Sustained	4474 W	7,000 W
115 VAC, 400 Hz Power	384 W	1,000 W
Peak Power	4854	12,000 W

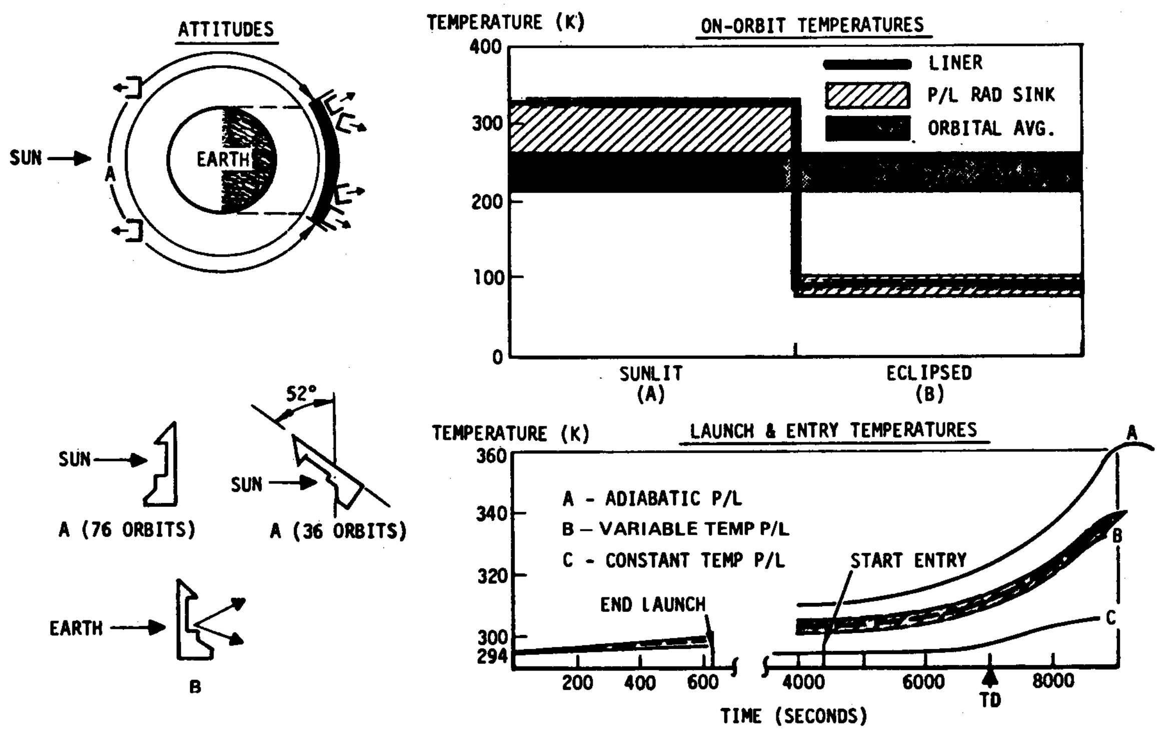


Figure 6. Shuttle Thermal Environment

Payload bay temperatures, estimated for three different thermal configurations of payloads, are shown in Figure 6 for both the launch and return (descent) phases. The probable bounds on the bay temperatures during the ascent phase would be near nominal room temperature, i.e., 295° - 300°K. For reentry, bay temperatures for an adiabatic payload might reach 365°K about 2000 sec (approximately 1/2 hour) after touchdown. At the other extreme of a constant temperature payload, i.e., one with an infinite sink, the bay temperature would approach only about 305°K. Thus, for some configurations, the payload bay thermal environment will exceed payload temperature limits; however, payload temperatures are expected to remain within limits due to thermal capacitance and use of insulations. Certain elements, e.g., film canisters, may require localized thermal protection.

A candidate thermal control system for some of the astronomy class instruments is a thermal canister embodying a combination of active and passive control. High performance insulation and radiating areas, plus heaters and circumferential and longitudinal variable-conductance heat pipes could be used to maintain temperatures and temperature gradients within appropriate limits.

Orbit Selection

Several orbits were considered as candidates for Missions 1 and 2. The low altitude orbit, number 5 in Figure 7 at 370 Km (200 n. mi.) circular and 28° inclination, not only minimized the angle between the ecliptic and orbital planes for the time of launch, but also minimized usage of the Orbital Maneuvering System (OMS) compared to the other orbits except the 6 and 7 orbits. However, with the exceptions of orbit 6, the average dose rate for trapped radiation environment is less for a specific amount of shielding than for other orbits. The No. 6 orbit is poorer than the No. 5 orbit with respect to the duration of contact pass time.

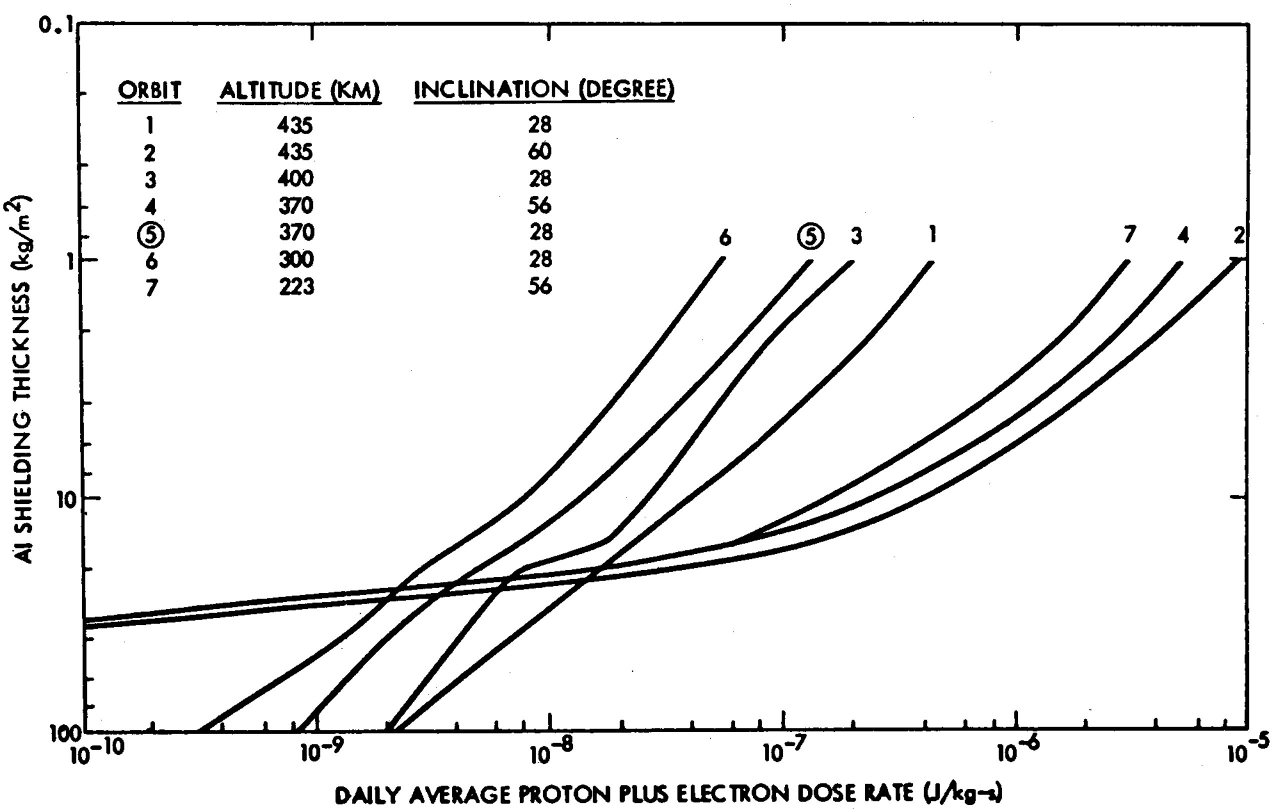


Figure 7. Trapped Radiation Environment

SMALL INSTRUMENT POINTING SYSTEM (SIPS)

C. Henrickson, Ball Brothers Research Corp.

The Small Instrument Pointing System (SIPS) will allow presently developed small instruments up to the size of ATM instruments to fly on Spacelab without extensive modifications.

The SIPS is conceptually envisioned as an adaptation of the mounting and pointing hardware which has been developed for the OSO program, with modifications enabling maximum benefit to be derived from the shuttle operational environment. Figure 1 shows SIPS with two thermal canisters.

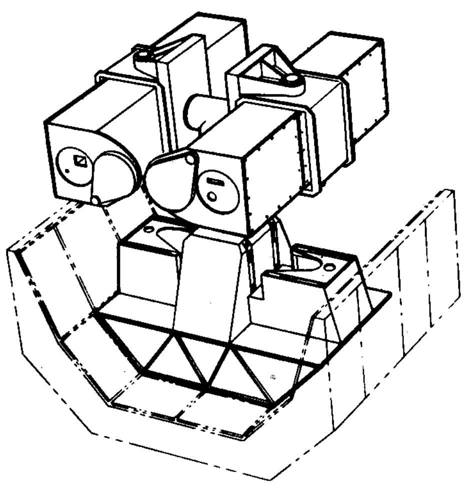


Figure 1. SIPS with Two Instruments

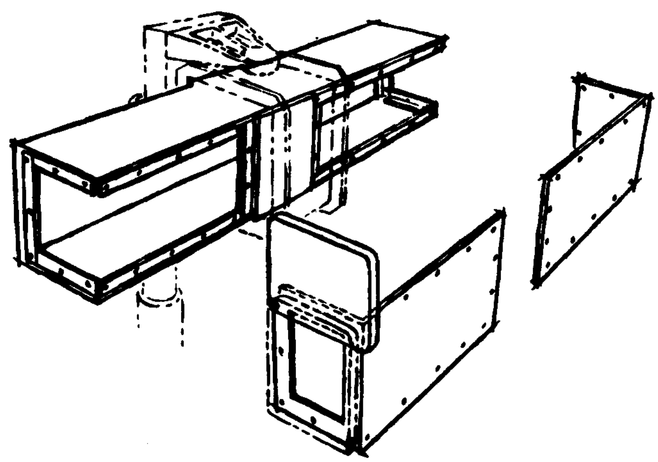


Figure 2. Cannister Concept

The most likely major characteristics of this pointing system are presented in the following paragraphs.

An instrument canister is held in a rectangular frame that is similar to the "elevation frame" that held the pointed instruments on OSO-H. This frame is supported top and bottom by trunnions that allow each about 10 degrees of right-left freedom for fine pointing. The trunnions can rotate through 90 degrees elevation to give both independent coarse elevation control and independent fine up-down pointing. The elevation drive is located at the top of a deployable pedestal. The pedestal itself can rotate to provide coarse azimuth control. By means of this pedestal, the instrument is retracted into a "cradle" during launch and landing. The system will be capable of deployment and operation in a lg environment.

No separate roll gimbal is provided. However, when the shuttle is oriented such that observation is at the zenith, the azimuth drive becomes a coarse outer roll gimbal and full 3-axis gimbal capability is achieved. An inner roll gimbal that could provide fine roll stabilization, as well as rotation through ± 90° for slit orientation, is under study as optional hardware for those experiments, that need roll control, such as "side lookers", polarimeters, imaging devices, and slit spectrographs.

It should be noted that this mount would usually accommodate two separate fine-pointing instruments, supported on opposite sides of the pedestal, as shown in Figure 1. The two systems would share deployment and coarse azimuth control but could pursue observations of either different or identical points lying within a strip of about 10 × 90 degrees.

The SIPS canister is sized to accommodate instruments with dimensions up to 91.4 × 91.4 × 315 cm (36 × 36 × 124 in). These dimensions will allow any instrument up to ATM size to be enclosed. The upper limit on weight handling is expected to be about 340 Kg (750 lbs). The inner roll gimbal should hold standard Aerobee payloads (38 cm in diameter) and, hopefully, Aerobee 350 payloads (56 cm in diameter).

Pointing Capability

The SIPS can operate in either of two modes. The first is an "open loop" mode in which the shuttle orbiter serves as a reference. The second is a "closed loop" mode in which sensors on or in the instrument serve as the pointing reference.

In the open loop the SIPS is pointed using information from the Orbiter's navigation systems. The gimbals are then locked with respect to the Orbiter and the pointing is done by the Orbiter. Accuracy is dependent on the inherent pointing capability of Orbiter and the distortion of the Orbiter due to the thermal variations and gradients. Accuracy will probably be limited to several degrees.

In the closed loop mode, accuracy and stability can be extremely good depending principally on the type of reference sensor(s) used. With Spacelab provided low-noise sensors (sun sensors, rate integration gyros, or star trackers using bright stars), stability of 1 arcsec should be possible. The absolute accuracy will depend directly on the sensor complement for a particular instrument, but should be on the order of an arc minute with a package that includes a star tracker and good rate integrating gyros.

Environmental Canister

The canister will provide protection from shuttle-borne contamination and will also facilitate instrument temperature control. Ideally, it will accommodate existing instruments without modification of their tie-down fixtures. The canister's basic structure can be in the form of a channel, as shown in Figure 2. ATM instruments (and others of that size) can be tied down to the thicker base wall (bottom of the "U") using the original non-redundant fixtures. Alternatively, if the instrument is sufficiently stiff, it may be hard attached to the base wall with small dimensions between the attachment points.

With the canister and thermal controls, the SIPS weight is 703 Kg (1550 lbs). To carry a second canister, add 290 Kg (640 lbs). The canister can be separated from the SIPS and sent to the experimenter. He can then mount his instrument to the canister, test his system and only after it is fully ready for flight will it be coupled to a SIPS. This allows for the maximum use of the SIPS while providing much flexibility to the experimenter.

Thermal Control

Thermal controls range from simple passive systems to complex active systems depending on instrument needs and environment. Simplified thermal modeling has been performed on two representative instruments. The models include the instrument and SIPS but not the thermal canister. These models added to a Shuttle bay model in development will be used to evaluate several possible canister thermal control concepts.

