INTERIM REPORT OF THE ASTRONOMY SPACELAB PAYLOADS STUDY

EXECUTIVE VOLUME

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PREPARED BY THE

ASTRONOMY SPACELAB PAYLOADS PROJECT

JULY 1975

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

GREENBELT, MARYLAND

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PREFACE

This report describes the progress of the Astronomy Spacelab Payloads Project work at the Goddard Space Flight Center, a project which is in its inception year of activity. This project was organized to evolve and develop astronomical research in space, using the Spacelab in conjunction with the Space Shuttle. The astronomical research under consideration includes the various fields of Solar Astronomy or Solar Physics, Ultraviolet and Optical Astronomy and High Energy Astrophysics. These fields include scientific studies of the sun and its dynamical processes, of the stars in wavelength regions not accessible to ground based observations, and the exciting new fields of X-ray, gamma-ray and particle astronomy. Many of these new channels of observations are only observable from above the earth's atmosphere, and hence the ability to carry large complex payloads into near earth orbit will greatly expand our capability to see the universe and its physical processes. The interesting infrared Astronomy is not included because a cooled, one-meter-class telescope is under study by the Ames Research Center as an extension of the NASA program with aircraft using the Kuiper Airborne Observatory.

Several studies of the scientific research programs using the Space Shuttle have been made, i.e., Proceedings of the Space Shuttle Sortie Workshop, Volume II Working Group Reports (NASA Goddard Space Flight Center, Greenbelt, Maryland, 1972); Final Reports of the Space Shuttle Payload Working Groups, Volumes 1-5 (NASA Goddard Space Flight Center, Greenbelt, Maryland, 1973); Spacelab Programme: Views of the ESRO Spacelab Payloads Groups — Utilization of the Spacelab for Science (ESRO, Neuilly-sur-Seine, France, 1973), Scientific Uses of the Space Shuttle (Space Science Board, National Research Council, National Academy of Sciences, Washington, D.C., 1974), and Program for High Energy Astrophysics (1977-1988), by the ad hoc planning group of the NASA High Energy Astrophysics Management Operations Working Group. The Space Shuttle will be the primary transportation system into near-earth orbit beginning in the next decade and accordingly the transport system for astronomical instruments free of terrestrial interference. The Space Shuttle is different from the conventional rocket system for injection of satellites into orbit in several respects: the capability to return the instruments, the presence of man in the operation, maintenance and assembly of instruments, the substantial payload carrying capacity of 30 tons per flight, and the relatively low cost-to-weight ratio into orbit. These differences have been important considerations in the work of the Astronomy Spacelab Payloads project, affecting in a substantial way the methods and procedures for astronomical research in space. The work to date has been based on past experience from earlier programs and missions with satellites—The Orbiting Solar Observatory (OSO), the Orbiting Astronomical Observatory (OAO), the Small Astronomical Satellites (SAS), the Interplanetary Monitoring Platforms (IMP),

the manned missions—Gemini, Project Apollo, the Apollo-Soyuz Test Project (ASTP) and especially Skylab and its Apollo Telescope Mount (ATM) for solar physics. The experience gained from research with balloons, sounding rockets and aircraft affords a source of proven instruments which may be incorporated into Space Shuttle flights with moderate changes and relatively small increases in cost. The presently planned satellite flights for astronomy include the High Energy Astronomical Observatory (HEAO block I and II), the International Ultraviolet Explorer (IUE), the Large Space Telescope (LST) and the Solar Maximum Mission (SMM). These missions not only are additional sources of experiments and scientific experience but they also parallel the astronomy program with Spacelab. The Astronomy Spacelab Payloads Study has been concerned with evolving an optimum program of scientific research for the period of the early 1980's using the Spacelab/Space Shuttle, a program of research responsive to the projected progress in the field of astronomy and utilizing the techniques, instruments and operational modes of the Space Shuttle; a program advancing the field of astronomy—incorporating the general participation of the scientific community—cost effective and scientifically productive.

This Astronomy Spacelab Payloads Project requires an immediate and realistic start, i.e., the definition of the early experiments and subsystems of the payloads of the early 1980's. For many investigations in astronomy, the scientific return is almost linearly dependent on the observational time available; the five minutes available with a sounding rocket flight still provide a useful mode for scientific discovery and instrument development—but the five year operational lifetime of the OAO or one LST yields a tremendously large scientific return. The Shuttle provides in the Spacelab mode of operation of a week to a month, perhaps as much as ten percent of the observational time of a free-flying satellite, but it also provides a low cost means of integrating instruments for operation in orbit—a block of observational time generally large enough for significant scientific results—a test and calibration of sophisticated instruments which may later be integrated into a long-lifetime orbiting spacecraft which can be man maintained. For these reasons in the Astronomy Spacelab Payload Study the possible experiment modes have been at present limited to use the Spacelab system and define the optimum payloads, experiment complexes and subsystems, in the Sortie mode of the early 1980's. As a first step the pallet mode of operation has been studied; the pressurized module has not been included in the study, because nearly all astronomical instruments require direct access to space—some sophisticated instruments may require assembly by the mission specialists while in orbit in the pressurized module.

This Interim Report of the Astronomy Spacelab Payloads Study includes in addition to this brief summary volume, three substantive volumes describing the scientific areas of Solar Physics, Ultraviolet and Optical Astronomy and High Energy Astrophysics, an Engineering Volume describing the various systems to be

incorporated into the Spacelab Payloads, and a Mission Analysis Volume describing several dedicated and mixed scientific Space Shuttle missions for the early 1980's. The scientific programs of experiments are the basis for defining the subsystems and planning several sets of possible missions. The actual missions will be organized and undertaken in conjunction with the scientific community following the procedure of announcements of the opportunities. Several special facility instruments have been identified; these facility instruments, capable of contributing to a wide variety of scientific investigations, are being defined by Facility Definition Teams chosen after an announcement of opportunity. These Definition Teams have operated with support from university, government, industrial and non profit institution groups. In addition the importance of international participation is recognized and is included in these studies.

This Astronomy Spacelab Payloads Study has the objective to utilize effectively the Space Shuttle for astronomical research beginning in the early 1980's. The scientific programs, after the preliminary definition and mission analysis, will be evaluated with respect to required resources, costs and manpower. This procedure is expected to require several iterations prior to assigning resources and scheduling the missions.

In this volume the scientific and mission volumes are briefly summarized. Schedule considerations are then presented. A costing approach and cost estimates of various experiments, subsystems and missions are also presented. A number of conclusions and issues so far identified at this stage of the Astronomy Spacelab Payloads Study have been listed. The Appendix contains the members of the principal teams that are currently involved in the ASP project; also included are the participating scientists of the Small Payloads Workshop. The mission analysis section is based on an ASP study performed by Rockwell International. The ASP Project wishes to express its gratitude and appreciation for all the support received.

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SOLAR PHYSICS PROGRAM

A Solar Physics Program on Spacelab is being planned to advance the understanding of physical processes on the Sun beyond that currently achieved with ground-based, rocket, satellite and Skylab observations by using the capabilities of the Space Shuttle. The goals of the ASP program include the identification and definition of scientific problems that can be effectively studied using Spacelab, the development of large facility solar instruments to carry out this research, and the development of a program that includes balloon/sounding rocket/spacecraft-class instruments on early missions and provides for the orderly development of facility class instruments to attain ultimate observational goals on later missions. To achieve these goals, four Facility Definition teams have been formed via open competition among members of the community of solar physicists. These four teams cover the areas of (1) a one-meter solar telescope, (2) a EUV/XUV/Soft X-ray facility, (3) a hard X-ray imaging facility and (4) a quick reaction and special purpose facility. These teams are charged with providing detailed scientific justification for each facility, defining representative observing programs to allow in-depth planning of a set of flights, developing detailed technical definition of the facility and defining representative focal plane instrumentation. Each team is also responsible for estimating costs for its facility and addressing science and cost trade-offs for various design options.

The One-Meter Telescope Facility Definition Team is concerned with the development and use of a solar telescope of large aperture for diffraction-limited observations extending over near UV and visible wavelengths. This instrument is suited to studies of the heating of the solar chromosphere by searching for evidence for the formation and dissipation of shock waves, by studying the turbulence spectrum of the photospheric intensity and velocity fields, and by evaluating the relationships of magnetic fields to the structure and behavior of the chromospheric network. High spatial resolution will allow detailed studies of mass transport by giving details of the features which are the source of mass injection into the transition region. The telescope is valuable for observing the magnetic field configurations associated with various types of solar activity and the fine scale phenomena in sunspots. Coupled with a spectrometer, the telescope can be used to study small volumes of solar matter to determine the abundance distribution of elements as well as abundance variations in flares or sunspots. The meter class telescope will have an aperture of about 1 meter, a focal length of about 30 meters, and a field diameter greater than 4 arc min. Three operational modes for coupling to various instruments include a birefringent filter tuneable from 2750 Å to 11000 Å, a spectrograph, and a multiple instrument capability programmable during flight. The telescope would be mounted on the Instrument Pointing System (IPS); roll control and offset pointing requirements are severe.

The Solar EUV-XUV-Soft X-ray Facility Definition Team is concerned with the solar spectrum from 2000Å to 2Å, which includes emissions of the solar atmosphere from the high photosphere through the chromosphere into the corona. Radiactive equilibrium does not hold in these regions and deposition of mechanical energy must take place. Observations in the EUV and soft X-ray region can be used to calculate such physical parameters of the atmosphere as electron densities, ion abundances, velocities, temperatures and departures from thermodynamic equilibrium. However, the OSO and ATM observations have made it clear that the chromosphere, transition region and corona contain fine structures with scales smaller than the resolution of instruments carried by either spacecraft. It is therefore essential to make observations in these wavelength regions with a resolution of one arc second or better to understand more fully the physical phenomena that are present. As with the one-meter telescope, observations of phenomena that will lead to an understanding of mass and energy balance and the transport and dissipation of non-thermal energy in the solar atmosphere will have a high priority with this facility. However, the EUV-XUV-Soft X-ray observations are directed toward understanding these processes in the tenuous transition region and corona whereas the one-meter telescope observes the photosphere and chromosphere. Simultaneous observations with the two facilities as a portion of the Solar Telescope Cluster was envisioned by the National Academy of Sciences Study on Scientific Uses of the Space Shuttle and represents an ultimate capability for attacking these fundamental problems in solar physics. The EUV/XUV/Soft X-ray facility will also study the large scale organization of the coronal magnetic field as revealed by magnetically confined coronal material in loop prominences, streamers and interconnections between active regions.

The EUV and soft X-ray facility contains three instruments: a normal incidence off-axis telescope in the range from 400Å to 1500Å, a XUV Wolter type telescope for 100Å to 600Å and a nested Wolter Type 1 full figure of revolution telescope for the 2 to 100Å range. The XUV telescope with a spatial resolution of 0.5 arc seconds would have a length of 2.8 meters and an area of 400 cm^2. Focal Plane Instruments would include a spectrometer with a $\Delta\lambda/\lambda \approx 3 \times 10^3$ for obtaining spectroheliograms and a spectrometer with a $\lambda/\Delta\lambda \approx 2 \times 10^4$ for line profiles.

The Hard X-Ray Imaging Facility Definition Team is concerned with the development of instruments to study X-ray, gamma-ray and neutron emissions from the flaring and non-flaring sun, to study the triggering mechanism of flares, to determine the energy content of flares and to observe the release of charged particles during flares. The spectral energy distribution of X-rays and gamma-rays in continuum and line emission is needed as well as the temporal variations and morphology in this spectral region. The hard X-ray imaging facility will consist of four instruments: a full-sun 5-600 keV spectrometer with temporal resolution of 10^{-2} sec; a hard X-ray imaging collimator operating in the 5-100 keV

range with spatial resolutions of 4 arc sec Full Width Half Maximum (FWHM) a nuclear γ-ray spectrometer for the 50-100 MeV range and an X-ray polarimeter for the 5-100 keV range located behind the hard X-ray imaging collimator if possible.

The Quick Reaction and Special Purpose Facility Definition Team is concerned with the use of small instruments for various solar physics problems. Such instruments can be included with the facility instruments or on multi-discipline missions. Several classes of instruments are being studied by this team: Solar Physics (but not facility) instruments, monitoring instruments, multi-disciplinary instruments, solar education experiments and quick reaction operations. The solar physics instruments include gamma-ray and neutron telescopes that will explore the processes of electron and proton acceleration in flares and visible and near UV coronagraphs that will infer coronal densities, the temperature profile of the corona and solar wind, solar wind velocities, the Hydrogen to Helium abundance ratio as a function of position and the structure of the coronal magnetic field. Rocket and balloon class instruments which have traditionally provided great opportunity for innovative measurements are also included in the program. Monitoring instruments for measuring the level of solar emissions and solar education experiments also are included in the scope of this team.

The Facility Definition Teams have begun by specifying the instruments they plan to study and developing the justification for each facility. In the coming year, these teams will define representative focal plane instruments, define concepts of facility operation and user involvement, identify areas requiring research or technical development and assist with technical specifications and reviews for conceptual or definition studies of their instruments.

Although the ultimate scientific objectives of the program require facility level instrumentation, early solar physics flights on Spacelab will probably make use of existing instrumentation that can be modified to upgrade its performance. Such instrumentation can be used to extend the work of Skylab and lay the ground-work for observing programs to be carried out by the facility instruments. Several preliminary scientific missions using current instruments are outlined on the following page, "Typical Early Solar Spacelab Flights." Instruments that might typically be flown in the early missions have been used to assess the capabilities of Spacelab to assure that suitable support systems will be provided. Two possible approaches consist of either reflight of an ATM-like canister of instruments or the use of an individual pointing control for each major instrument. The former approach has been discussed by the Marshall Space Flight Center as the Multiple Telescope Mount while the latter is the approach being taken in studies conducted at the Goddard Space Flight Center.

The technical work of the ASP Solar Physics Office has concentrated on developing flight opportunities for experiments of small or intermediate size. Studies

Typical Early Solar Spacelab Flights

Scientific Objectives: Studies of the morphology and evolution of coronal structures in relation to the underlying photospheric field.

Possible Instruments:

(a) A broad-band X-ray telescope or slitless EUV spectrograph (ATM upgraded), to observe coronal structures having $1 \times 10^6 \leqslant T_e \leqslant 1 \times 10^7$ °K.

(b) A white-light coronagraph (ATM or SMM derivative) to record the large-scale structure of the outer corona.

(c) Hα telescope (ATM derivative) with provision for operation as a flicker magnetograph, to provide concurrent magnetic field information. A measurement of the vector field would be desirable but probably not available for this flight.

Spacelab Resources Required: 1½ pallets

Scientific Objectives: Studies of the physical properties of extended coronal structures to provide boundary conditions for models of the solar wind.

Possible Instruments:

(a) A high sensitivity XUV (100Å–600Å) spectroheliograph to determine n_e and T_e, relative abundances, and perhaps line of sight velocities as a function of position in the corona (SMM derivative).

(b) A white light coronagraph to infer n_e as a function of position (ATM derivative).

(c) EUV (600Å–1500Å) spectroheliograph (ATM derivative) to establish properties of the transition region and chromosphere at the base of coronal structures (alternatively, an UV coronagraph (1000Å–3000Å) if available from the rocket program).

Spacelab Resources Required: 1½–2 pallets

Scientific Objectives: Preliminary studies of energy transport into the chromosphere and lower corona; mass and energy balance in the solar atmosphere.

Possible Instruments:

(a) An XUV facility or upgraded SMM EUV spectroheliograph.

(b) An X-ray spectrometer/spectroheliograph (SMM or rocket derivative).

(c) A meter-class telescope with magnetograph, if available. Otherwise an Hα telescope (ATM derivative?) with provision for operation as a filter magnetograph.

Spacelab Resources Required: 2–3 pallets

of a suitable pointing control, interface requirements between experiments and Spacelab, and the problems of assembling and operating groups of instruments in space, either as mixed-discipline or single discipline missions, have been addressed. Our efforts show that such experiments could be flown and used to bring back many hours of scientific observations. Our technical studies will continue and expand as we approach the time when decisions concerning actual hardware starts will be made. These studies will attempt to examine and present all technical aspects including costs that will figure prominently in the choice of a flight program. Specifically, the studies should provide the basis for selecting the order of priority in building the facility instruments and deciding on the appropriate apportionment of resources between the building of facility instruments and the upgrading and reflight of existing hardware.

UV ASTRONOMY

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 the Shuttle-Spacelab era astronomers will for the first time be able to bring to bear a full array of observatory-class space instrumentation on the outstanding astronomical problems of the day. In a rapidly evolving science one cannot predict what problems will be timely in the 1980's. 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 populations 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 extraterrestrial life.

To begin the exploitation of the Shuttle-Spacelab potential for UV-Optical Stellar Astronomy in the era starting with the Oribter Flight Tests in 1979-80 and continuing with Spacelab missions in the early 1980's, two facilities for the accommodation of scientific instruments are being defined:

1. A general-purpose, one-meter class Spacelab UV-Optical Telescope (SUOT) facility (see page 14) to be mounted on an ESA-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. Many 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. 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 have been identified by astronomers participating in the first Spacelab Astronomy Small Payloads Workshop, held at GSFC on February 13-14, 1975.

The SUOT, requiring two pallets, or a SIPS-mounted array of "small" instruments, requiring one pallet per SIPS, can readily fly in combination with payloads from other disciplines or in conjunction with automated-satellite launches. A pallet-only Spacelab payload, dedicated to UV-Optical-IR astronomy can be assembled with combinations of SUOT and SIPS pallets as shown in Figure 3. (page 25)

The SUOT Facility Definition Team has concentrated on four illustrative areas of research, summarized below, which have outstanding scientific merit, to which the Spacelab facility can make unique contributions and which impact the telescope design. Many other interesting programs have been considered in less detail, but will undoubtedly be strong candidates for SUOT observing programs.

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 arc min field of the LST f/24 camera. These include stellar evolution in globular and open clusters, the history of star formation in nearby galaxies and studies of intergalactic matter in clusters of galaxies. 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 $m_v = 24$ or 25 with a 30 min exposure. With SUOT a definitive study of the properties of a broad variety 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 turn-off in nearby galaxies (e.g., surveys to $M_v = +6$ in the LMC) will be accessible with SUOT. Many globular clusters can be sampled for color

and luminosity data to $M_v = +10$ 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 that LST by a factor ~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/arc sec^2 at reduced angular resolution, and SUOT will realize an important gain over ground-based telescopes, especially in the near infrared, due to the darkness of the night 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 900-1150 Å 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, it can accommodate the large Rowland spectrograph required, and it can fly with high risk detectors developed in a continually evolving technology. 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. Detection of the high 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 ionized hydrogen and helium around stars. 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 black-body cutoff.

The SUOT will be the first space telescope with adequate aperture and adequate calibration control to extend precisely calibrated spectrophotometric measurements to stars faint enough for use as reference standards by LST. This is facilitated 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 red-most capability of photomultipliers. On other flights the same instrumentation on SUOT would provide 10 Å bandpass UV spectrophotometry with one percent precision or better to limiting magnitudes $m_v \gtrsim 16$ for a variety of important objectives.