Note: This is only an interim report. Those areas undergoing further analysis and definition include thermal control, launch and landing restraint mechanism, engineering and operational interfaces with Shuttle, and pointing control. A final report on this work is due in June 1975.

SUBSYSTEM REPORTS FROM GODDARD SPACE FLIGHT CENTER

POINTING

W. Nagel, GSFC

In addition to the SIPS, there are two other pointing systems planned. As a result of the Small Payloads Workshop, a third system is being studied.

Orbiter

The orbiter can be used as a pointing system. The inputs to the control system can be either from the navigation system or from sensors mounted on the pallet or the instrument. If the inputs of the navigation system are used for pointing, there will be the errors inherent in the navigation system plus errors due to distortions of the Shuttle from temperature gradients and mechanical distortion at the pallet. This latter source of error may lead to accuracies of no better than 2° - 4°. Using a pallet mounted star tracker and observing celestial targets, pointing accuracy improved to ±0°.35, with 0.1° deadband.

Instrument Pointing System (IPS)

The IPS is a system being studied capable of pointing large, heavy payloads accurately. Several arrangements have been investigated for the IPS. A conventional gimbal arrangement, an inside out gimbal arrangement and a suspended pallet concept.

Any of these would be automatically controlled by the computer utilizing on-board sensors. Table 1 lists some of the requirements for IPS.

Table 1
Requirements for IPS

- Pitch and Yaw Pointing Accuracy ±1 $\widehat{\text{sec}}$ 3σ
- Pitch and Yaw Pointing Stability ±1 $\widehat{\text{sec}}$ 3σ
- Roll Pointing Accuracy ±30 $\widehat{\text{sec}}$ 3σ
- Roll Pointing Stability ±10 $\widehat{\text{sec}}$ 3σ
- Slew Rate 30 deg/min
- Gimbal Range ±50° Pitch and Yaw ±90° Roll
- Size Payload 2 M Dia × 6 M Long
- Weight 3000 kg

Tiny Instrument Pointing System (TIPS)

The Workshop brought out the need for a less sophisticated pointing system than either IPS or SIPS with weight carrying capabilities considerably reduced from either. As a result of these needs the concept of TIPS has been introduced with accuracy of 1 arc-minute and stability of 10-15 arc-seconds. It will have 3-axes and support about 100 kg.

MECHANICAL

D. Miller, GSFC

Payload Attachment Location in Payload Bay

Thirteen (13) primary payload structural attachment points are provided along the payload bay. With the exception of the aft most position, each attachment consists of three points, one on each longeron and one at the keel. The aft attachment consists of attachment points on the two longerons, but none at the keel. The attachment points in Spacelab are identified in blueprints. The allowable reaction loads which may be reacted in each direction (X, Y, Z) at each primary attachment point are shown in Figure 7-20 of Reference 1.

Pallet Attachment

There are 24 hard points for payload attachment on each pallet. The hard points are ball/socket joints bolted to the pallet structure having load carrying capability of:

X direction	2910 kg
Y direction	1880 kg
Z direction	7650 kg

Figure 1 demonstrates typical use of hard points.

Pallet Description

The pallet's cross-section is U-shaped and is made of aeronautical shell-type construction. It provides hard points for mounting heavy experiments and a large panel surface area to accommodate various payload configurations. The

[1] "Space Shuttle System Payload Accommodations", JSC 0770, Vol. XIV, Rev. C., JSC, July 3, 1974.

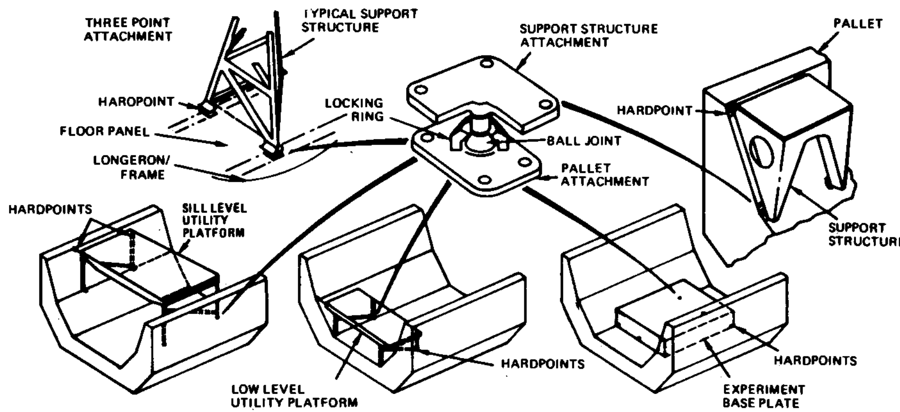


Figure 1. Typical Use of Hard Points

pallets are modular (3 M nominal length) and can be flown independently or interconnected. As many as three pallets can be interconnected.

To increase the surface mounting area and particularly the viewing capability of the pallet, additional experiment utility platforms can be provided as shown on Figure 1. Two types of platforms are proposed: one 1.5 meters wide and mounted horizontally at sill level, the other 1.5 meters wide and mounted horizontally at the first frame kink (from the top) of the pallet. In both cases the platforms can be mounted between any two main frames (not end frames) whether or not the pallet segments are rigidly connected or separately suspended. The platforms are flat and consist of a grid of beams covered with honeycomb sandwich panels, in a similar manner to the pallet. The intersections of the pallet beams provide mounting for hard points to accommodate heavy pieces of equipment while lighter experiments are attached via inserts in the sandwich panels (8 mm diameter honeycomb inserts with metric self-locking thread at any requested hole pattern).

The pallet floor has a limited load capability and precautions will be necessary to avoid damage. Pressures are limited to 50 kg/M^2. Figure 2 shows a basic two pallet configuration with igloo, forward utility bridge and other pallet features. The igloo is a cylinder with controlled temperature and pressure (N_2 atmosphere) capable of containing the following data management and power distribution equipment:

3 computers
2 I/O units
1 mass memory
3 subsystem RAUs

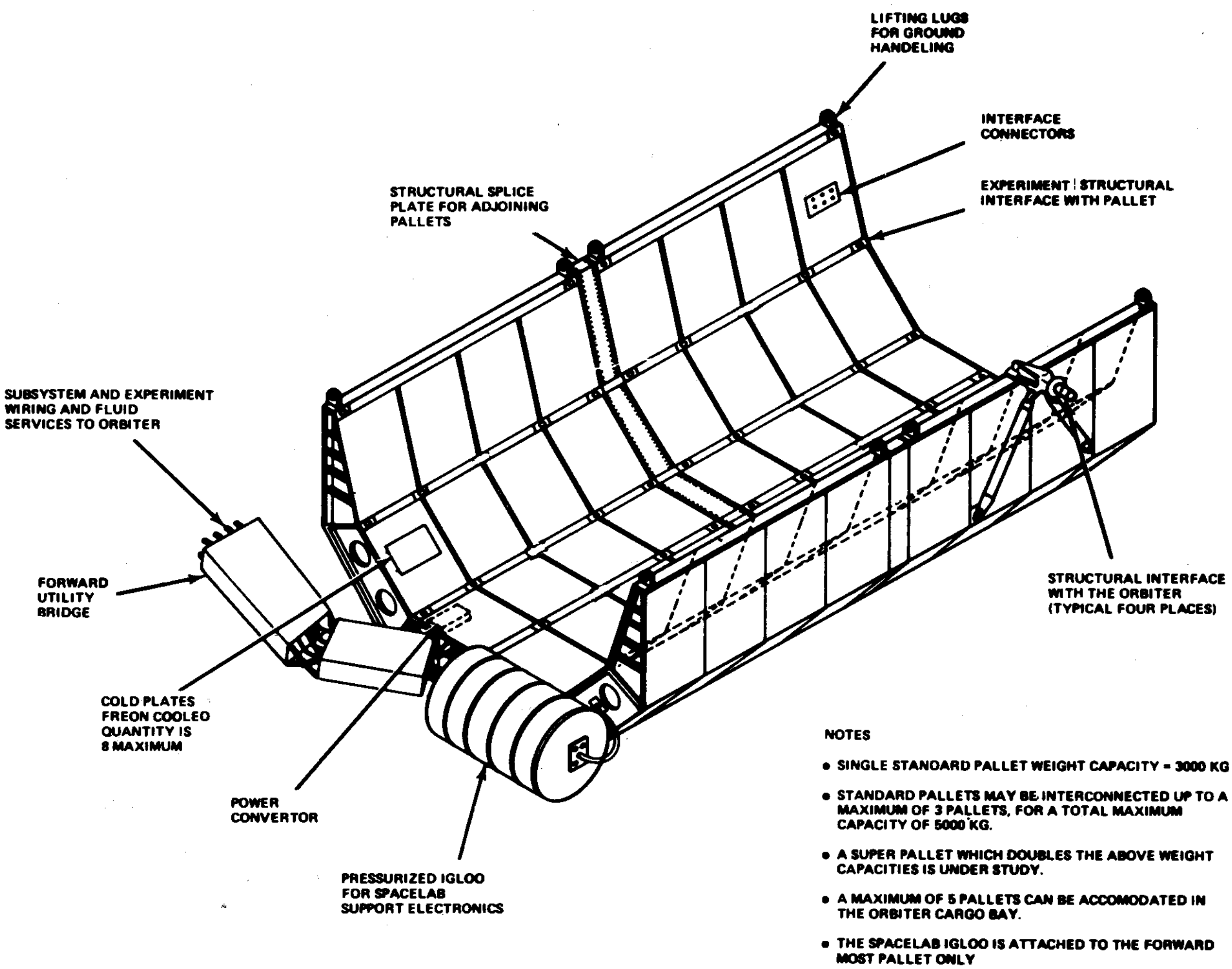


Figure 2. Two Pallet Configuration with Igloo

3 experiment inverters (50, 60, and 400 Hz)
1 subsystem inverter
1 emergency inverter
1 power battery and bit
1 power control box
1 secondary power distribution box
1 caution and warning logic

The same igloo structure, although designed for subsystem installation, is offered to the user as an option for experiment-peculiar equipment installation (e.g., experiment support container). In this option, the igloo is mounted to the pallet floor.

Pallet Dimensions

Figures 3 and 4 give two views of the pallet and include its dimensions in inches.

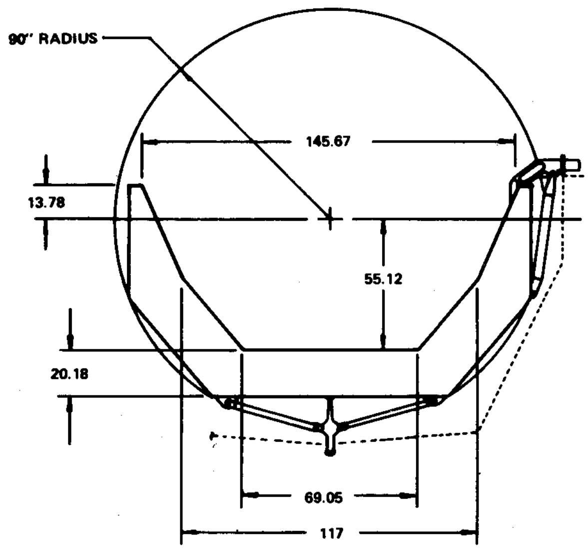


Figure 3. Pallet End View

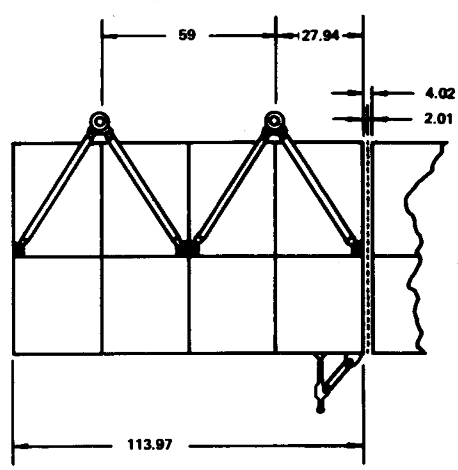


Figure 4. Pallet Side View

Pallet-Only Mode

For the astronomy missions the "Pallet-Only" mode is the only mode presently planned. This mode may consist of from one to five pallets.

THERMAL

S. Ollendorf, GSFC

The thermal problems normally encountered in space are of concern to and are being investigated by GSFC. Some of the areas being studied are listed below.

SIPS

A thermal cannister enclosing the instruments using the SIPS is being designed to allow a favorable, constant operating temperature. As design goals, it will hold instrument bulk temperature at 20 ±10°C dissipating between 20 and 200 watts of power.

Pallet Mounted Equipment

A thermal analysis has shown that radiation can be trapped between the pallets and Shuttle giving rise to hot spots. Methods are being investigated to alleviate this problem.

Experiment Thermal Problems

GSFC is investigating thermal problems on specific experiments that appear to have unique thermal requirements. Figure 1 shows a typical instrument model on a pallet with nodal points.

Thermal Model of Spacelab

A thermal model of Spacelab is being prepared by GSFC and results will be available at a later time to experimenters. This information should enable an investigator to determine the effects of the thermal environment on his equipment and properly correct for them with heaters, radiators, insulations, heat pipes, thermal covers, or whatever may be necessary. Figure 1 of Reference 1 is the overall Spacelab thermal model being used for analysis.

[1] Thermal Design Support for the Astronomy Shuttle Payloads, Almgren, D. W., and Bartoszek, J. T.; Available through GSFC-ASP Study Office.