These include extension of the interstellar extinction law into the far ultraviolet; measurement of spectral energy distributions for X-ray binaries, QSO's, Seyfert galaxy nuclei, faint blue stars, nuclei of planetary nebulae, etc; measurement of bolometric luminosities for individually resolved globular and galactic cluster stars; determination of circumstellar and interstellar extinction properties for complexes of stars within H II regions; measurement of polarization of planets, nebulae and 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 narrowband 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). Specific solar system programs might include mapping of distinct geological provinces on Mercury; observations of the 100 m/s UV clouds on Venus, giving better understanding of zonal and meriodional motions in its atmosphere; studies of the relation between Martian water ice clouds and the large Martian volcanos; establishment of cloud heights and the planet-wide distribution of ammonia in the Jovian and Saturnian upper atmospheres; a search for cloud structure on Uranus, providing the first accurate value of the planet's rotating period; a UV spectroscopic search for biologically important molecules in the atmospheres of Jupiter, Saturn and Titan; high angular resolution IR spectroscopy yielding better localization and quantitative measure of H_2O vapor on Jupiter; direct establishment of the argon abundance in Mars' atmosphere; etc.

To illustrate a typical 96-orbit observing program for the SUOT, based on the FDT science program, it is assumed that the SUOT is carrying a wide field electrograph for use during orbital night, a far-UV spectrograph for use primarily in sunlight and a diffraction-limited planetary camera for short observing sequences each day. In this example, one could return from orbit with data for the following:

- Stellar population studies of M31, M32 and M33 to $M_v = +1$ - 42 exposures.
- Studies of ionization/excitation structure of two supernova remnants (crab, S147) at high angular resolution - 12 exposures.
- A search for faint extensions in one radio galaxy (Fornax A) and in one group of interacting galaxies (Stephan's Quartet) - 8 exposures.

- A search for distance indicators and intergalactic matter in the Perseus and Pegasus clusters of galaxies - 18 exposures.

- Surveys of 3 fields near the south galactic pole for faint blue halo stars, for QSO's and for faint clusters of galaxies - 15 exposures.

- Far UV-spectroscopy of 19 distant OB stars, 6 heavily reddened OB stars associated with dark clouds, 8 sub-dwarf O-type stars, 11 planetary nebula nuclei, 4 binary X-ray sources and 4 planets.

- High angular resolution imaging studies of the bright planets in 6 bandpasses and with four polarizers in one bandpass, once per day for 6 days.

The SUOT facility will fulfill to a great degree the roles of two telescopes envisioned by the Optical and Ultraviolet Astronomy study group at the 1973 Woods Hole Summer study of the NAS Space Science Board--the diffraction limited f/30 one meter telescope and the f/7 one meter deep-sky survey telescope. 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 arc seconds (70% encircled energy) at wavelengths >2000Å. 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 difficulties of flattening the strongly curved field of a system as slow as f/30. To preserve image quality in the 0.2-0.3 arc sec range, the telescope facility will provide internal image motion compensation to 0.02 arc sec (1σ) or better by articulation of the secondary mirror. Error signals in pitch and yaw will be generated by focal plane star trackers, 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 ESA 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. The FDT desires that at least four focal plane devices 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 5 m long SUOT will occupy two 3 m pallet elements when stowed for launch and landing and will thus occupy 40% of the payload volume in a 5 pallet Spacelab flight configuration. 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.

Spacelab Astronomy payloads analogous to current sounding-rocket, balloon, airplane or Explorer satellite class instruments will typically have a minor impact on the overall Spacelab system, a weight $\leqslant$450 kg, dimensions smaller than one pallet element (3 m length) and stabilization requirements in the arc second range. The support facilities for small astronomy payloads will provide a powerful extension of NASA's current sounding-rocket program. By analogy with that program, payloads will be developed with relatively short lead-time to bring the most current technology to bear on timely astronomical problems. 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 to the GSFC Small Payloads Workshop. The participants described currently existing or planned payloads so as to provide a realistic set of subsystems requirements. It was not expected that the scientific programs described would be the same as those of greatest interest in the early 1980's. Nevertheless, a sample of these will illustrate kinds of tasks one might undertake. These include

- very high resolution ($\lambda/\Delta\lambda = 3 \times 10^5$) far-UV spectroscopy ($\lambda < 1150$ Å) of bright stars for interstellar matter research, to measure the temperature of the intercloud medium, to ascertain the physical differences between H I and H II regions, to study rates of formation, destruction and excitation of molecular H_2 and to precisely determine the gas density in the vicinity of the Sun,

- a far-ultraviolet (1050-2000 Å) direct imaging and spectroscopic sky survey to obtain a wealth of data on stars, nebulae, galaxies and quasars,

- narrow-band, infrared photometry to identify compositional classes of zodiacal cloud particles, to define the spectrum of the middle IR cosmic background, to survey the galactic plane for extended regions of non-thermal emission and to obtain the first detailed IR survey of the Virgo cluster of galaxies,

- a coarse angular resolution search for energetic sources of extreme ultraviolet radiation,

- establishment of a precise absolute energy calibration for a network of about 40 hot stars brighter than V = 6 to serve as secondary standards of absolute flux for other orbiting telescopes,

- determination of the temperature and density structure of faint surface brightness objects, such as supernova remnants, planetary nebulae, emission and reflection nebulae and galaxies from their images in the ultraviolet light of high excitation forbidden lines of a number of ions,

- exploratory ultraviolet polarimetry of stars and other galactic sources, the zodiacal cloud and the earth's airglow,

- near-ultraviolet spectroscopy of stars for investigations of stellar chromospheres, the dynamics of extended atmospheres, mass transfer in close binaries including X-ray sources, and stellar chemical abundances.

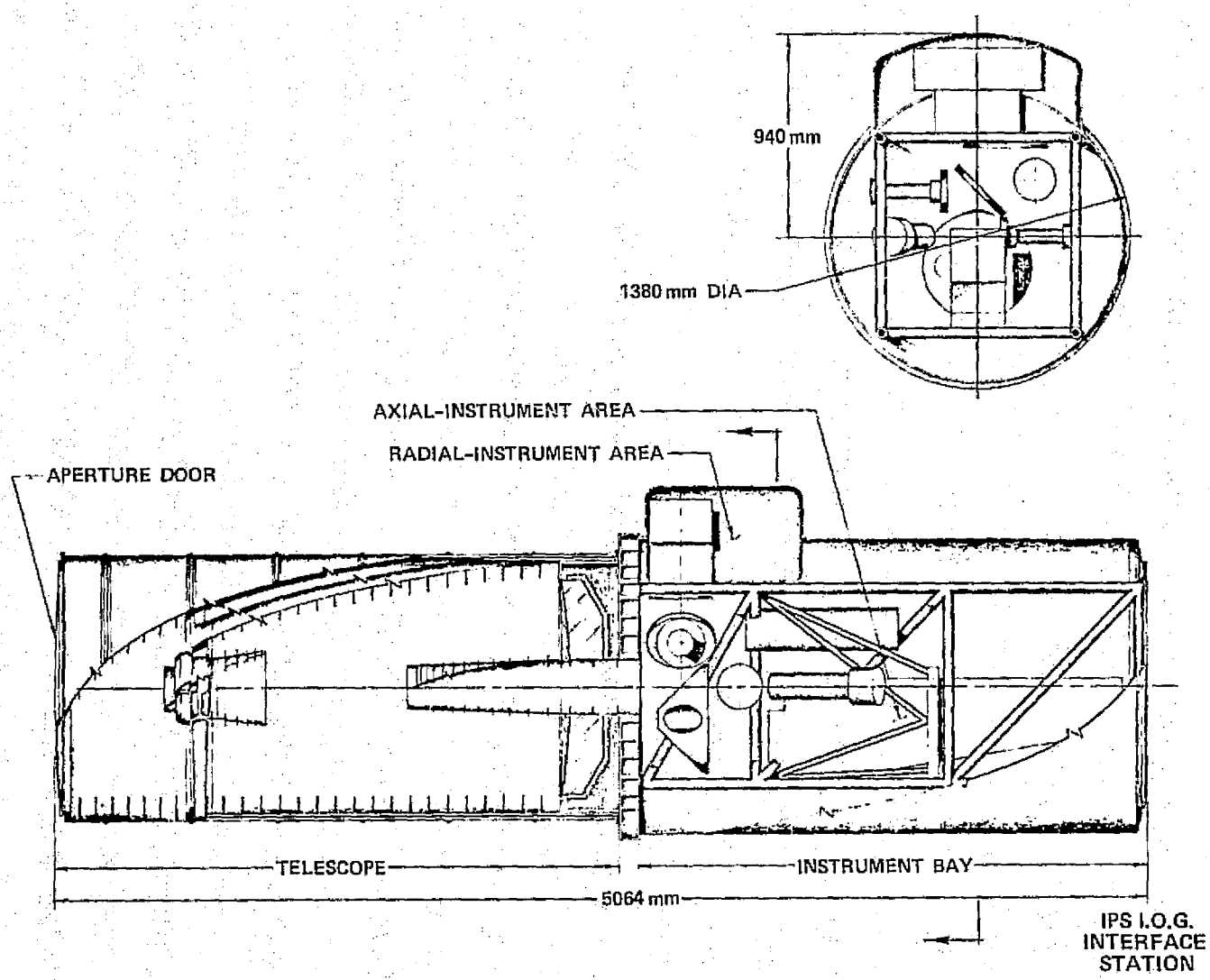

Figure 1. Preliminary Concept for the One-meter Spacelab UV-optical Telescope Facility

HIGH ENERGY ASTROPHYSICS

High energy astrophysics includes the studies of celestial X-rays, gamma rays, and cosmic rays. Observations of these radiations must rely almost exclusively on instrumentation carried into space. The Spacelab promises to extend the results of high energy astronomy into previously unexplored regions and yield a continual wealth of discoveries by allowing the transport of large and complex instruments above the atmosphere for extended viewing periods with frequent flight opportunities.

The scope of high energy astronomy includes nearly all astronomical objects ranging from normal stars (such as the sun and its environment) to stars at the endpoint of stellar evolution (such as white dwarfs, neutron stars, and possibly black holes). It also includes the study of our galaxy, its interstellar medium, other galaxies, clusters of galaxies and the intergalactic media. Outstanding discoveries highlight the remarkable progress in this field, and fundamental new results can be expected. To mention just a few of the results in hand: the observation of X-ray sources, such as Hercules X-1, which can only be explained as compact binary objects, and Cyg X-1, in which the first manifestation of black holes was apparently found; the discovery of X-rays from galaxies and from the intergalactic medium; the emergence of the new field of high energy gamma ray astronomy, which has provided strong direct evidence that cosmic rays are largely galactic and that the Crab and Vela pulsars are emitting photons in excess of 10^8 eV with consequently startling implications for the source particles' energies; and the recognition that the energetic nuclei of the cosmic radiation cover the entire periodic table of the elements and that their abundance distribution testifies to their thermonuclear origin.

Investigations of energetic particles, the oldest of the three disciplines of high energy astronomy, are evolving into a new area. Accurate determinations of the elemental composition, isotopic composition, and energy spectra over a wide range of energies and for all known elements have become possible and will contribute to a clearer picture of the nature of the particle sources and the acceleration mechanisms. The interpretation of these results is closely interwoven with the recent developments in the understanding of explosive nuclear synthesis. All of these studies of the cosmic rays require large instruments of the size and weight which can be accommodated by Spacelab.

Although the rich rewards ultimately to be achieved by gamma-ray astronomy have long been recognized, it is still in its early stages of development. Most importantly, however, it has recently moved across the threshold of "upper limit experiments," and the next major improvements in instrument sensitivity and angular resolution should provide further important information about the

distribution of cosmic rays in our galaxy, galactic structure, time variations of gamma ray sources, and the energetic extragalactic diffuse gamma ray background. As in the case of the cosmic rays, these instruments will be large and heavy. The Spacelab will not only provide the opportunity to obtain significant scientific results because of its capability to fly large instruments, but will, as in the case of cosmic rays, provide the opportunity to test the large, complex gamma ray instruments ultimately to be flown on free flyers.

Discoveries in the past few years have clearly established that X-ray observations are an essential tool in the study of many of the objects of greatest current astrophysical interest such as pulsars, quasars, Seyfert galaxies, clusters of galaxies, and the intergalactic medium. The study of compact X-ray emitting objects in binary systems permits investigations of the properties of stars near the end point of stellar evolution and of the physics of matter at extreme pressures, densities and magnetic fields. In the coming decade, X-ray observations will likely be extended to the corona of main-sequence and giant late-type stars, as well as to peculiar stars such as flare stars. The instruments needed for the next step in several different areas of this fast expanding field are ideally suited to the Spacelab.

Several previous studies have shown that the technology for experiments in the field of high energy astrophysics has developed to the point that instruments could be built in time for the earliest Spacelab missions and some even for the engineering flights. These experiments could produce very significant scientific returns in many areas of all three of the primary disciplines of high energy astrophysics. Further, there is already a very large community of experienced experimenters who are capable of developing the instruments and analyzing the data. The strength of the field has developed through satellite flights including the IMP, OGO, SAS, Pioneer, and HEAO series, as well as an extensive balloon and sounding rocket program.

Unlike some other fields such as optical or radio astronomy, there cannot be a major ground based program of X-ray, gamma ray, and cosmic ray observations because of the overlying blanket of air. As a result, high energy astrophysics relies almost exclusively on instrumentation carried into space. It is, therefore a relatively new and truly space age field; however, a multitude of exciting and scientifically very significant results have been forthcoming and, as expected, have attracted an exceptional group of scientists, who are anxious to pursue this new field vigorously.

The types of instruments to be flown on the shuttle Spacelab missions in high energy astrophysics have been outlined in Scientific Uses of the Space Shuttle, published by the National Academy of Sciences, Woods Hole, 1973 and in more

detail recently in A Program for High Energy Astrophysics, 1977-1988 by the Ad Hoc Planning Group of the High Energy Astrophysics Management Operations Working Group. To make the study at Goddard Space Flight Center as meaningful as possible, it has included "typical" experiments which are basically a subset of those listed in the National Academy of Sciences report. The subset was chosen with the goal of not only having representative experiments from each of the disciplines of X-rays, gamma rays, and cosmic rays, but also experiments which would present the more severe constraints. The typical experiment studied are listed in the table below.

High Energy Astrophysics Typical Experiments

GSFC Number	1973 National Academy Identification	Description
GI.	SX-1	Large Area X-ray with Concentrator
GII.	SX-3	High Energy X-ray Sources
GIII.	SX-7	Bragg Spectrometer
GIV.	SG-8	High Energy Gamma Rays
GV.	SG 5 & 8	Low Energy Gamma Rays and Nuclear Lines
GVI.	SC 1 & 4	Cosmic Ray Ionization Spectrometer
GVII.	SC 1 & 4	Cosmic Ray Transition Radiation Spectrometer
GVIII.	SC-4	Negatron Positron
GIX.	SC-2	Isotope Abundance

These experiments were divided into two high energy astrophysics missions, which were then studied by Goddard Space Flight Center and industry. In considering the problems of incorporating experiments into the Spacelab, the assistance of a wide range of knowledgeable scientists in the university community, as well as in government laboratories has been sought to make the study as meaningful as possible.

Several general concepts related to high energy astrophysics in the Spacelab era have emerged and strongly influenced the direction of the study. First, most if not all of these experiments can each be accommodated on a single pallet element. Second, in almost every case the technology exists and in many cases the experiments would be extensions of instruments which have been flown successfully on balloons or sounding rockets. Third, there is no single facility type instrument which dominates the field; rather there are a large number of generally quite different experiments with different objectives. Fourth, on the basis of past experience in high energy astrophysics, balloon, sounding rocket, and satellite experiments, the principal investigator concept is clearly the most appropriate one to adopt for Spacelab. In this concept, the principal investigator is responsible for the instrument, including its meeting the scientific objectives, quality control, and maintaining the cost within the budget guidelines. In the larger experiments, based on past experience and the present thinking of the high energy astrophysics scientific community, the experiment team would consist of members of several institutions. The scientist from the various universities and/or government laboratories would combine their talents to develop the experiment, but one scientist, the principal investigator would have the primary responsibility.

In studying payloads assembled from several high energy astrophysics experiments, it was found that in general, with the exception of a few experiments, it was relatively easy to interchange instruments with little or no impact on the scientific objectives of the individual experiments. Further, most instruments fit efficiently onto a single pallet segment. The flexibility that is gained from these two features greatly facilitates the integration of high energy astrophysics instruments into missions and the interchange of instruments if one develops difficulty.

A prime concern of the study has been the accomplishment of the scientific objectives of the experiments at a minimum cost, thereby maximizing the available opportunities. A major element of the cost control effort in this program has been to identify components which are common to many experiments and thus could be procured in large quantity from commercial manufacturers. With this in mind, a set of low power, space-qualifiable modular electronics is being developed. Another area of cost control is the careful study of reliability and limited risks, within the necessary constraints imposed by the Spacelab mission.

Other cost savings features which should be fully utilized are the recovery and re-usability, the larger weight capability relative to satellites of the past, and the greater power available to the experiments. The ability to recover and re-fly instruments allows: extending the objectives and observing program of a given instrument, making minor modifications and improvements for future observations rather than having to build an entirely new instrument, and using the same subsystems for many different experiments.

The present stage of experimental development in high energy astrophysics as outlined earlier and the expected high scientific return justify selection of high energy astrophysics experiments for the earliest missions. It is, therefore, desirable to have a selection of high energy astrophysics experiments soon so that procurement of the selected experiments may begin in the spring of 1976. With this schedule, high energy astrophysics experiments can be ready for a dedicated high energy astrophysics mission on the second regular Spacelab mission in 1980, and it will also be prepared to supply experiments for the engineering flights in 1979 and early 1980 and on other early missions where space is available.

The study undertaken at the Goddard Space Flight Center of the incorporation of individual high energy astrophysics experiments into a high energy astrophysics mission, as well as the incorporation of high energy astrophysics experiments into general astronomy and other missions will continue in its present form until the spring of 1976 when it is envisioned that the effort will be rechanneled toward the actual selected experiments. Consultation with University scientists will continue, as will the special institutional studies of some of the typical experiments with the aim of better defining the cost factors and interface problem areas.

Following selection of experiments, the NASA Goddard Space Flight Center will negotiate a contract with each principal investigator. It will be the primary responsibility of the principal investigator to insure that the scientific objectives are achieved within the allotted costs, including the development of the experiment, analysis of data and publication of results. Scientific working groups will be established consisting of all principal investigators and the Associate Spacelab Project Scientist responsible for high energy astrophysics. The teams will be responsible for assuring that the scientific goals of the high energy astrophysics missions and high energy astrophysics experiments on mixed missions are achieved insofar as possible.

MISSION ANALYSIS

Typical dedicated missions in each of the three Astronomy disciplines; High Energy Astrophysics, Solar Physics, and Ultraviolet/Optical Astronomy have been synthesized and analyzed. In addition, several combined astronomy discipline missions were investigated including a mission made up of non-facility class experiments, a mission including a facility class telescope, and a mission delivering a spacecraft. The purpose of the mission investigations was to determine:

1. the extent to which productive astronomy research can be accomplished through the use of the Orbiter/Spacelab system;

2. the constraints placed upon typical astronomy payloads by the Orbiter/Spacelab system; and

3. the tradeoffs between dedicated and combined discipline missions.

Scientific requirements were generated for each of the subsystem and environmental areas for all of the above missions. The compatibility of each of these areas with the Orbiter/Spacelab capabilities and constraints was then investigated. A mission profile was constructed for the optimum orbit to meet the particular scientific objectives with Orbiter crew and Payload Operations Control Center (POCC) activities defined. Each subsystem and pertinent environmental area was then analyzed in detail and results described along with integration, test, and post flight aspects of the missions. Conclusions and recommendations were then discussed.