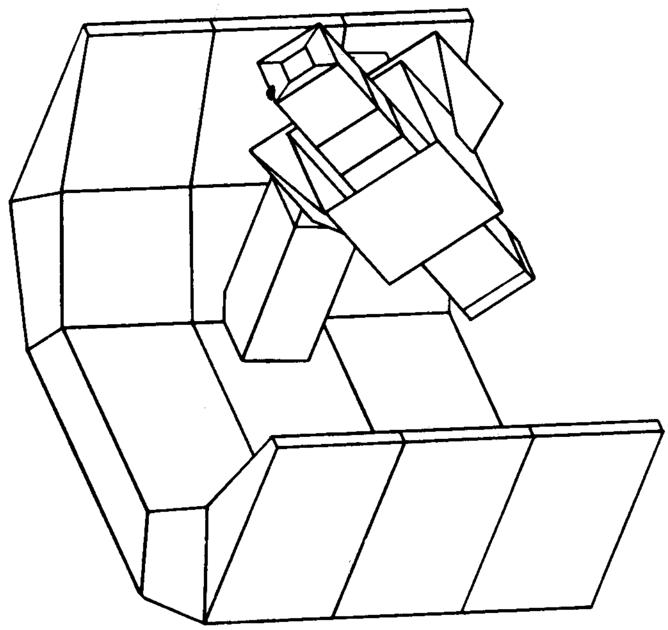


Figure 1. Typical Instrument Model
on Pallet with Nodal Points

Shuttle Environment

Figure 2 shows a typical profile of responses of payloads during the reentry and post landing phases. The upper curve shows a case where the payload rejects no heat to the walls (adiabatic). The lower curve shows the response of a payload with fixed thermal mass. Most payloads will fall within these extremes if not thermally protected.

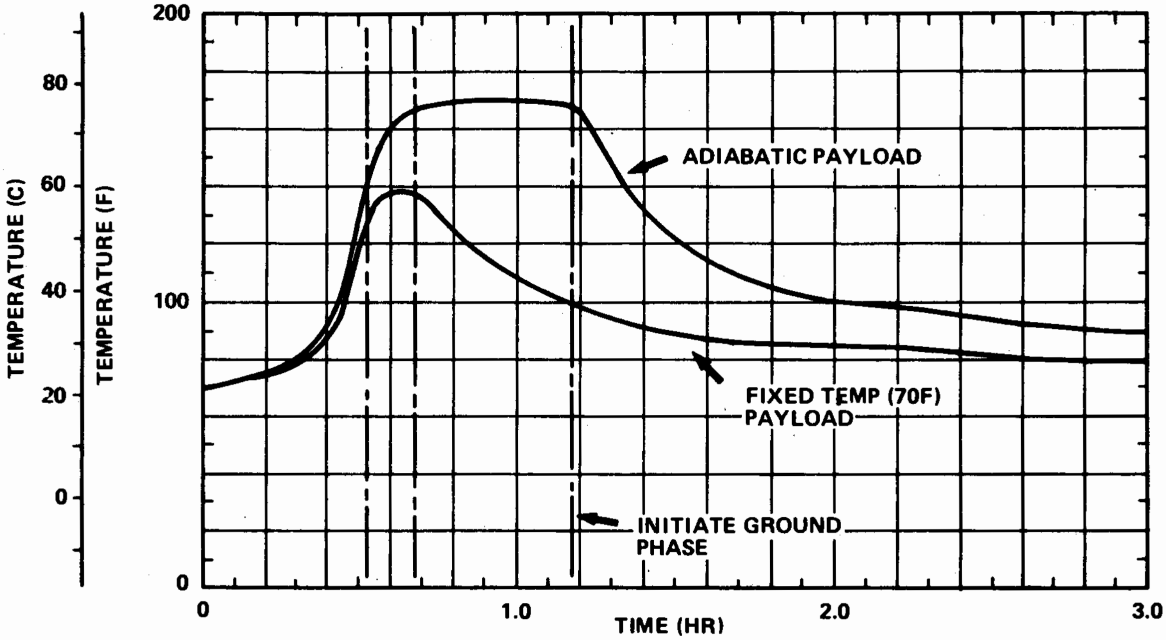


Figure 2. Typical Entry Profile of Temperature versus Time

Note: Fixed temperature payload is one which has a fixed operating temperature (70°F). The curve is the temperature profile for best temperature control. Ground phase initiation corresponds to the opening of the payload bays.

TEST, EVALUATION AND INTEGRATION

R. Heuser, GSFC

The test and evaluation facilities for the astronomy payloads will be available at GSFC. An experimenter should be able to coordinate his tests with GSFC's Test and Evaluation (T&E) Division personnel to assure that insofar as possible, the optimum series of tests are defined to assure reliable and productive operation of the payload in-orbit.

Information Required From Experimenters

Generally, experimenters must provide adequate information to form a baseline or criterion against which the results of functional and environmental tests can be compared. The purpose of the test may be either to measure a characteristic or to evaluate performance. The detailed information required of the experimenter will vary depending on the purpose of the test and the nature of the experiment. The actual tests to be performed will be decided on a case by case basis. However, a more detailed philosophy/plan will be available in mid-1975.

Tests

Listed below are tests that may be performed at GSFC.

- Initial Magnetic Field
- Leak Detection
- Electrical Performance
- Pyrotecnic Performance
- Physical Measurements (Weight, Center of gravity, Moments of Inertia)
- Temperature and Humidity
- Vibration
- Acoustic Noise
- Shock
- Structural Loads
- Thermal Vacuum
- Antenna Pattern
- EMI

The user will supply payload-peculiar or unique hardware which may include bench test equipment and the personnel for its operation.

Not all of the tests listed may be required. However, because other experiments and man's safety are involved, stricter requirements will be placed on Shuttle payloads than on sounding rocket payloads. An experimenter may be able to demonstrate by analysis, with tighter requirement restraints, that his equipment does not require certain tests.

Integration

There are four levels or phases of integration. The first two levels (Levels IV, III) are performed at GSFC while the last two (Levels II, I) are performed at the launch site. The four levels are listed in Table 1.

Table 1
Integration Levels for a Spacelab Payload

Level	Location	Activity
IV	GSFC	Install Instruments/Support Equipment on Pallet Segments
III	GSFC	Experiment Checkout and Integration
II	Launch Site	Spacelab Integration
I	Launch Site	Orbiter - Cargo Integration
From initiation of Level IV through launch is approximately 22 weeks.		

This process is being reviewed from the point of view of the small payloads experimenter. Hopefully, ways will be found to reduce the lead time, minimize the time invested by the experimenter, and to make the payload accessible up to a few days before launch.

Note: The integration levels, the activities and locations are under reivew and are subject to change.

COMMAND AND DATA MANAGEMENT

H. McCain, GSFC

General

The Command and Data Management System (CDMS) provides a variety of services to the Spacelab payload by means of a dedicated data processor, data bus and interfacing units. These services include data acquisition, monitoring, formatting, processing, displaying, caution and warning, recording and transmission in addition to providing command and control capability for the Spacelab payloads. An additional set of identical equipment provides the same services to the Spacelab subsystems.

Figure 1 illustrates the assemblies comprising the CDMS with respect to experiments. Experiment outputs including status and scientific data are sampled by Remote Acquisition Units (RAU), converted from analog to digital form and transferred to the experiment-dedicated computer by the input/output (I/O) controller.

RAU

The RAU can acquire both analog and digital data. The analog portion converts the signals to 8 bit resolution digital. The 32 high level inputs have a range from 0 to 5.12V while the 32 low level inputs range from 0 to ±256mV. Maximum sampling frequency is 100 Hz. The inputs are single-ended with 10MΩ impedance.

The 60 digital inputs have Transistor-Transistor Logic (TTL) levels. The average data rate is 100 Kbps with a maximum rate of 1 Mbps for 1 msec.

High Data Rate Inputs

There are both analog and digital high frequency data inputs. Both are 75 ohm impedance and both feed into a high rate multiplexer. The analog input has bandwidth of 6 MHz. This information may go either to a 5 MHz recorder or to the downlink transmission. The digital rate is up to 50 Mbps with biphase level coding. This information can either go directly to the downlink at 50 Mbps or stored on tape at 30 Mbps.

TV Signals

TV signals generated by experiment-supplied cameras can be acquired by the Spacelab closed-circuit TV system. There is one input provided in each rack

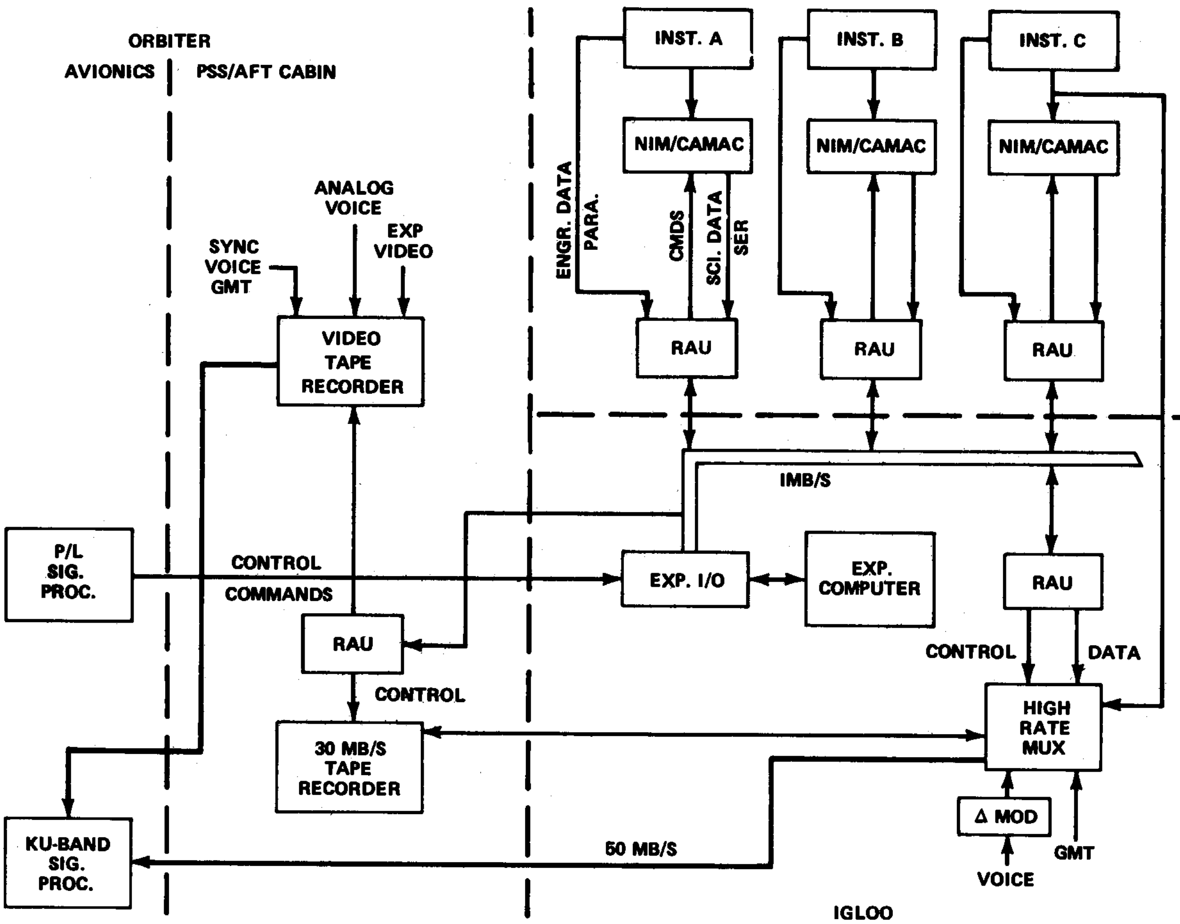


Figure 1. Assemblies Comprising CDMS

Note: GSFC is studying the use of NIM/CAMAC with power requirements and reliability suitable for Spacelab use.

segment and on each pallet. The signal can be monitored at the Orbiter crew station or the operator console on the TV monitors or it can be transmitted by the Orbiter RF equipment to ground. For non-direct transmissions times the video signal can be recorded.

Data Processing

The CDMS provides a dedicated on-board computer for processing data which has been acquired by the experiment data bus system. The processing outputs are displayed on cathode ray tubes (CRT) and transmitted and/or delivered back to the experiments depending on the mission requirements. The computer facilities allow general processing, such as checkout, sequencing and control of experiments, data reduction, filtering, averaging, histograms, computing, etc. Application software is supplied by the experimenter.

Computer

Table 1 summarizes the characteristics and capabilities of the Spacelab computer.

Table 1
Computer Characteristics and Capabilities

Formats

Operands: 16, 32 and 24+8 (floating point) bits

Instructions: 16 bits

Control Unit

Micro-programmed control unit

Control memory capacity:

1st level: 256 40-bit words
2nd level: 32 40-bit words

Number of Instructions

100 instructions including:

- Single-word (16 bits) and double-word (32 bits) call and store
- Fixed-point arithmetical operations on 16 and 32 bits, and floating-point arithmetical operations on 32 bits (24 + 8)
- Logic and comparison operations
- Shift operations
- Fixed-to-floating and floating-to-fixed conversions
- Conditional and unconditional jumps

Floating point (32 bits = 24 + *)

Add: 9.0 μsec minimum
17.1 μsec maximum

Multiply: 26.4 μsec minimum
27.3 μsec maximum

Divide: 27.9 μsec minimum
28.8 μsec maximum

Digital Input/Output

Data exchange with peripherals may be serial or parallel, depending on either of two modes of operation: programmed (controlled by the program) and channel (independent of the arithmetical unit).

Data exchange takes the following times:

Serial

30.9 μsec in the programmed mode
32.1 μsec in the channel mode, and at a maximum frequency of 31 K words/sec in the locked channel mode

Parallel

4.0 μsec in the programmed mode
1.8 μsec in the channel mode, and a maximum frequency of 555 K 16-bit words/sec in the locked channel mode

Table 1 (Continued)

Addressing Modes Immediate, direct, indirect, relative to a base, indexed, relative to program counter Number of Addressable Registers 20 by micro-instructions, of which 12 can also be addressed by instructions Computing Speed Single-word length (16 bits): Add (register-to-register: 1.8 μsec Add (register-to-memory): 2.4 μsec Multiply: 7.5 μsec Divide: 9.0 μsec Double-word length (32 bits): Add: 3.6 μsec	The maximum number of addressable channels is: 496 on the serial bus ·2,048 on the parallel bus Memory • Type: 18 mil ferrite cores, 3-D, 3 wire configuration • Capacity: 39 K 16-bit words for the basic version, extendible to 64 K 16-bit words in 8 K word modules • Cycle time: 1.2 μsec

PAYLOAD OPERATIONS CONTROL CENTER (POCC)

R. Tetrick, GSFC

The general concept is to provide a capability for an experimenter to operate an experiment aboard the Shuttle for the period of the Shuttle flight. The concept permits the experimenter to evaluate and operate his experiment from a POCC on the ground. Depending on the complexity of the operation, the payload specialist aboard the Shuttle would assist in operating the experiments to provide the appropriate data. The scientific personnel on the ground will analyze the data and provide input to the near real-time operation of the experiments. This permits a number of scientific disciplines and skills to be involved in the evaluation and planning of the payload operations. The concept of operation is to control the experiment and the pointing platform from the ground with minimum Shuttle operations support other than to maintain attitude, power up and down of experiments, change film cartridges, etc.

The operations concept for the various Shuttle mission phases are described in the following paragraphs.

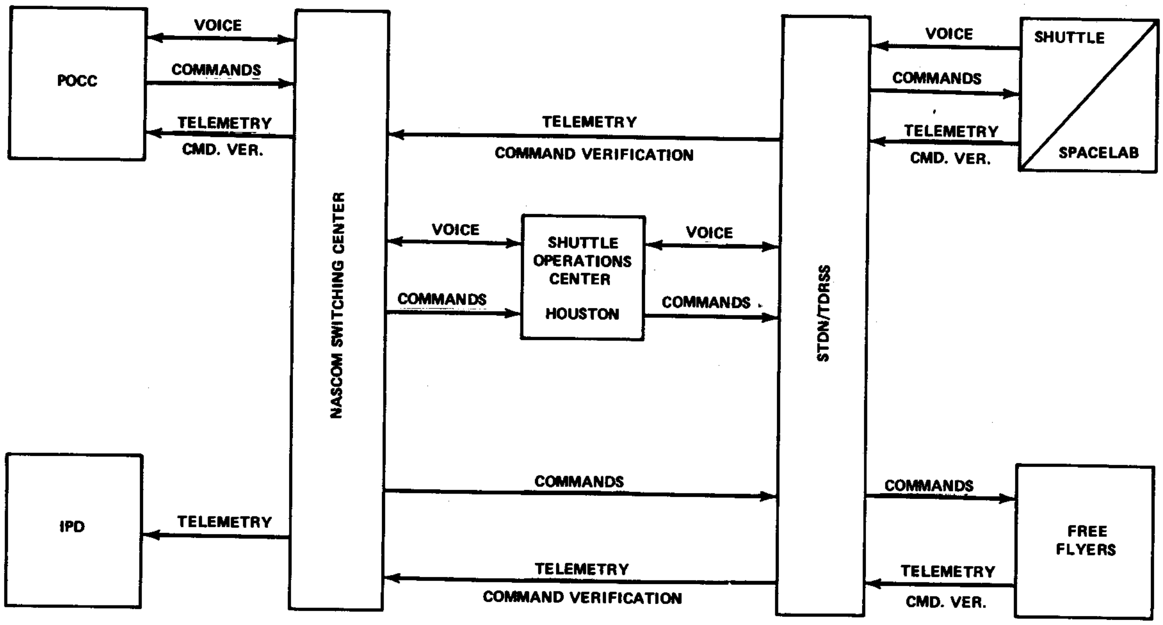


Figure 1. Payload Operations System Overview

Pre-Launch Phase Functions

During pre-launch, it is conceived that the POCC will support T&E activities by decommutating, displaying, and evaluating the experiment performance. The POCC will continue in these roles through the various levels of integration, up to and including Level I of the T&E procedure.

During pre-launch the system must have the following capabilities:

1. Payload evaluation and control from the GSFC POCC.

2. Payload telemetry data transmission from the various integration and test facilities to the POCC.

3. Payload commanding from the POCC to the various facilities including the launch site for payload checkouts and launch readiness. The Shuttle communication simulator should also provide the interface to present the POCC with the Shuttle flight command interface.

4. Voice communications to coordinate test and checkout operations and report launch readiness between POCC, Shuttle Mission Control Center, and launch operations personnel.

Post-Launch Operations

During all phases of activity after launch the POCC will be involved in monitoring and controlling the experiments.

During ascent, the POCC would be in a monitor and advisory posture. On-obrit, the POCC can provide experiment data for the evaluation and control of the payload. The POCC requires real-time telemetry data and command uplink to effect evaluation and operation of the payload.

During de-orbit, the POCC will serve to assure proper power down and de-activation of the Spacelab equipment. During actual descent the equipment is assumed to be inactive and the POCC should not require any inputs during this time.

Additional On-Orbit Capabilities

The POCC can provide the following functions and capabilities:

- Decommutate, evaluate, and display payload housekeeping data.
- Provide payload operations control via a real-time command link from the POCC.
- Process quick-look experiment sensor data and display for experiment analysis and operations planning.
- Provide computational capability for payload operations planning and experiment operations control.
- Provide payload attitude determination and control by interfaces with external computer systems or with Shuttle Mission Control Center.
- Coordinate with Shuttle MCC and payload specialist for Shuttle and Spacelab payload operations.
- Interface with orbit determination systems to provide orbital data for payload operations.

Payload Operations System Overview

Figure 1 illustrates the information and communication paths between the Shuttle, free flyers, tracking stations, and operations centers, including POCC, for payload operations.

CONCLUSIONS

D. Leckrone, GSFC

The Spacelab Astronomy Small Payloads Workshop provided a useful medium of interchange between a substantial group of potential Spacelab users and the engineers responsible for the development of support subsystems required to accommodate their instruments. A major goal of the Astronomy Spacelab Payloads study is to provide a benign environment with relatively simple interfaces to which sounding rocket and balloon class payloads of the sort that now exist may be adapted at low cost. The theme of interface simplicity pervaded the Workshop discussion. If Spacelab is to provide an acceptable extension of our current sounding rocket capability, an experimenter must be able to easily integrate and de-integrate his payload, have access to it at specified times during the integration process, and operate it (or even have it fail) without interfering with other payloads. He should be able to simulate and verify payload operations at his home institution. The current philosophy of the sounding rocket program for payload accommodation should be followed in the Spacelab program if scientific viability and instrument costs per observing second are to be maintained at an attractive level.

A major subsystem requirement is a 3-axis pointing platform with star trackers and a rate integrating gyro system available as part of the subsystem. The Small Instrument Pointing System (SIPS) concept, including thermal cannisters, is attractive with respect to its interfacing simplicity and to its possible commonality with solar physics instrumentation. The use of SIPS for UV-Optical Astronomy will require roll stabilization, accommodation of side-looking instruments (impacting both the fineness of roll stabilization and thermal cannister design), raster scanning, capability for payload evacuation or dry N_2 purge, and the accommodation of cryogenic dewars. In addition to venting provisions, the latter will require accessibility for cryogen top-off within eight hours of launch. The currently envisioned SIPS is somewhat over designed for many astronomy payloads and one might consider a smaller pointing system for 100-150 kg payloads with stability requirements of 10 arcsec. Alternatively one might mount more than one small instrument in a single thermal cannister. The possibility of deploying small payloads with current Aerobee pointing controls and retrieving them after use should be considered.

At present an overall concept for command and data handling has not been firmly established. Problems of concern are the integration and verification of software while maintaining maximum experimenter independence and self-sufficiency. Also, the relative roles of on-board payload specialists and a ground control center need to be defined. Two extreme positions with respect to the payload specialist role were expressed at the Workshop. On the one hand, command and data access to instruments through remote acquisition units (RAU's), coupled with a nearly full-time telemetry capability through TDRS might obviate the need for a payload specialist. On the other hand, observers with relatively simple instrument control and data requirements, who seek maximum interfacing simplicity, should not be required to interact with a very complex ground control center. Many participants envisioned a payload specialist performing simple operational tasks, such as power on/off collimation checks, command sequence initiation, manual film advance, performance monitoring, etc. Since it will usually not be possible to fly one payload specialist for each instrument, one will have to decide if he is willing to have his instrument operated by a payload specialist (an astronomer) who is not intimately familiar with it.

Other problems of concern to Workshop participants include the following:

- difficulties in using long light path instruments because of large scale payload bay thermal flexures and mutual interference with other instruments

- magnetic isolation requirements for electrographs and image intensifiers

- power requirements and vibration sensitivity of standardized electronics modules (NIMS, CAMACS)

- sky brightness and large column densities of light atoms and molecules introduced by orbiter vernier control-system exhaust

- protection of film from thermal "backsoaking" after re-entry

- the potential cost impact of NASA's testing and documentation requirements

- frequency of flight opportunities and choice of observing season to complete finite survey programs; total number of flight "slots" available per year.

Typical lead times for the initial development or adaptation of Spacelab rocket-class payloads range from two to three years. Therefore, NASA should begin to make payload development funds available for the initial orbiter test flights and early Spacelab missions in 1976. To continue the involvement of the scientific community in support subsystems development, Goddard Space Flight Center will regularly conduct Small Payloads Workshops and will actively encourage dialogues between individual experimenters and the engineering group leaders involved in the ASP study. The illustrative payloads discussed at the first Workshop will be utilized for on-going ASP mission analyses and subsystems design studies.

SECTION III.B.

A PRELIMINARY REPORT OF A STUDY TO ADAPT A UNIVERSITY OF WISCONSIN ROCKET PAYLOAD FOR USE WITH THE SPACELAB ON THE NASA SPACE SHUTTLE

INTRODUCTION

This is a preliminary report on the Wisconsin study to determine the effort required to adapt the Wisconsin UV calibration rocket payload for use with the shuttle borne Spacelab. The purpose of this particular payload is to establish a network of 40 well calibrated stars for future use. This will require two shuttle flights approximately six months apart with orbits chosen so that spacecraft night does not occur in the South Atlantic radiation anomaly.

The major work accomplished for this report is to carry the study to the point of payload delivery to GSFC for T and I. The time and cost estimates are felt to be fairly realistic.

We have made many assumptions for this first phase of the study:

1. A thermal canister on a SIPS is assumed.

2. A SIPS-provided "strongback" mounting surface is assumed.

3. A tracking device will be furnished by SIPS for installation in our instrument to utilize the zero order signal as the SIPS fine quidance signal.

4. The RAU has a parallel computer type data interface as well as A/D converters for housekeeping.

5. T & I will take no more than 2 months at GSFC.

6. Since calibration is the critical part of our package, we will be able to leave a mechanical and/or electrical duplicate with the SIPS while we recalibrate, if T & I should take more than 2 months.

7. We provide GSE for early checkout but NASA provide appropriate GOE for "quick-look" and real-time checkout.

8. Six months of programming effort on our part will suffice for both checkout programs and any simple command or control routines required for flight.

9. External vacuum lines will be provided so that an on-board vacuum system will not be needed. The latter is given as an option.

We have not yet studied operational problems such as: how is the payload commanded? By the Payload Specialist? By an on-board computer? From a ground station? Any or all combinations are possible.

What data need to be available on the ground? When? These and many other questions will be addressed in the remainder of the study. More planning will be required for a shuttle flight than a single rocket flight since a shuttle flight will take the place of scores of rocket shots.

A minor portion of the effort is contained in the changes we are already planning for this payload. The major mechanical and optical work is:

1. Mounting of the evacuated package to a strongback.

2. Mounting and alignment of the fine guidance sensor.

3. Design and construction of a simple on-board calibration device.

The major electronic effort is to provide a correct interface with the RAU. Also a more flexible GSE is envisioned than now exists for the Aerobee payload.

PAYLOAD DESCRIPTION AND MODIFICATIONS REQUIRED

The existing payload is described in Appendix A. The modifications are described in the following paragraphs.

Mechanical Description

The sounding rocket spectrometer instrument contains control electronics, spectrometer, slat baffle, and four two inch photometers in a seventy-five inch Aerobee can which is vacuum tight. Vacuum pumping is done externally through a valve in the nose cone. The mechanical changes to the basic instrument are minimal. The electronics section, which is about fifteen inches long and weighs twenty pounds, would be moved external to the vacuum or, thinking of it another way, the bulkhead would be moved forward between the electronics and spectrometer. This requires vacuum feed-thru connectors.

The startracker on the existing Aerobee instrument is mounted adjacent to the slat baffle and photometers, about fourteen inches aft of the front end of the Aerobee can. The startracker for the shuttle would be moved aft to the electronics bulkhead adjacent to the electronics. The startracker will then be external to the vacuum in a forward looking position at the zero order image of the spectrometer. This change will require a vacuum tight optical feed-thru through the bulkhead.

Additions to the present instrument include a calibration collimator section and a valve section. The collimator section will be at the forward end of the spectrometer attached where the slat baffle was. The collimator will be a ten inch diameter tube thirty-six inches long connected through a vacuum tight bulkhead ring on the forward end of the spectrometer. The vacuum pump connection can be made anywhere along the length of the collimator tube. The forward end of the collimator tube is supported by a bulkhead ring and will have a locating taper and valve seal surface. The valve section will be in a box twelve inches on a side with two ten inch diameter holes on the optical axis. The box is supported at the collimator end by a bulkhead ring. Inside the box the valve is supported, by opposite walls perpendicular to the viewing axis, on trunnions. The face of the valve carries an eight inch mirror which points into the spectrometer when the valve is sealed (for calibration purposes). When the instrument is in orbit the valve/mirror is retracted about two inches, rotated 90° CCW, and advanced two inches to a locked position leaving the viewing axis clear. When it is desired to seal the instrument the valve/mirror is retracted from its locked position, rotated 90° CW, and advanced to its sealed or calibration position. The slat baffle with the two inch photometers is mounted on the forward end of the valve box.

Mounting of the instrument to the SIPS canister will be done with the aid of a strongback or a girth ring. The instrument to strongback connection will be made at three or possibly four bulkhead rings. The bulkhead rings are located between electronics and spectrometer, spectrometer and collimator, collimator and valve box. The fourth ring, if needed, is between the valve box and slat baffle (see Figure 1).