In High Energy Astrophysics, two dedicated pallet-only Spacelab payloads containing 9 experiments were analyzed. One payload is shown in Figure 1. The payloads in this discipline in general are massive and require individual pallets. Pointing requirements are relatively coarse and most experiments are easily satisfied with the Orbiter Pointing Control available. Those X-ray experiments which do require pointing accuracy in the arc minute range are normally too large and massive to be satisfied with the Small Instrument Pointing System (SIPS). Both High Energy payloads were weight constrained and generally compatible with the other subsystem areas. Most High Energy experiments desire as much observing time as possible during the mission and thus extended missions would also be desirable for this discipline.

The Solar Physics Mission contained two balloon class experiments mounted on one pallet, 8 non-facility class and 2 facility class experiments mounted on four pallets utilizing four SIPS which provide the arc second pointing control required. (See Fig. 2.) In addition, the SIPS canister provides a satisfactory thermal environment. This mission is volume constrained because of the pallet volume

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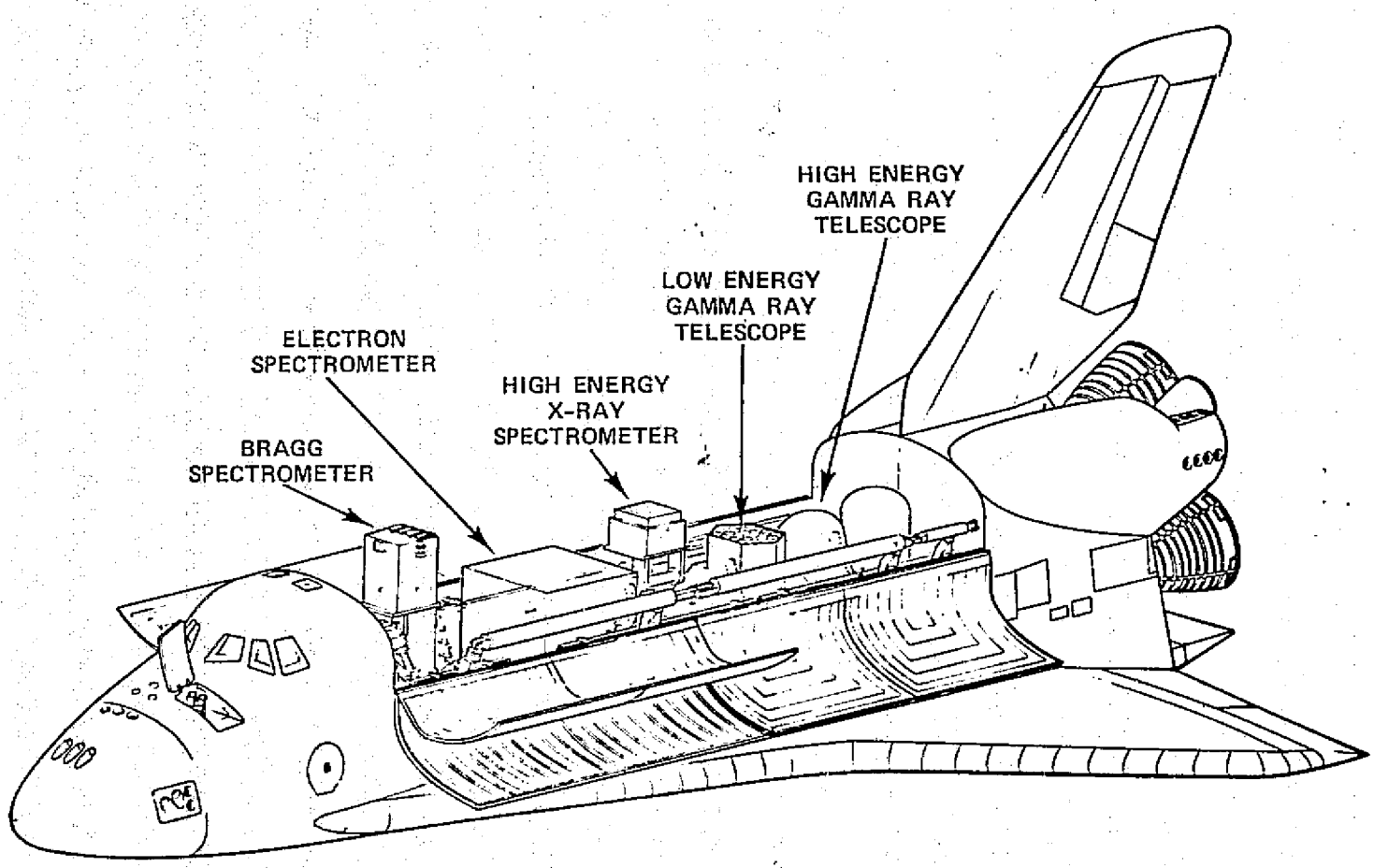


Figure 1. Shuttle High Energy Astrophysics Observatory

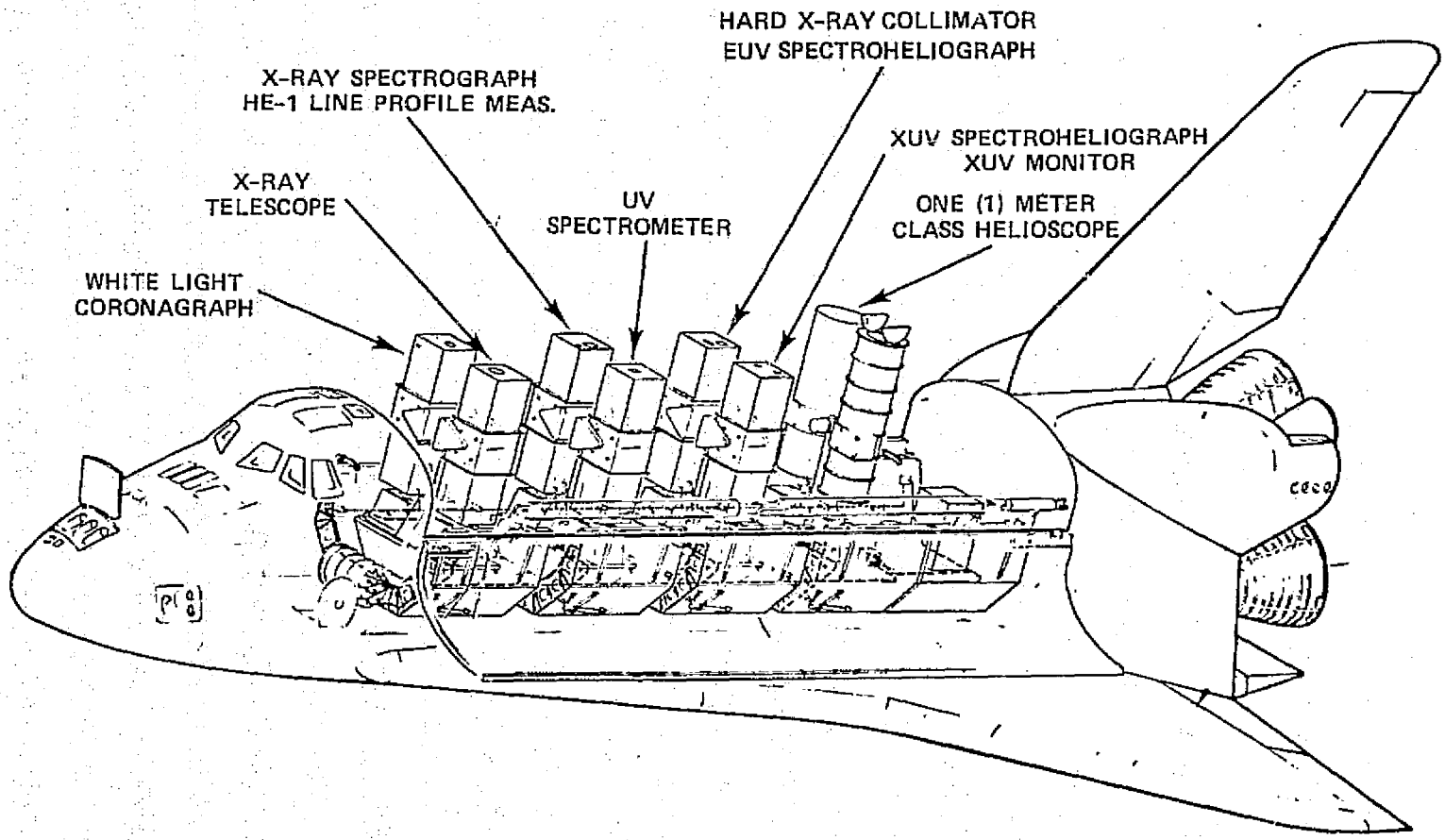


Figure 2. Shuttle Solar Observatory

taken up by the SIPS; however, it should be noted that each SIPS contains two individual pointing systems. This mission has the highest data rate requirement of all the missions studied and the video groundlink requirements can only be satisfied by time sharing or multiplexing.

The UV/Optical mission included the 1 meter facility class telescope (SUOT) on two pallets using the IPS and three additional pallets of research rocket experiments with three SIPS (see Fig. 3) for an overall total of 14 separate experiments. The experiments although able to satisfy the target viewing requirements were restricted in their flexibility by having to share the SIPS canisters and thus the available observation time (stellar targets profiles will in general vary for each instrument). A smaller rocket class pointing system would remove this restriction. The mission was constrained by the longitudinal center-of-gravity envelope (which was just within tolerance) and the contamination environment due to the RCS effluents which could result in column densities detrimental to the experiment optics. Additional shuttle free drift mode investigations which reduce or eliminate the RCS firings could reduce this problem.

The Non-Facility Class Combined Discipline Mission shown in Figure 4 consisted of three pallets containing research rocket and balloon experiments in the High Energy, Solar Physics, and UV/Optical areas respectively in addition to a High Energy experiment too large for a pallet. This mission (7 experiments in all) was in general weight constrained and able to satisfy the stated experiment requirements. A Facility Class Mission contained the 1 meter UV/Optical Telescope (SUOT) and the Solar and High Energy pallets. This payload was volume constrained and although the SUOT was considered prime, the solar viewing objectives and most of the High Energy objectives were also satisfied. The Spacecraft Delivery Mission consisted of the UV Non-Facility pallet along with the Solar Maximum Mission Spacecraft. This mission was also volume constrained and the UV viewing requirements were easily met while delivering a typical spacecraft.

The conclusion which can be made from the various missions investigated is that the dedicated mission approach is the most desirable and scientifically efficient since the orbit, orientation, and mission sequence can be optimized for a particular discipline. However, the three Astronomy disciplines are generally mission compatible. For example, the Solar Physics experiments can observe during the daylight side of the orbit and the UV/Optical during the night side with High Energy Cosmic and Gamma Ray experiments able to collect data over the entire orbit (except during Earth occultation). Therefore, since dedicated missions will not always be available, the maximum use should be made of available payload space in Astronomy Spacelab Missions, Spacecraft Missions, or other science discipline missions in order to obtain the greatest scientific return for the dollar.

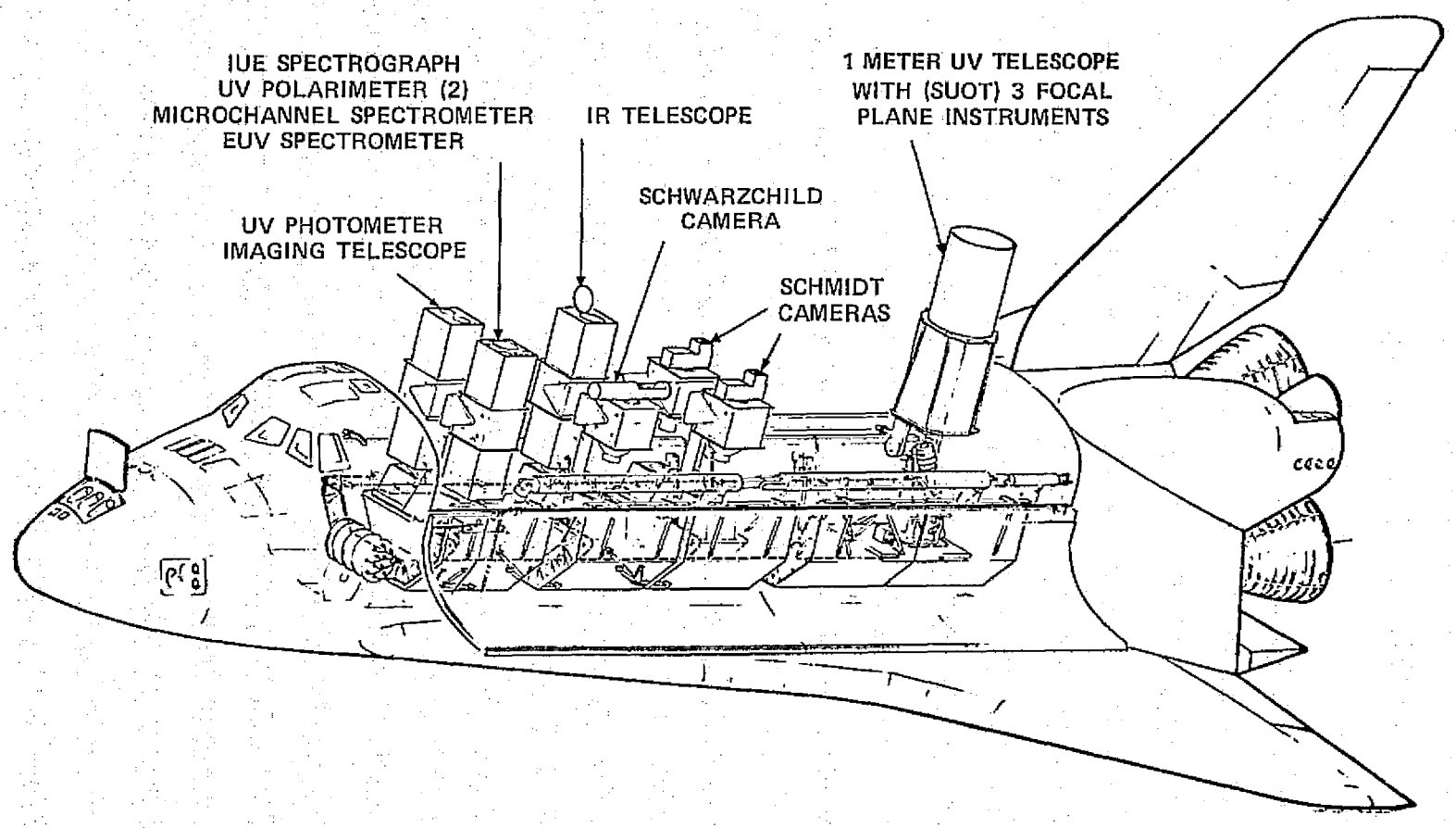


Figure 3. Shuttle Stellar Observatory

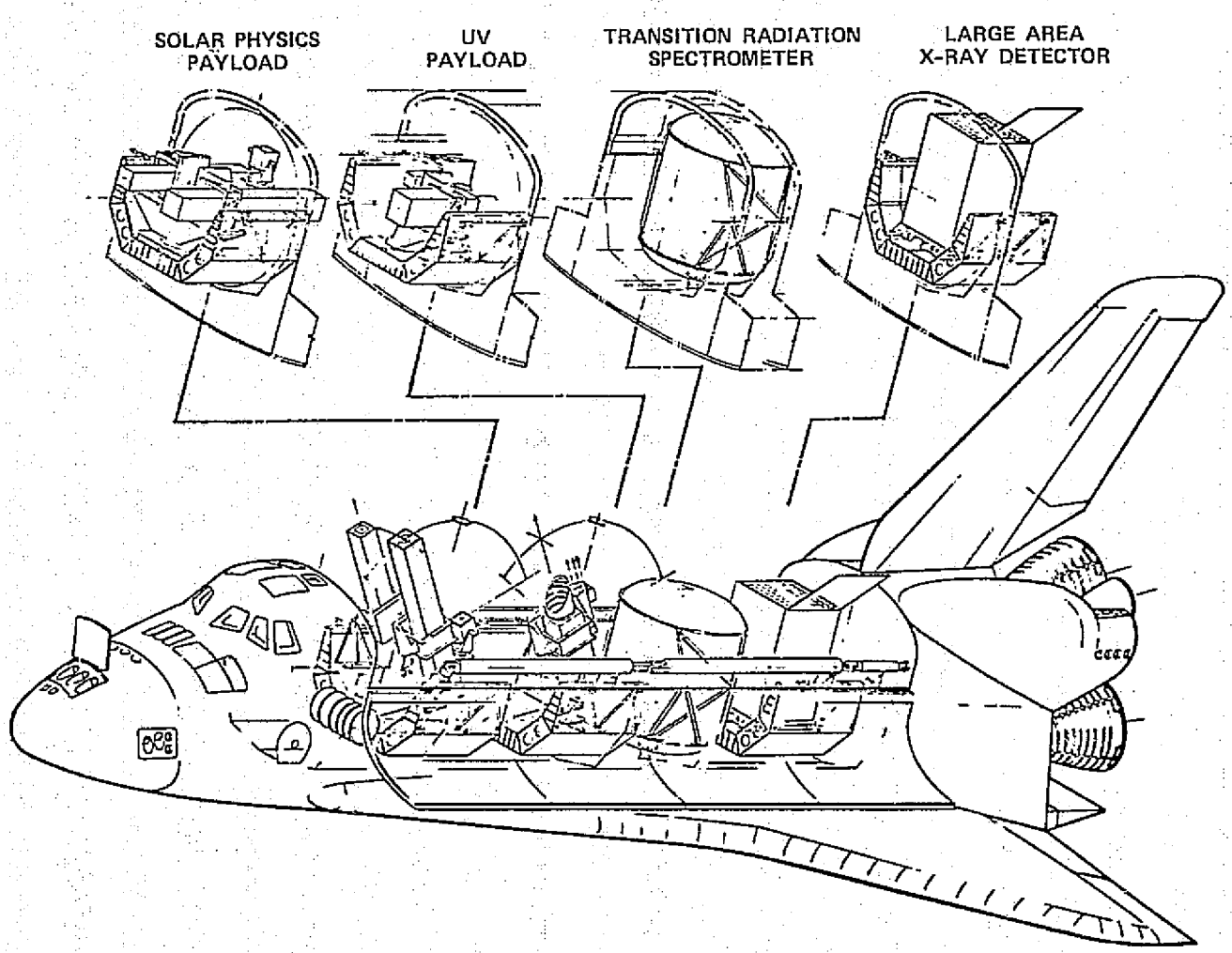


Figure 4. Combined Solar, UV, and High Energy Mission

SCHEDULE CONSIDERATIONS

The Solar Physics schedule will be dictated mainly by available funding and programmatic considerations. Typical time spans for procuring and obtaining a Solar Physics Facility Type Telescope are shown in Figure 1. The time spans are based on a three year development cycle and normal procurement cycles. The delivery date which is the beginning of the fourth quarter of CY 1980 was chosen to support an initial launch in mid CY 1981. Since it is unlikely that there will be funding to initiate procurements on all the Solar Physics Facility Telescopes at the same time, it is important that these facility telescopes be properly prioritized and their procurements be properly phased into the Solar Physics mission plans.