As an alternative to the strongback mounting, the girth ring mounting to the SIPS canister requires a narrow box kite-type frame which is held in the canister at the trunnions in the area of the pointing axis. The instrument would be supported through the center of the box kite frame with diagonal supports extending lengthwise fore and aft from the four extreme corners of the frame and radially inward to the bulkhead rings between the electronics and spectrometer sections, and to the bulkhead ring between collimator and valve sections.

The center of gravity can be adjusted by moving the instrument lengthwise within its limits or by repositioning the electronics or pump connection.

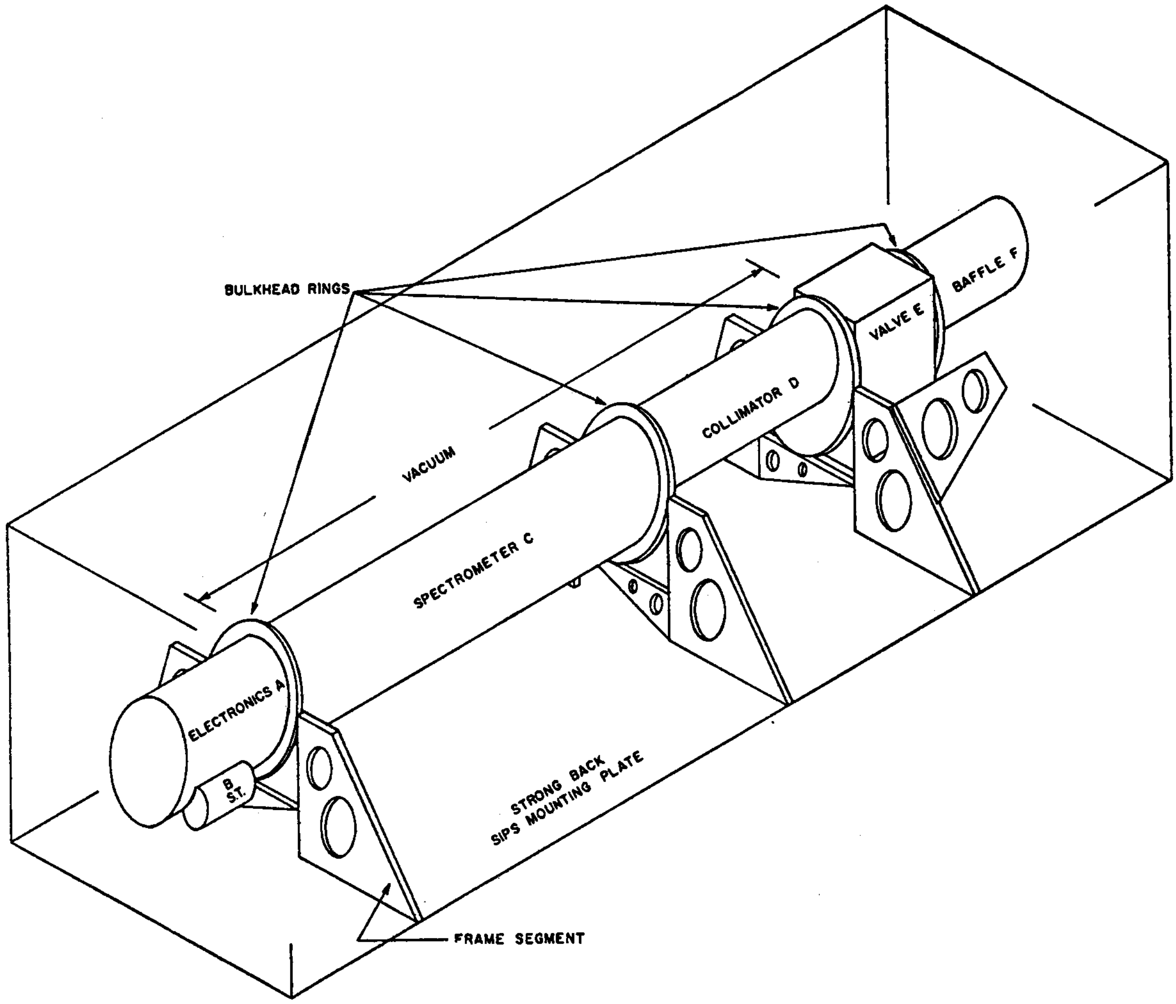


Figure 1. Wisconsin Instrument for Shuttle

Summary of Mechanical Changes

a. The electronics section is atmospheric pressure and therefore, requires vacuum tight feed thrus. The electronics may have to be moved off-center to give the startracker access to zero order.

b. The startracker is in air, therefore the optical path will require a vacuum tight feed-thru window.

c. The spectrometer is unchanged except for a vacuum tight bulkhead connection directly to its base.

d. The collimator needs appropriate plumbing for either the vacuum connection to exterior pumping or to on-board pumping. It also provides an optical path for calibration. The pumping port can be anywhere along the axis in spectrometer or calibration collimator.

e. The valve section contains a vacuum sealing valve to which a calibration mirror is attached.

f. The baffle contains slats to limit the field of view in the dispersion direction. The two inch photometers clamp around the baffle.

Frame segments can be fastened together in various configurations to form mounting stations for the bulkhead ring. The bulkhead ring is an Aerobee (or larger) male/female bulkhead connector with a flange on its periphery. The male/female connections are vacuum tight.

Optical Description

The experiment package consists of one objective-type grating spectrometer for the vacuum ultraviolet region and four small photometers for specific wavelengths in the near ultraviolet.

The spectrometer is a Monk-Gillieson type using a concave spherical mirror and a plane grating. The eight inch diameter mirror is illuminated by light from the star with the field being limited by a slat baffle. The wavelengths observed are determined by the positioning of individual open cathode channeltron multipliers along the direction of dispersion in the focal surface. As a rocket payload this spectrometer has been flown with five detectors defining 90 Å wide bandpasses between 600 Å and 1500 Å. For the shuttle flights an additional detector, smaller cathode areas, and a slight tipping of the grating will provide observations at six 40 Å wide bandpasses between 900 Å and 1800 Å. Because of the objective position of the grating in this instrument, the pointing accuracy necessary for good definition of the bandpasses wavelengths is ±15 arc seconds.

The four small photometers are two inch diameter telescopes with quartz lenses and interference filters and use photomultipliers as detectors. The interference filters define bandpasses several hundred Angstroms wide in the middle ultraviolet. The pointing accuracy necessary for these instruments is ±5 arc minutes.

Changes — There are several changes required to adapt this experiment for a shuttle flight in addition to those required for mechanical and electrical interfacing.

One change is considered necessary because of the absolute calibration required. The overall accuracy of the stellar flux measurements depends on both the accuracy of a laboratory measurement of the spectrometer sensitivity and the certainty one has that the sensitivity is the same during the flight. To monitor the stability of the spectrometer's response during the appreciable length of time between the absolute calibrations done in our laboratory before and after the flight, a field calibration system has been included as an integral part of the spectrometer.

The system consists of a sealed hydrogen lamp and a collimating mirror. The lamp will be either of the discharge type which has been used with the spectrometer on rocket flights or, hopefully, a more stable rf-excited version. The lamp is limited to wavelengths longer than 1050 Å because of the necessity of a window, but emits light throughout the rest of the vacuum ultraviolet. The eight inch diameter collimating mirror is mounted on the valve which provides the vacuum seal for the spectrometer and is completely removed from the field of view when the valve is in its open position. An off-axis parabolic figuring of the mirror allows the lamp to be mounted out of the beam without astigmatism, and is available without cost since use will be made of a mirror on hand from a developmental OAO stellar telescope.

This on-board system is designed to be used both for field calibration before launch and as an in-flight calibration source. A field calibration can be done at any time that the spectrometer is under a high vacuum. The high vacuum condition must be present to even turn on the channeltron detectors in the spectrometer for test purposes. As presently conceived the high vacuum is achieved when required by attaching an external pumping system to the experiment. This assumes that the experimenter will have access to the experiment for this purpose on several occasions, one of which would be shortly before launch. An alternative to attaching the external pumping system is to provide sufficient internal pumping to maintain a high vacuum constantly in the spectrometer, thus allowing testing of detector operation and field calibration checks to be done remotely.

Another required change is in the location of the startracker. On the shuttle the startracker will provide guidance through the spectrometer itself using the visible light in the zero order from the objective grating. This is a very direct way of assuring that the spectrometer remains aligned to the startracker and full use can be made of the startracker's pointing ability. This would limit the use of this startracker to fine pointing only.

Requirements — The experiment requires a clean high vacuum environment for satisfactory operation. An upper limit of 10^{-5} torr is set by channeltron detectors. The fact that the spectrometer is vacuum tight protects it during the launch phase and until actual operation from contaminants released in the initial out-gassing from the payload bay. A vacuum of 10^{-6} torr and reasonable absence of oil would be adequate for operation provided the canister protects all sections of the spectrometer from significant thermal cycling during the time that the spectrometer vacuum valve is open. This seems compatible with our expectation that the canister will provide darkness for the experiment during the sunlit portions of the orbit.

Electronics

All detectors will be operated in a pulse counting mode and several new channeltrons will be added. The characteristics of the RAU (at present not known) are assumed to be a computer I/O bus structure.

A flexible GSE is being designed for T & I and a new control panel for use in the Spacelab is laid out. The details of these designs are given in Appendix B.

OPERATIONS

Rationale

The purpose of this instrument is to establish a sequence of internally consistent photometric standards in the ultraviolet for use by other instruments. This sequence of standards will include UV bright stars for use by small instruments and fainter stars for use by larger instruments.

For the convenience of users of this sequence a network of about 40 standard stars will be established around the celestial sphere. For reasonably complete sky coverage two missions will be required—one in the spring or summer and one in the fall or winter. Internal consistency will be maintained among the stars observed during each mission by observing in a closed sequence so that the first star to be observed will also be the last. This sequence will be repeated twice during each mission. The program stars observed during different missions will be tied together by including an overlap of about 10 stars that each sequence will have in common.

Star Selection Criteria

Program stars were selected according to the following criteria.

a. Stars with spectral types equal to or earlier than B8 and (with one exception) V magnitudes less than 6.0 were chosen from the Bright Star Catalog (Hoffleit 1964). In order to avoid standards with continua which are declining rapidly with decreasing wavelength, we have chosen, somewhat arbitrarily, B8 as the latest spectral type for this program. Stars fainter than sixth magnitude were not included in order to be certain that the startracker guidance system would function properly.

b. For full sky coverage the network was planned to have, as closely as possible, one star for every 2 hours in right ascension near the celestial equator and one star for every 4 hours of right ascension at declinations +60° and -60°. In addition some stars were chosen at intermediate declinations.

c. Stars with known variability or with emission line spectra were rejected.

d. Stars with bright companions were rejected. This rejection occurred if the secondary or a field star closer than 10 arc minutes contributed more than 1% of the combined light in the visual.

e. Stars previously used as standards in the visual (Oke 1964; Hayes 1970) and in the ultraviolet (Bless, Code, and Fairchild 1974) were included when they satisfied the other criteria.

Fifty-eight stars which satisfied these criteria are listed in Table 1, Appendix C. This list does not include all stars which satisfy the selection criteria. The final list will be chosen after the capabilities of the instrument, the startracker, and the SIPS have been better defined.

An additional 14 stars fainter than V magnitude 6.0 are listed (Table 2, Appendix C) to supplement the brighter sequence in the event that guidance on faint targets proves possible. The faint stars listed here are more likely to be undetected variables or to have bright companions than the stars in the bright sequence. It is not intended that this faint star list should limit the choice of standards.

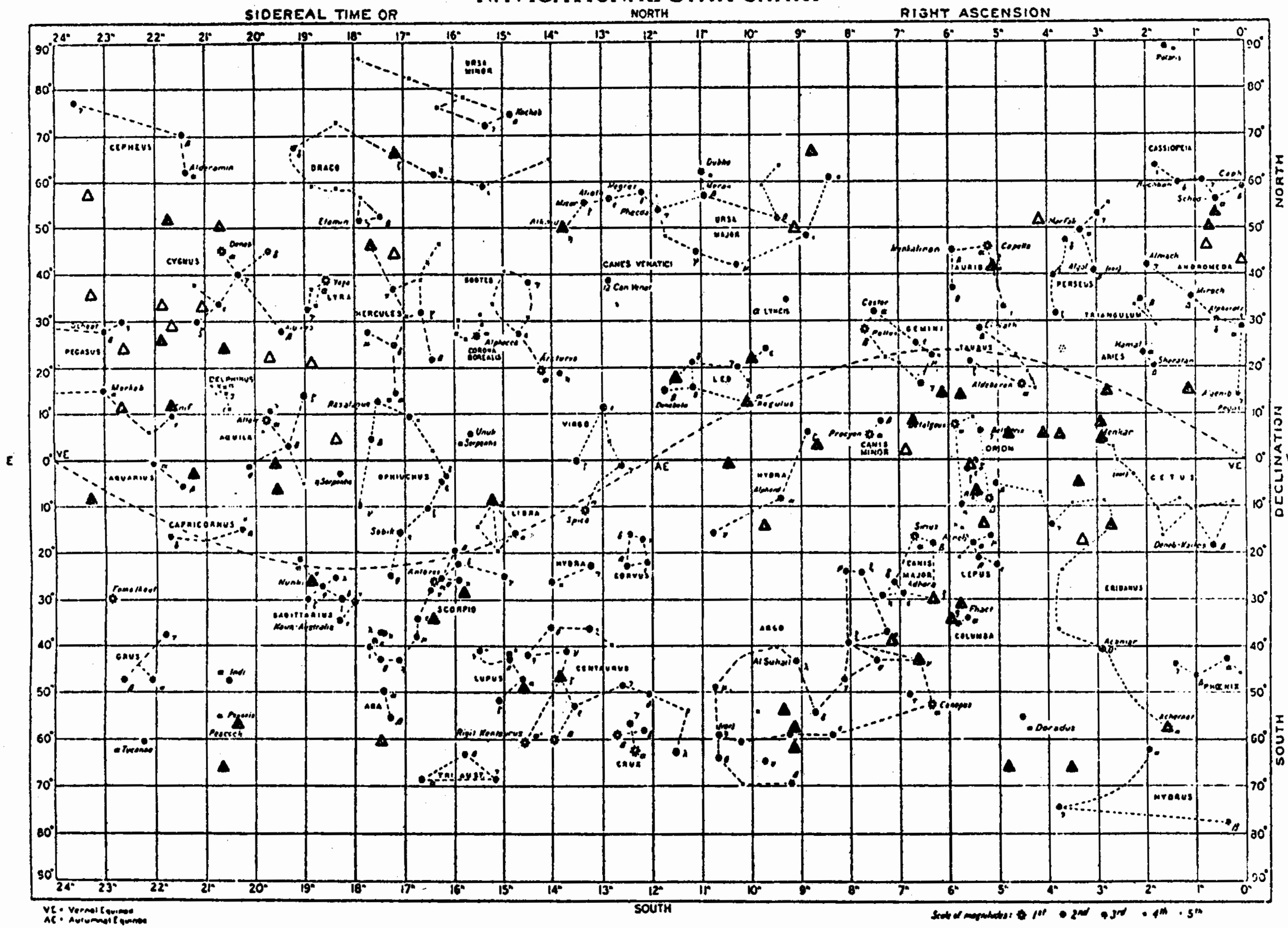
The locations of the stars in the sky on these two lists are shown in Figure 2.