Development of facility telescopes will proceed via broad representation from the scientific community. The selection of facility definition teams in solar physics and stellar astronomy represents NASA's initial steps in the development of such facility telescopes.

A representative time span for procuring a focal plane instrument for a facility telescope is also shown in Figure 1. The instrument delivery was phased to be available at the same time as the facility. The time from Announcement of Flight Opportunity to delivery is four years. Here again the focal plane instruments should be coordinated with the facility procurements. It is planned to procure the initial focal plane instrument for each facility with the facility as a joint procurement. The intent is to minimize future interface problems that could arise. This will probably necessitate a special selection or an AO issuance earlier than shown.

The time spans and milestones for the non-facility instruments from AO to delivery should be the same as for the focal plane instruments. The schedule shown in Figure 1 is for a flight in mid CY 1981. Here again the procurement will probably have to be time phased for budgetary reasons and the issuance of the Announcement of Flight Opportunities should be scheduled accordingly.

A major consideration for the non-facility instruments is the Mission Approach—that is, should the ATM instruments which are selected for Solar Physics missions be used on a Multiple Telescope Mount (MTM) or should they be flown with independent pointing systems? The approach taken will affect the ATM instrument interfaces and subsystem support requirements. It can be seen that this decision should be made during the early part of CY 1976.

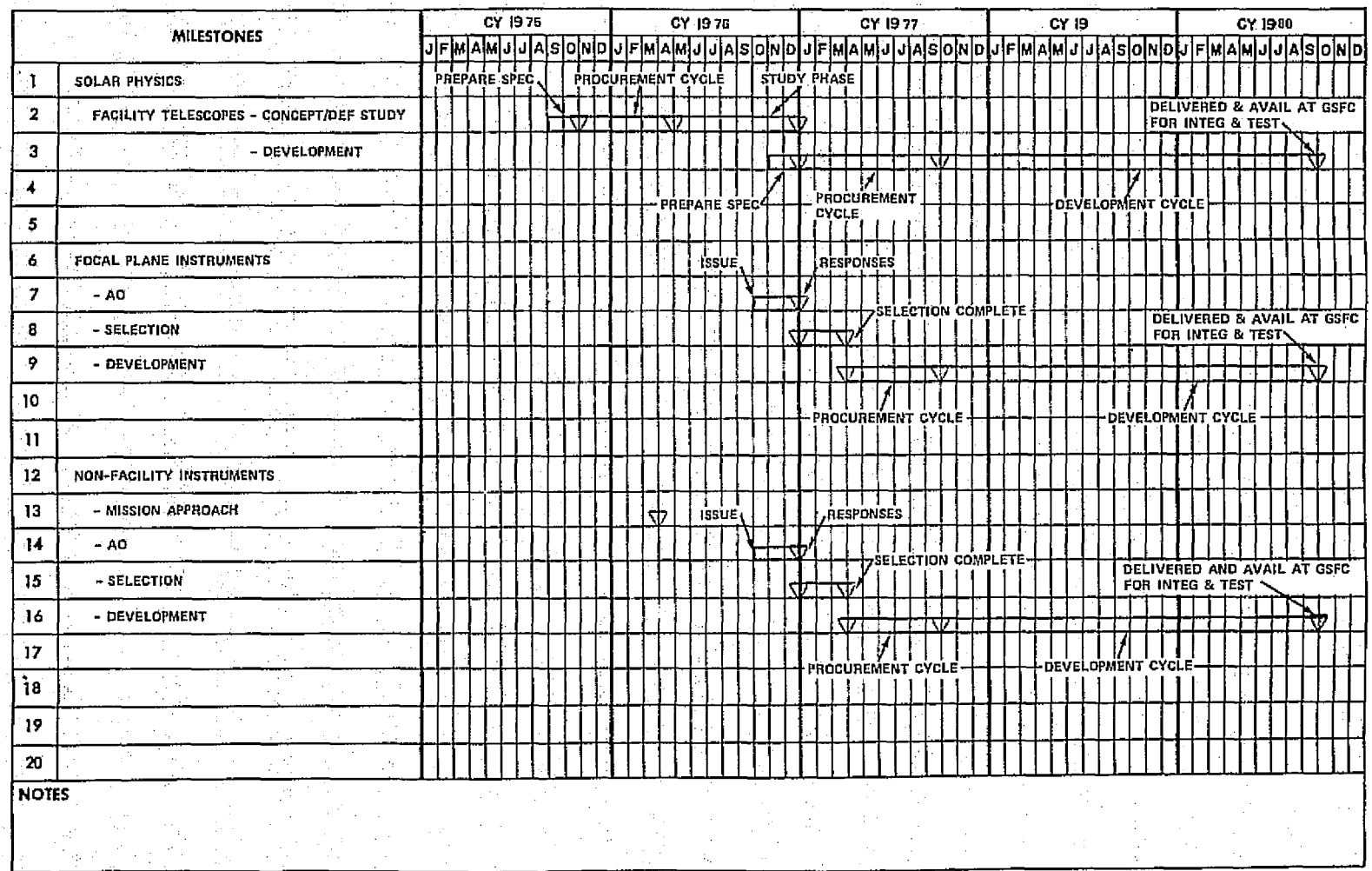
Key schedule dates and time spans for UV Optical Astronomy are shown in Figure 2. The facility telescope (SUOT) schedule is predicated on supporting a launch in mid CY 1981. The procurement of the focal plane instrumentation for the SUOT will be initiated by an Announcement of Flight Opportunity (AO). The AO is envisioned as an open or on-going type which would not require any reissuances. Initially three instruments will be procured for the first SUOT flight. It is intended to have the builders of these instruments work closely with the

SUOT contractor. This close liaison is virtually mandatory if the interface problems are to be kept to a minimum.

The schedule for the non-facility type instruments or Small Astronomy Payloads is also shown. While the time spans shown are similar to the times for obtaining the focal plane instruments, there will be many Small Astronomy Payloads which will be based on modifying existing sounding rocket and balloon payloads. The development cycle in this case will be considerably shorter. These payloads could be available for the Orbital Flight Test Program which is scheduled to fly in 1979-80. Here again the AO would be an open ended type and all solicitations of proposals for instruments (facility or non-facility type) will be closely coordinated—the intent being to make the UV Optical scientific community aware of all ASP flight opportunities prior to any proposal generation activity.

It can be seen that the period available for the mission approach is of the utmost importance. Here the SUOT Definition Study can be influenced and planning for the types of instruments (focal plane and small astronomy) that should be considered for the initial UV flight must be initiated.

The schedule considerations for High Energy Astrophysics are shown in Figure 3. The initial experiment selection dates were selected to provide experiments for an HEA mission in early CY 1980. It is anticipated that the initial experiments will be based on existing hardware. The initial mission will be over subscribed to allow flexibility in the assembly of the final payload in the event of an experiment developing difficulties that would impair the schedule. The selection of subsequent experiments will be on a yearly basis to insure experiments being ready for subsequent missions and will continue on a regular basis.



NOTES

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Figure 1. Milestone Schedule — Solar Physics