Observing Techniques

Techniques used will depend upon the capabilities of the SIPS, the availability of assistance from the Payload Specialist, and the availability of telemetry links between the spacecraft and the experiment's ground operations equipment (GOE).

It is currently anticipated that, when the telescope is not in the checkout phase of operations, two stars and their associated sky positions will be observed during each spacecraft night. The instrument pointing, search patterns (if the SIPS pointing tolerances prove inadequate), and data acquisition cycles will be preprogrammed. The required data will be telemetered as soon as possible to the

NAVIGATIONAL STAR CHART



▲ POSSIBLE UV STANDARDS △ SUPPLEMENTARY FAINT STARS

Figure 2. Locations of Possible UV Standard Stars

GOE where the experimenter's staff will monitor the data. If this monitoring reveals problems the experimenter's staff will be able to re-program the observing sequence and re-run the instrument checkout if necessary.

Depending upon his workload, the Payload Specialist may take over some of the functions of the experimenter's ground staff.

At the altitude of typical Spacelab missions it is expected that particle fluxes in the South Atlantic Anomaly will be at least 10^3 smaller than the fluxes which affected the OAO-2 instruments. Therefore, it is hoped that the SAA will not be a major observational problem. By choice of launch time and by careful timing of observations it is possible to eliminate nearly all the effects of the SAA on the measurements. The planned repetition of all observations will also minimize errors resulting from Spacelab passage through the SAA.

Checkout Phase

An in-orbit checkout of the instrument and its capabilities will be required. This will be done during the first one or two spacecraft nights (after observing commences). Real time telemetry and commanding of the instrument from the control center will be required at this time.

The Payload Specialist may take over some of the functions of the experimenter's ground staff during this phase.

For example, using our planned control panel (Appendix B, Fig. 4), manual commanding of the payload might begin with turning on the main +28 volt circuit breaker. This provides power to the payload control logic and eventually the detector electronics. The Payload Specialist then enables all (10 detectors) or part of the payload and also the experiment Low Voltage switch. He then pushes the Expt Command Enable button which causes the CDMS computer to sample the control panel switches and issue the desired command to the control electronics via the RAU output lines. The command is stored in control latch registers within the payload. The command, however, is not yet executed. The status of this control register is sampled by the computer with an Input Digital Status command and this digital word is compared with the desired command to insure that the experiment received the proper command. If so, CDMS will light the Command Enable push button which is a signal to the Payload Specialist that he may execute this command. He will then push the Execute button which clears the Command Enable light and activates the control power relays of each selected detector. The change in power status should be indicated on the control panel above the individual detector switches. Assuming all power levels are proper and a brief warm up period has elapsed, the P.S. now enables the High Volts and pushes the Command Enable button as before followed by the Execute button.

The seemingly redundant procedure of Command Enable and Execute is a safety precaution against accidental and possible undesired commands.

The payload also has a calibration source on board that can be moved into position in front of the payload for a pre-flight and in-flight calibration. The source is controlled by two switches on the panel. One switch positions the source and the other controls the lamp. For safety purposes these two lines are direct from the panel to the calibration source. Ground control of the source may be possible if the panel is switched to Remote mode.

The control panel may also indicate the status of the startracker mounted on the payload. A meter will show star presence or relative magnitude. A tracker lock-on indicator will also be on the panel. Joy stick control of the SIPS might take place by the Payload Specialist.

This mode of operation will probably be used initially, but if all goes well control can be transferred to on-board processor routines.

Model Observing Schedule

In Appendix C we have presented model observing schedules for two possible launch dates. These model schedules are meant to be complementary and were constructed assuming that the photometry program would be prime for its SIPS during about one-third of the five day observing period allowed in a seven day mission. Each includes 25 stars chosen from Table 1. Ten stars are common to both schedules and are marked by asterisks.

MISCELLANEOUS

Costs and Manpower

We estimate that it will cost $120,000 and take about one year to deliver a modified payload to GSFC for T & I. We also estimate that another $70,000 and another year will be required to support two flights.

Details of these estimates are given in Appendix D.

Testing

Vibration and vacuum testing will be done at Wisconsin. Mass properties and acoustic noise tests will be performed at GSFC. We assume that all testing and integration at GSFC will require about two months of effort.

Safety

There are no hazards to personnel involved with our package. The ability of the package mounted to the strongback to sustain "crash" level loads will be determined by analysis.

Hazards to our own equipment and that of other payloads consist primarily of EMI generated by failed high voltage power supplies. These conditions will be monitored and indicated on the panel in the Spacelab so that manual corrective action can be taken. It is expected that this hazard may result in loss of data but not in destruction of other instruments.

We are not carrying any high pressure systems, explosive devices, or radioactive material.

OPTIONAL EQUIPMENT

a. If a long stay at GSFC is necessary for some reason, it will be required that we return our package to Wisconsin for another calibration. We could then provide a prototype (w/o detectors) that would be mechanically and electrically similar to the flight model.

b. A cheaper solution would be to leave an electrical simulator only.

c. If suitable vacuum lines are not available through an umbilical connection during the prelaunch phase it will be necessary to include some vacuum equipment as part of our package.

d. Each of these options has cost estimates in Appendix D.

APPENDIX A

THE PRESENT PAYLOAD

APPENDIX A

THE PRESENT PAYLOAD

The existing rocket payload includes a spectrograph which feeds five detectors with sensitivities between λ600 Å and λ1500 A, each with about 90 A bandwidths, and four individual filter photometers sensitive to radiation from about λ1900 Å through the visual region with bandpasses ranging from 30 Å to about 200 Å.

The spectrograph consists of an 8-inch spherical mirror (whose field of view is limited to about 2° by slat collimators) which illuminates, with a converging bundle of light, a 600 line/mm plane diffraction grating blazed at λ1200. The resulting spectrum, with a dispersion of about 17Å/mm, is focussed on Bendix windowless channeltrons fixed in the focal plane; these detectors are operated in a pulse counting mode. The entire payload is evacuated before flight to minimize out-gassing problems.

The four photometers mentioned above are of a type we have flown many times before—two-inch quartz refractors with six-layer MgF_2-Al interference filters to shape the ultraviolet pass bands, and EMI 6256b photomultipliers operating in a DC mode. The total package weighs about 190 pounds and is 77 inches long.

Each of the channeltron detectors has a pre-amp within the detector housing. The pre-amp output feeds an amplifier discriminator which in turn converts the low level signals to a fixed pulse width T^2L levels. These pulses are counted in a 16 bit high speed counters which have a fixed integration time of 500 msec as governed by a stable 32 Hz crystal clock. The contents of the counters are jam transferred into 16 bit shift registers and shifted out serially to the telemetry by the same clock which governs integration time. The counters are then reset. The shifting sequence takes 500 msec to empty the shift registers after which another data dump is taken and the process repeated. Count rate capability is 133,000 counts/sec before overflow. The master clock is fed to telemetry in order to decode the binary bit stream to actual photon counts. This clock has a fiducial pulse interjected on it to indicate the start of the shifting sequence. All signal levels are T^2L.

The photomultipliers are operated in the DC mode. Each of the four linear DC amplifiers are two range auto switching amplifiers giving a dynamic range of 50. Output levels are 0 - +5.0 volts.

There are 25 housekeeping channels monitoring the following:

- All power supply levels - both LV and HV
- Battery voltages

- Vacuum condition (thermocouple)
- PM amplifier offsets/background (X20)
- Calibration lamp current

Toward the latter part of the flight while slewing between stars, a UV calibration lamp is turned on to check and calibrate the channeltron detectors.

The payload requires two battery voltages:

+28 Volts ± 4 Volts and
-12 Volts ± 2 Volts

Total current:

3 amps (28 V)
0.2 amps (12 V)

Power:

approximately 100 Watts.

APPENDIX B

UW ASP ELECTRONICS

APPENDIX B

UV ASP ELECTRONICS

Since the payload-to-shuttle electrical interface, RAU, has not been defined as yet, the following discussion of proposed hardware design and cost estimates will probably be subject to some change.

Data management and control of the UW ASP can be easily handled with an interface that allows information to be passed between the payload and the CDHS computer in a more or less standard "hand-shaking" format. This technique allows multiple experiments to operate simultaneously easily. The payload electronics requires only minor modifications and additions to operate with such a system. Figure 3 shows the proposed electronics system.

We assume that the RAU interface has a 24 bit input data bus and a 24 bit output bus. If desired, these 48 lines can be reduced to a single 24 bit 2-way bus to reduce line count. In addition, there is an interrupt line which signals to the CDHS computer that attention is required and a clear interrupt (optional) which is the response. Digital data are strobed onto the 24 bit input bus in response to an Input Data command and digital status by an Input Status command. Experiment control is via the 24 bit output bus and Output command. The Master Clear line resets the experiment into a 'no operation' condition. In order to handle the analog housekeeping data, the interface can accept (at least) 32 signals (0 - +5 volts).

The 10 photon detectors within the payload are operated in a pulse counting mode. The detector output pulses are counted in 17 bit photon counters with fixed integration periods of 100 milliseconds. Counter capacity is 1.3 megaphotons per second. The counters operate in a free run mode with the only dead time (50 nanoseconds) being that of transfer of the counter contents to 17 bit storage registers followed by counter reset.

The 10 registers are gated sequentially onto a common data bus. To identify the counter, a 4 bit ID word is also strobed onto the bus with the 17 bit data word. This data frame is shown below.

CNTR ID 4 BITS	M S B	DATA WORD	L S B

DATA FRAME

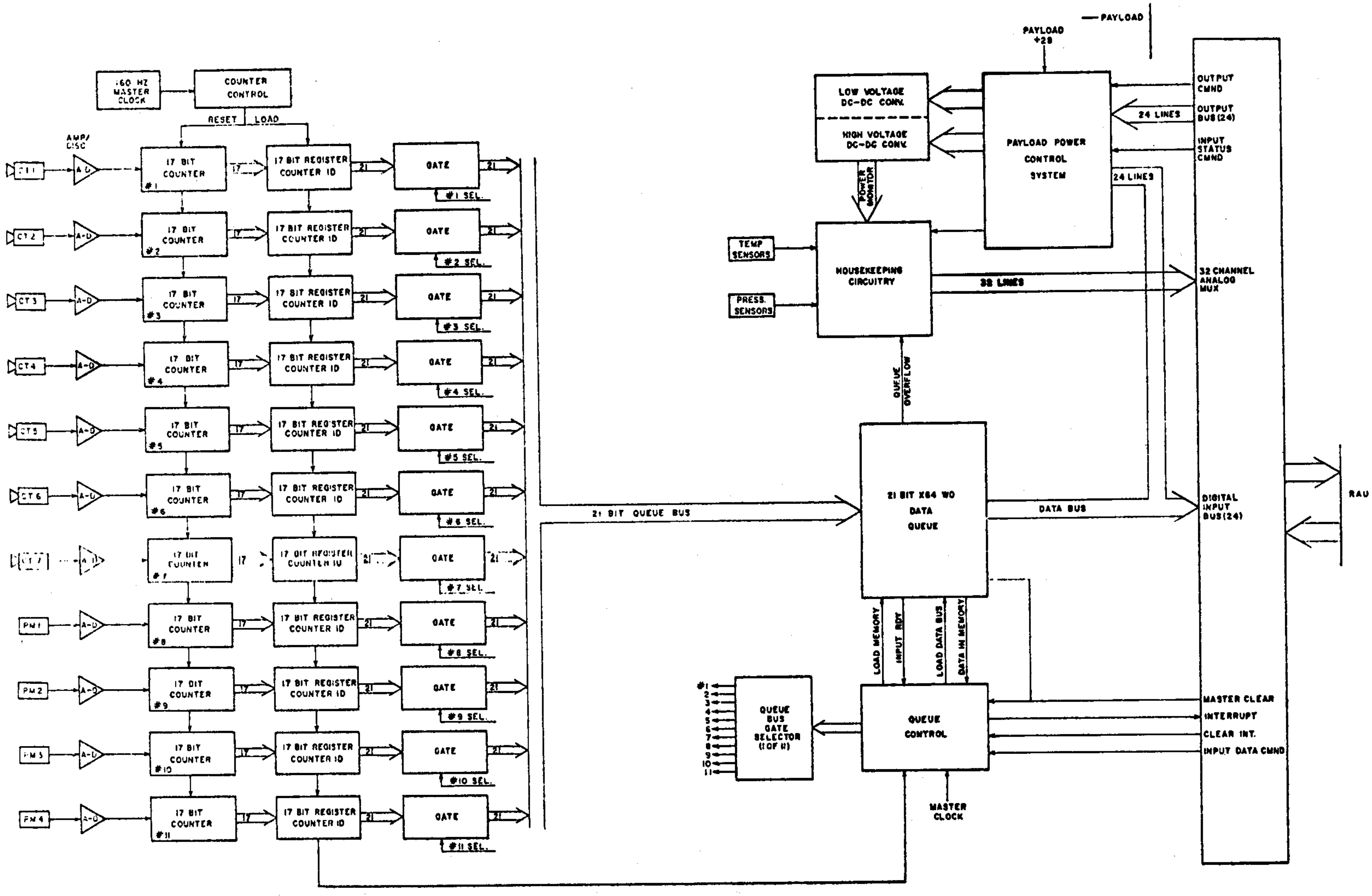


Figure 3. Spacelab to Payload Interface

A small data memory, a first in—first out 21 bit x 64 word queue, is included inbetween the data bus and the RAU input lines. This small addition, readily expandable, allows the RAU data-way to remain inactive or busy for up to 1/2 second before it must take data from the queue before loss of data occurs. Data in the queue would be indicated by a high level on the interrupt line. To remove data from the queue, the CDHS/RAU generates an input data command. Data will remain stable on the input lines for the duration of the command ($>$100 nsec) plus $>$5 nsec. The average bit rate equals 2.31 K bits/second, not counting housekeeping. Sampling rate for analog housekeeping can be 5 samples/second/channel. Assuming a 9 bit A/D conversion within the RAU, this would result in a housekeeping rate of 1.4 K bits/second or a total of 3.71 K bits/second for the payload. The digital data would be stored in raw (unprocessed) form onboard Spacelab to be transmitted whenever possible to the control center for quick-look and detailed analysis. The CDHS computer would be programmed to check the status of the experiment and warn the Payload Specialist of any anomalies.

Experiment control could be the responsibility of the Payload Specialist via a control panel furnished by us. The panel, Figure 4, can control the power to each of the 10 detectors and their associated electronics. Figure 5 shows the control system. The control panel is linked to the CDMS computer instead of directly to the experiment. The reason is that experiment control, as an alternate, can be easily accomplished at the ground control center.

The control panel allows selective power control of individual subsystems rather than a simple +28 V experiment ON/OFF switch. This method was chosen because if a malfunction should occur, the malfunctioning detector can be shut off. Power status of each detector will be fed to the RAU via the analog housekeeping lines. The computer will sample these levels and indicate the status of each detector on the control panel. Should any anomaly exist, a warning light and a possible audio tone will be generated to alert the Payload Specialist that a problem exists and corrective action is required. The faulty subsystem will be indicated by a flashing status light above the power switch of that detector and/or computer CRT console.

Ground Support Equipment

GSE is defined as equipment required to check and calibrate the payload when the payload is not integrated with the Spacelab. The assumption is made that GSFC will provide the ground experimenter with a console for payload control and data analysis when the payload is part of the Spacelab system. The GSE shown in Figure 6 was developed for operator convenience, portability and minimum cost. It can be constructed at this laboratory. A minicomputer and its peripherals already exist and therefore are not considered in the estimated cost for the GSE. The control panel is identical with the Spacelab panel previously

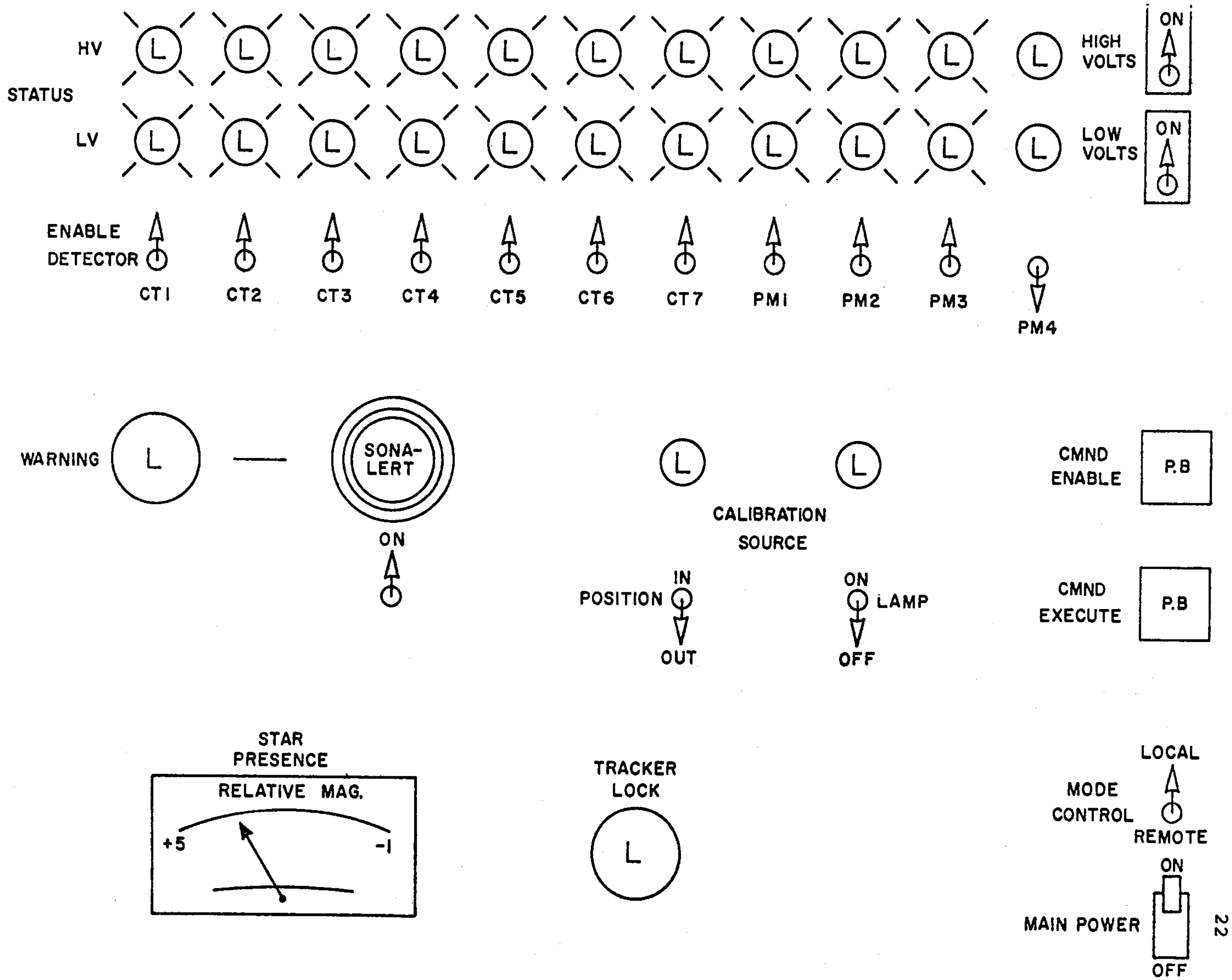


Figure 4. Control Panel

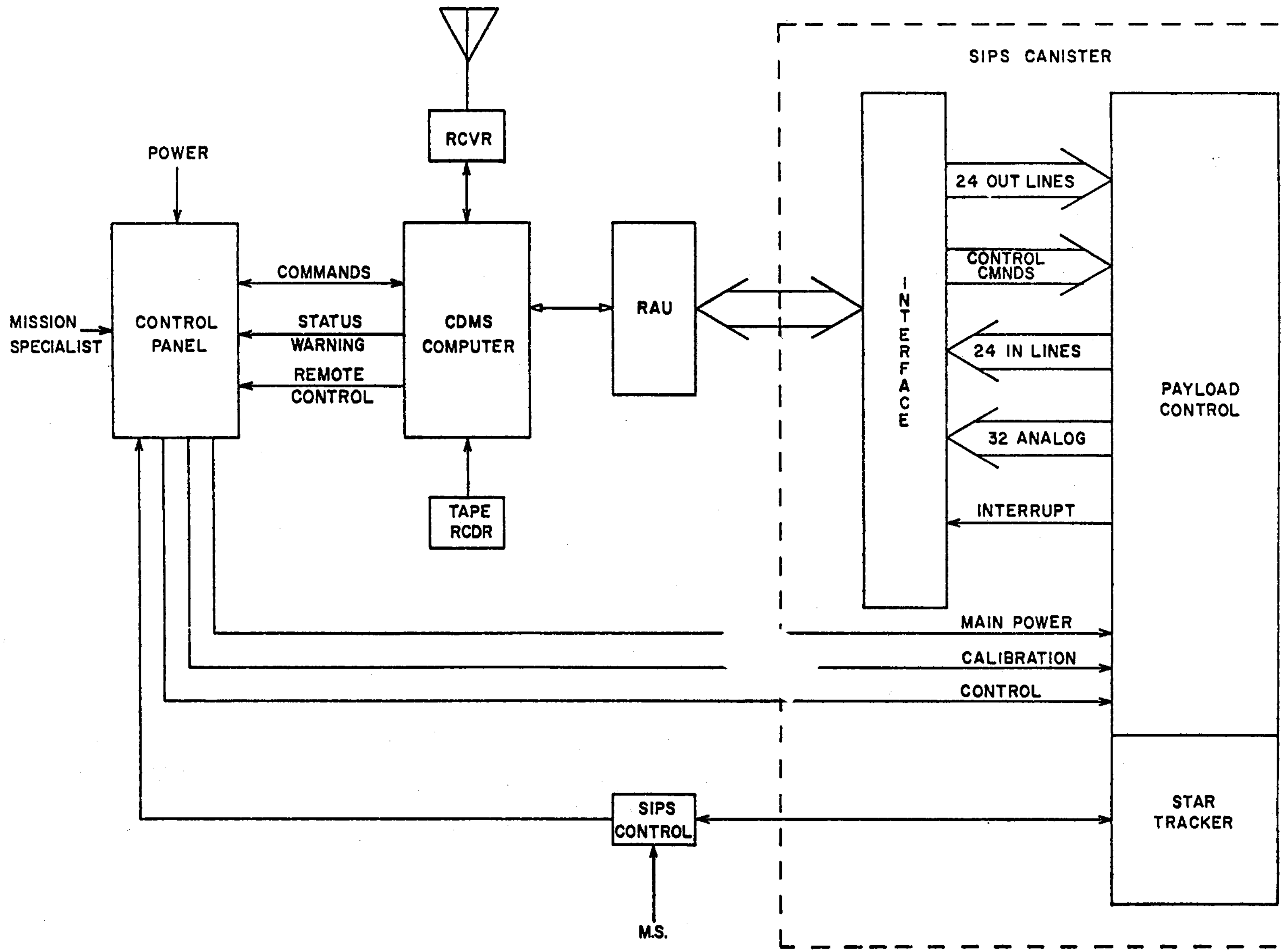
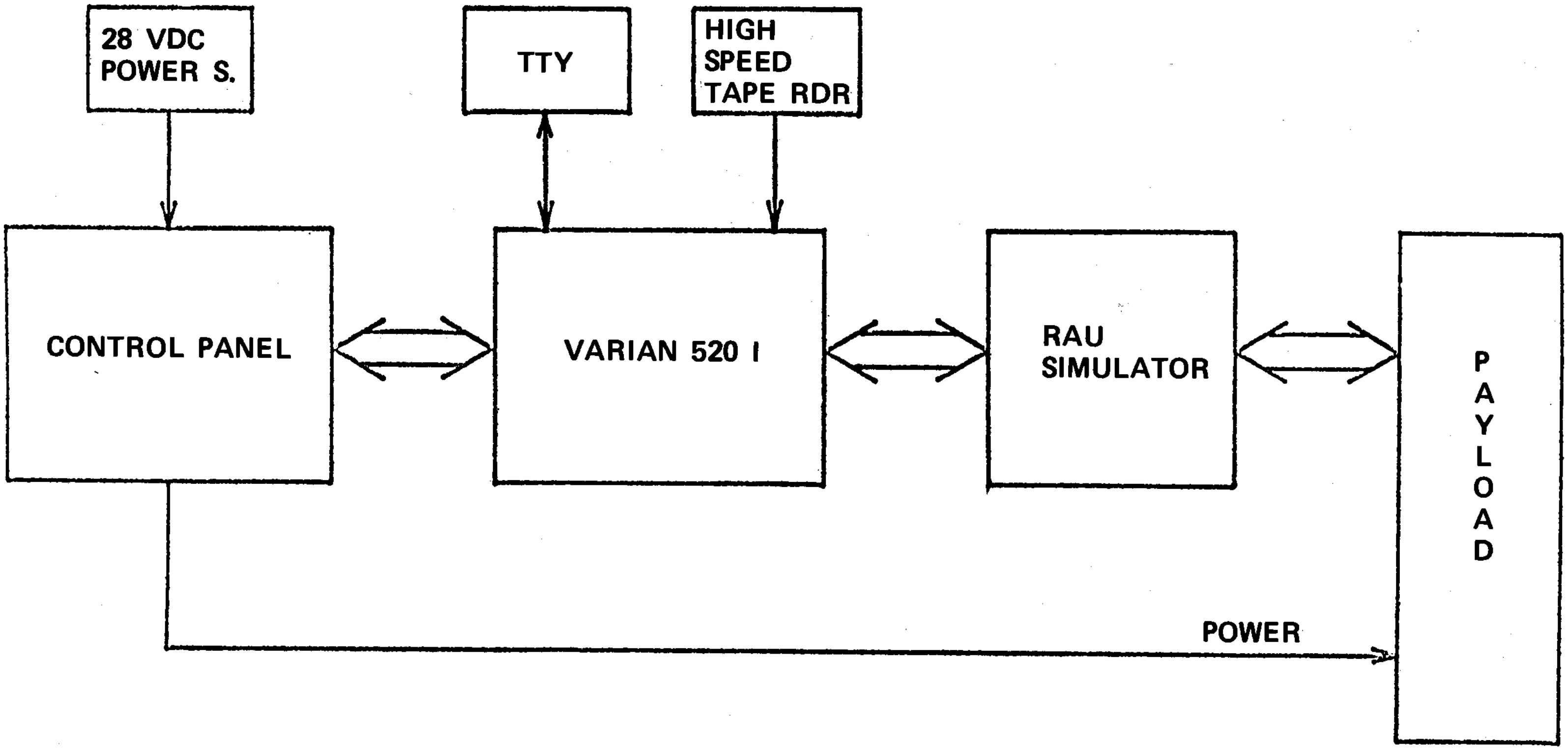


Figure 5. Control System



28 VDC
POWER S.
TTY
HIGH
SPEED
TAPE RDR
CONTROL PANEL
VARIAN 520 I
RAU
SIMULATOR
PAYLOAD
POWER

Figure 6. GSE

described. The computer will control the payload, monitor status, and collect data which will be printed out on the teletype. Additional hardware required includes the control panel and RAU simulator.

Payload Simulator (Optional Equipment)

Prior to payload integration at GSFC, Wisconsin will provide a payload simulator. This will allow the Spacelab systems personnel to check out the software in advance of formal integration.

The simulator can be one of two types. It may be of similar weight and dimension as the flight payload—in effect a prototype, but without detectors or optics to minimize expenses. A "photon simulator" would provide data for the counters. A less expensive alternative would be an electronic simulation only. Following formal integration, the payload is returned to Wisconsin for calibration and the simulator is remounted within the Spacelab so that as other payloads arrive T & E the Wisconsin "payload" can be checked out with the others for possible interference.

Test & Integration

Some T & E can take place within this laboratory and at General Environments Corporation in Morton Grove, Ill. This corporation can perform complete payload vibration tests and subsystem thermal vacuum tests if required. Mass properties and acoustic vibration tests would have to be done at GSFC. A more detailed study of T & E will follow this report at a later date.

APPENDIX C

STAR LISTS AND OBSERVING SEQUENCES

APPENDIX C

STAR LISTS AND OBSERVING SEQUENCES

Table 1

Possible Ultraviolet Standards

Name	α (1950)	δ (1950)	SP	V	B–V	U–B	Comments
ζ Cas	$0^h34.17$	53°37.5	B2IV	3.64	-0.20	-0.85	OAO-2
ξ Cas	$0^h39.25$	50°14.5	B2.5V	4.78	-0.11	-0.63	OAO-2
87 Psc	$1^h11.47$	15°52.0	B8III	5.95	-0.07	-0.41	OAO-2
α Eri	$1^h35.84$	-57°29.4	$B3V_p$	0.49	-0.17	-0.67	OAO-2
π Cet	$2^h41.75$	-14° 4.2	B7V	4.23	-0.14	-0.44	OAO-2
σ Ari	$2^h48.72$	14°52.5	B7V	5.40	-0.08	-0.45	OAO-2
λ Cet	$2^h57.03$	8°42.5	B6III	4.69	-0.12		
93 Cet	$2^h59.75$	4°09.4	B7V	5.63	-0.10		
17 Eri	$3^h25.75$	-4°56.0	B8V	4.72	-0.09	-0.28	OAO-2
22252	$3^h30.34$	-66°39.5	B8V	5.82	-0.06		
29 Tau	$4^h01.10$	5°53.7	B3V	5.36	-0.02		m = 6.2
40 Tau	$4^h01.10$	5°18.4	B3V	5.31	-0.08	-0.58	OAO-2
π^4 Ori	$4^h48.42$	5°31.3	B2III	3.69	-0.17		OAO-2
η Aur	$5^h03.00$	41°10.0	+B3V	3.17	-0.18	-0.67	OAO-2
λ Lep	$5^h17.27$	-13°13.8	B0.5IV	4.28	-0.27	-1.01	OAO-2
ν Ori	$5^h29.52$	-7°20.7	+B0V	4.62	-0.26	-1.07	OAO-2
ε Ori	$5^h33.67$	-1°14.0	+B0Ia	1.69	-0.19	-1.04	Oke & Hayes std. OAO-2
μ Col	$5^h44.13$	-32°19.7	09.5IV	5.16	-0.28	-1.07	OAO-2
133 Tau	$5^h44.88$	13°53.4	B2IV-V	5.27	-0.16	-0.68	OAO-2 Δm = 6.3
ε Dor	$5^h49.95$	-66°55.3	B6V	5.10	-0.15	-0.47	OAO-2
γ Col	$5^h55.77$	-35°17.6	B2.5IV	4.36	-0.18	-0.65	OAO-2 Δm = 8.4
ξ Ori	6^h 9.10	14°13.5	B3IV	4.47	-0.18	-0.66	OAO-2
ζ CMa	$6^h18.39$	-30° 2.2	B2.5IV	3.02	-0.19	-0.71	OAO-2
ν Pup	$6^h36.23$	-43° 8.4	B8III	3.17	-0.11	-0.38	OAO-2
16 Mon	$6^h43.80$	8°38.5	B2.5V	5.94	-0.19		
54893	7^h 7.18	-39°34.7	B2IV-V	4.82	-0.19	-0.68	OAO-2

Table 1 (Continued)

Name	α (1950)	δ (1950)	SP	V	B–V	U–B	Comments
η Hya	$8^h40.61$	3°34.4	B4V	4.29	–0.20	–0.74	Oke & Hayes std. OAO–2
74604	$8^h44.32$	66°53.6	B8V	6.15	–0.11		
α Car	9^h 9.65	–58°45.7	B2IV–V	3.43	–0.19		
79447	$9^h10.14$	–62° 6.7	B3III	3.96	–0.19		
κ Vel	$9^h20.56$	–54°46.8	B2IV–V	2.49	–0.20	–0.74	OAO–2
κ Hya	$9^h37.90$	–14° 6.3	B5V	5.06	–0.16		
87015	$10^h00.03$	22°11.5	B2.5IV	5.51	–0.20		
α Leo	10^h 5.73	12°12.5	B7V	1.35	–0.11	–0.37	OAO–2 Δm = 6.5 Oke & Hayes std.
β Sex	$10^h27.73$	–0°22.8	B6V	5.04	–0.14		
90 Leo	$11^h32.10$	17°04.4	B4V	5.95	–0.16		
η UMa	$13^h45.57$	–49°33.7	+B3V	1.88	–0.19	–0.68	OAO–2 std.
ζ Cen	$13^h52.41$	–47° 2.9	B2.5IV	2.54	–0.23	–0.90	OAO–2
ρ Lup	$14^h34.50$	–49°12.2	B5V	4.04	–0.15	–0.55	OAO–2
β Lib	$15^h14.30$	–9°12.3	B8V	2.60	–0.11	–0.37	OAO–2
ρ Sco	$15^h53.80$	–29° 3.9	B2IV–V	3.88	–0.20	–0.82	OAO–2
148703	$16^h28.11$	–34°35.7	B2III	4.23	–0.17	0.79	OAO–2
ζ Dra	$17^h08.64$	65°46.2	B6III	3.18	–0.13	0.43	OAO–2
δ Ara	$17^h26.58$	–60°38.7	B8V	3.61	–0.10		m = 7.1
ι Her	$17^h38.03$	46° 2.2	B3IV	3.80	–0.18	–0.69	OAO–2
σ Sgr	$18^h52.16$	–26°21.5	+B2.5V	2.07	–0.21	–0.74	OAO–2
ι Agl	$19^h34.13$	–1°23.9	B5III	4.36	–0.08		
κ Agl	$19^h34.21$	–7° 8.5	B0.5IIIn	4.96	–0.01	–0.88	OAO–2 Hyes std.
α Pav	$20^h21.72$	–56°53.8	B2.5V	1.92	–0.20	–0.71	OAO–2
28 Vul	$20^h36.34$	23°56.4	B5IV	5.05	–0.15		OAO–2
υ Pav	$20^h37.41$	–66°56.6	B8V	5.14	–0.06	–0.27	OAO–2
51 Cyg	$20^h40.67$	50° 9.8	B2V	5.38	–0.10		OAO–2
15 Agr	$21^h15.56$	–4°43.8	B5V	5.68	–0.13	–0.51	
206540	$21^h40.10$	10°35.8	B7III	5.88	–0.11	–0.51	OAO–2
π^1 Cyg	$21^h40.32$	50°57.6	B3IV	4.66	–0.11	–0.69	OAO–2
16 Peg	$21^h50.79$	25°41.0	B3V	5.06	–0.18	–0.70	OAO–2
ζ Peg	$22^h38.95$	10°34.7	B8V	3.39	–0.09	–0.27	OAO–2 Δm = 8.0
Ψ^2 Agr	$23^h15.30$	–9°27.7	B5Vn	4.40	–0.11	–0.55	OAO–2

Table 2

Faint Star Supplement

Name	α (1950)	δ (1950)	SP	V	B–V	U–B	Comments
Hd 73	0^h 3.03	43° 7.4	B1.5V	8.48	-0.18	-0.91	
4460	0^h44.50	47°32.0	B1V	8.41	-0.16	-0.92	
20340	3^h13.46	-17°00.8	B3V	7.97	-0.13	-0.62	
25787	4^h 3.96	51°19.2	B2V	7.65	0.02	-0.75	
51507	6^h55.09	1°33.5	B3V	8.00	-0.11	-0.61	
7770	9^h 2.90	49°48.7	B2IV	7.51	-0.21	-0.76	
156110	17^h12.00	45°25.8	B3Vn	7.56	-0.17	-0.74	
176254	18^h56.53	20°33.2	B2V	6.74	0.03	-0.56	
186412	19^h41.27	22°22.5	B5V	6.82	-0.08	-0.51	
201345	21^h 5.86	33°11.7	ON9V	7.66	-0.13	-0.95	
BD+28°4211	21^h48.93	28°38.1	sd0	10.53	-0.34	-1.26	Stone std. secondary OAO-2
208973	21^h57.00	33°23.5	B2V	8.22	-0.10	-0.72	
BD+25°4655	21^h57.40	26°12.1	sd0	9.67			OAO-2
214930	22^h39.03	23°35.1	B2IV	7.38	-0.14	-0.68	

Model Observing Schedule: June 1 Launch

Relative Orbit	Observing Activity
1	Check Out
2	η UMa*, ζ Dra*
3	ι Her, π^1 Cyg
4	16 Peg, ζ Peg
5	ψ^2 Agr, κ Agl
6	σ Sgr, α Pav
7	ν Pav, Eri*
8	HD 22252*, ϵ Dor*
9	ν Pup, HD 79447*
10	κ Vel*, ζ Cen
11	ρ Lup, δ Ara
12	ρ Sco, β Lib
13	β Sex*, α Leo*
14	90 Leo, η UMa*
15	ξ Dra*, ι Her
16	π^1 Cyg, 16 Peg
17	ζ Peg, ψ^2 Agr
18	κ Agl, α Sgr
19	δ Ara, α Pav
20	ν Pav, α Eri*
21	HD 22252*, ϵ Dor*
22	ν Pup*, κ Vel*
23	HD 79447, ζ Cen
24	ρ Lup, ρ Sco
25	β Lib, β Sex*
26	α Leo*, 90 Leo
27	η UMa*

Model Observing Schedule: December 1 Launch

Relative Orbit	Observing Activity
1	Check Out
2	α Leo*, η Hya
3	ϵ Ori, π^4 Ori
4	π Cet, 87 Psc
5	ξ Cas, ζ Cas
6	51 Cyg, ζ Dra*
7	η UMa*, HD 74604
8	η Aur, 133 Tau
9	υ Ori, ζ CMa
10	γ Col, ν Pup*
11	HD 22252*, α Eri*
12	ϵ Dor*, HD 79447*
13	κ Vel*, κ Hya
14	β Sex*, α Leo*
15	η Hya, ϵ Ori
16	π^4 Ori, π Cet
17	87 Psc, ξ Cas
18	ζ Cas, 51 Cyg
19	ζ Dra*, η UMa*
20	HD 74604, η Aur
21	133 Tau, υ Ori
22	ζ CMa, γ Col
23	ν Pup*, HD 22252*
24	α Eri*, ϵ Dor*
25	HD 79447*, κ Vel*
26	κ Hya, β Sex*
27	α Leo*

APPENDIX D

COST BREAKDOWN (OVERHEAD AND FRINGE BENEFITS LUMPED WITH SALARIES) 1975 DOLLARS

APPENDIX D

COST BREAKDOWN (OVERHEAD AND FRINGE BENEFITS LUMPED WITH SALARIES) 1975 DOLLARS

A. Optical-mechanical effort to modify the payload and calibrate it once before delivery to GSFC:

	Cost in Thousands
Construction	
Materials	4
Instrument Maker (10 MM)	20
Physicist (3 MM)	8
Calibration (up to delivery)	
Instrument Maker (1 MM)	2
Physicist (4 MM)	11

B. Electronic effort required to modify and integrate the instrument for delivery to GSFC:

	Cost in Thousands
Design and Construction	
Materials	8
Engineer (5 MM)	13
Electronic Technician (7 MM)	15
Programmer (3 MM)	6
Integration at Wisconsin	
Engineer (1 MM)	3
Electronic Technician (1 MM)	2
Programmer (1 MM)	2
Administrative Cost	
Travel — 2 trips (1 MM)	4
Project Manager (4 MM)	15

		Cost in Thousands
Administrative Cost (Continued)		
Astronomer (planning) (3 MM)		7
TOTAL COST TO DELIVERY TO GSFC WITHOUT OPTIONAL EQUIPMENT	120	
C. Additional calibration and support of 2 flights:		
Calibration		
Physicist (9 MM)		24
Testing and Integration		
Engineer (2 MM)		5
Programmer (2 MM)		4
Operations		
Programmer (1 MM)		3
Astronomer (1 MM)		2
Project Manager (2 MM)		7
Travel		
14 Man Trips		4
4 Man Months		8
Data Analysis		
Programmer (1 MM)		3
Astronomer (3 MM)		10
TOTAL ESTIMATED TESTING AND FLIGHT	70	
D. Options:		
Prototype		15
Electronic Simulator		3
Onboard Vacuum System		19
TOTAL OPTIONS	37	
TOTAL ESTIMATED COST W/O OPTIONS		190
WITH OPTIONS		227