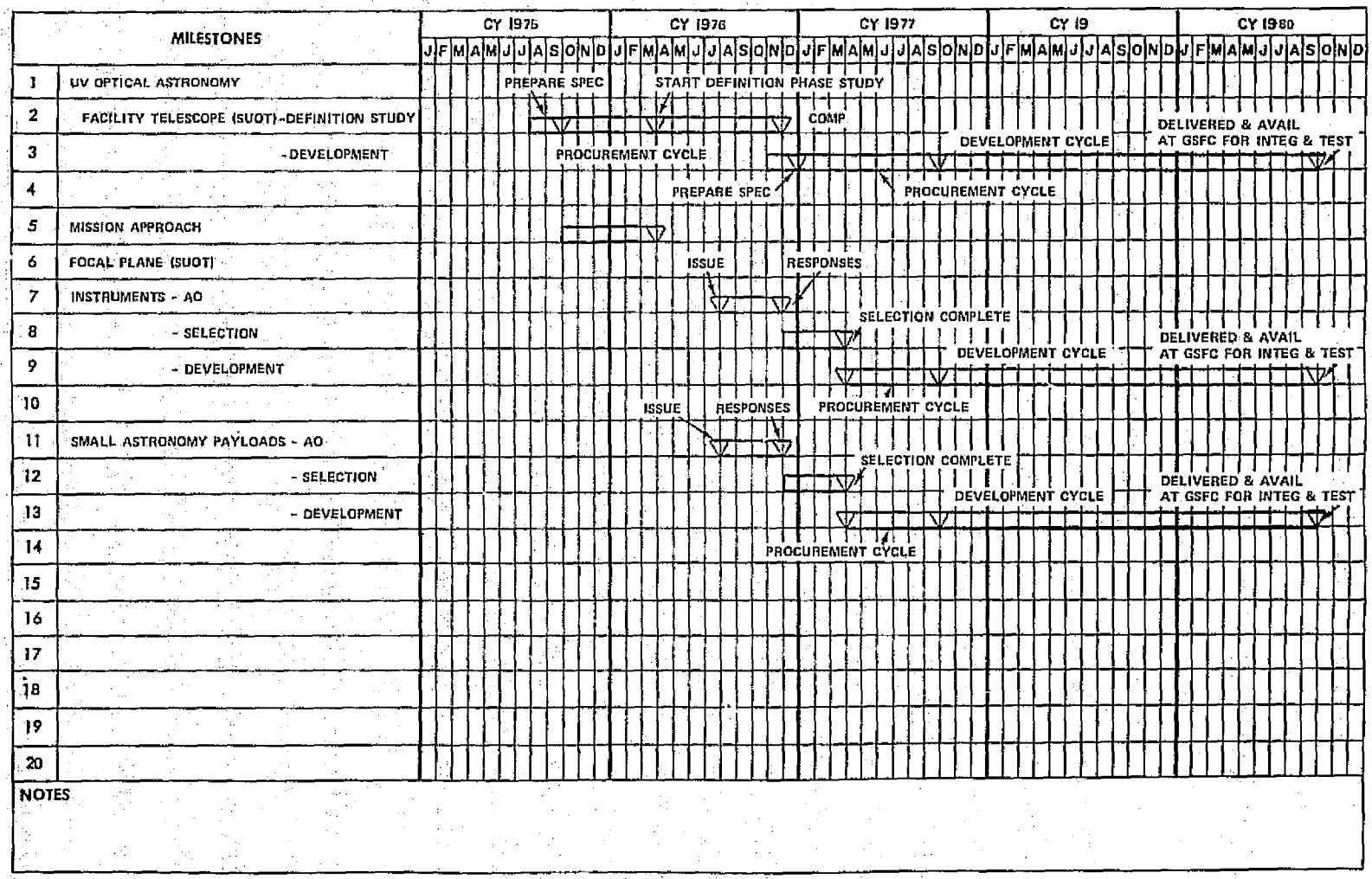

Figure 2. Milestone Schedule — UV — Optical Astronomy

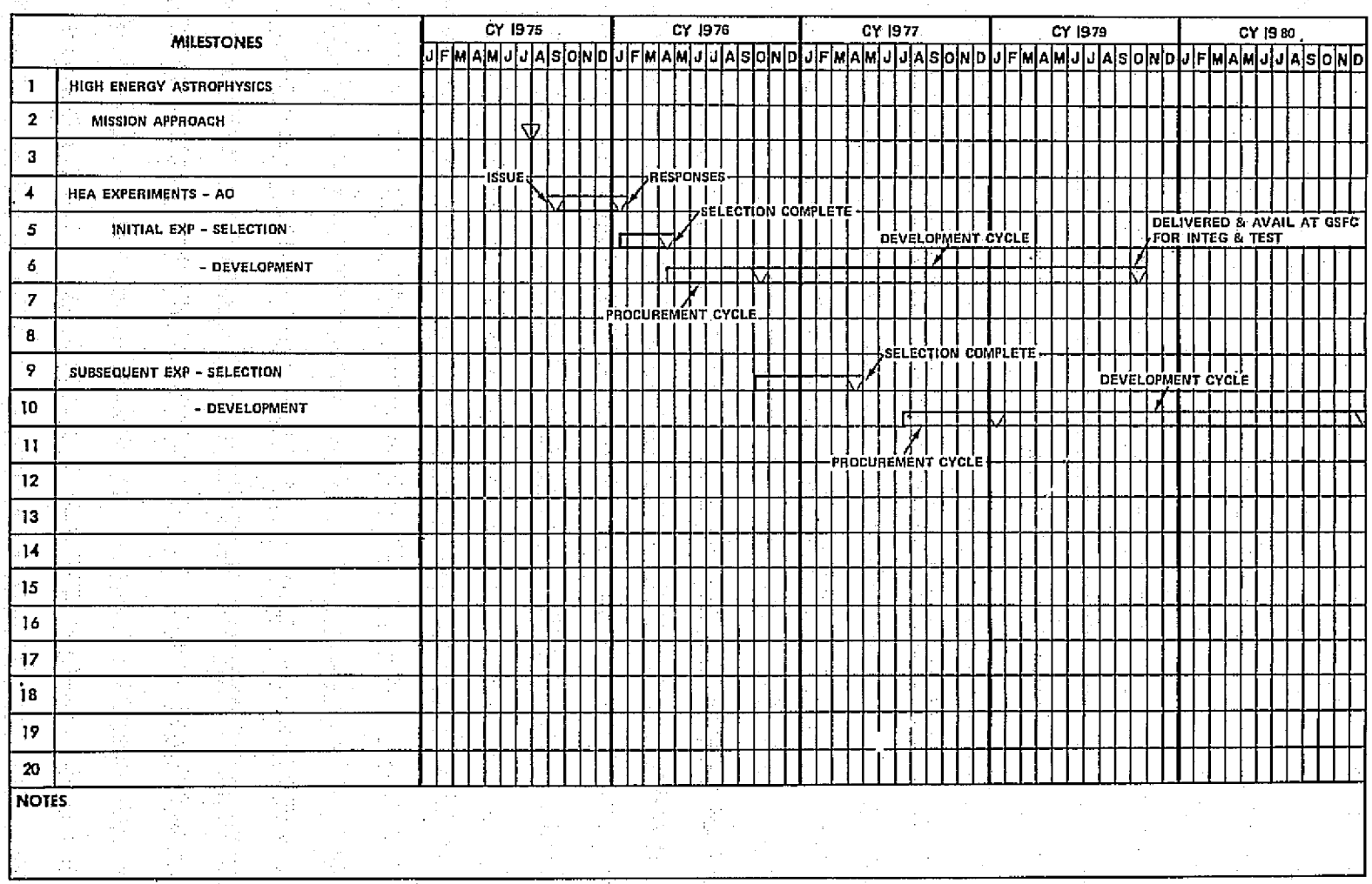

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Figure 3. Milestone Schedule — High Energy Astrophysics

COSTS

There are many different ASP missions for which costs must be generated. For example, there will be an initial set of dedicated missions in each of the three basic scientific disciplines (High Energy Astrophysics, Solar Physics, and UV/ Optical Astronomy). These will be flown with an initial set of experiments and focal plane instruments. In addition, there will be mixed discipline ASP missions. As time progresses, the experiments and instruments will be refined and different payload configurations will be generated. A "building block" approach to costing appears to be most useful, since it is impossible to visualize now all the ASP missions which could be flown in the future. The "building block" approach allows future mission costs to be synthesized from the material presented herein. A "building block," more commonly called a mission element, is a physical system or an item of work for which reasonable cost estimates can be made. It is similar to the element of a work breakdown structure.

The objective of this Cost Analysis Section, therefore, is to present the cost items that will be used for generating the total cost of any conceptual ASP mission, which can be synthesized from the correct mission elements. In addition, the detailed costs available at this time will be given from which this synthesis can be made. As the development proceeds and better data becomes available, this approach allows individual mission element costs to be changed. Subsequent mission cost estimates, thus, will be more reliable.

ASP payloads have been designed to be in harmony with the general Space Shuttle philosophy, which includes utilizing the reflight and payload recovery aspects of the Shuttle to minimize the cost of gathering scientific data. In particular, the cost of ASP payloads will be minimized by:

- utilizing the reflight capability of Shuttle
- using Shuttle as an engineering test bed
- using Shuttle to develop ASP experiments in an evolutionary manner
- refurbishing and reusing payloads

The estimation of reasonably close values for ASP payload costs was difficult to make at this time in the development cycle. Experiments, facilities, and support equipment are not precisely defined and basic changes in instruments and their modes of operation can still be made. Any costs listed, therefore, are fairly gross estimates based on meager design data reinforced by a good deal of judgement and experience with similar equipment. Thus, the available cost estimates in some cases are based on experience with similar astronomy type payloads previously flown on balloons, sounding rockets, and spacecraft.

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Extrapolation of cost data from previous experience has many pitfalls. Chiefly, these involve not recognizing the changed parameters which apply in the Shuttle situation as contrasted to the balloon situation, for example. In most cases, the more obvious of these changes have been recognized, for example, the changed acoustic environment. However, in other equally important areas, the influence of the changed circumstances has not been made clear.

Many estimates are incomplete because the experiment design has not progressed to the point where it is possible to get a reasonably firm estimate for some cost components of the experimental package. In some cases, questionable validity arises either from a P.I.'s general lack of experience with spaceflight or from the lack of experience which stems from his attempt to develop an experiment in a totally new area. Considerable care was taken to account for these effects by suitably adjusting (usually upward) the cost estimate made in such cases.

Closely related to the lack of experience question is the state-of-the-art question. Even the most experienced P.I. can produce cost estimates that are questionable if he is developing an instrument which represents a considerable advance in the state-of-the-art in some key development area. The closer the experiment resembles some previous experiment in a scientific sense, the more valid the cost estimate.

Fortunately, most non facility ASP instruments, in keeping with the general Space Shuttle philosophy, do not represent great technical advances. The telescopes, scintillation counters, spectroscopes, detectors, etc., are mainly derivatives of existing devices. They have parameters, such as sensitivity, which are representative of their class. The principal feature, which distinguishes them is their size, which in most cases is larger than anything previously used in space.

The following science costs are based, in the main, on having a Principal Investigator responsible for the science and hardware for non-facility instruments and facility focal plane instruments. It is recognized that the P.I. will have to be adequately supported in understanding and working with the interfaces. Pointing provisions will be provided by either (a) the orbiter, (b) a Spacelab provided Instrument Pointing System (IPS), or (c) a Small Instrument Pointing System which includes a Thermal Canister (SIPS). In the case of (a) and (b), the requirement is noted where applicable but not costed; the specific method of charging is not known at this time. For case (c), the SIPS, only the costs of a refurbished system is used; it is anticipated the non-recurring development and initial acquisition costs will be funded on an overall project basis. These costs are shown on the following page.

The higher Non-Recurring and Initial Procurement costs are based on satisfying current satellite and spacecraft requirements for documentation, qualification

	Non-Recurring Development (000)*	Initial Procurement Per System (000)	Refurbishment Per System (000)
SIPS & Thermal Canister	5100-2600	2100-1050	200
Sensors	400	200	50
	5500-3000	2300-1250	250

testing, reviews, etc. By judiciously reducing those requirements and accepting the attendant risk, it is believed a reliability consistent with the Sounding Rocket experience can be achieved with the lower cost estimates. Since the refurbishment effort with either approach would remain the same, these costs are considered constant.

In general, a Principal Investigator selected for a flight experiment would be responsible for his experiment throughout the entire program effort, from initial experiment selection through publication of results. He is also responsible for organizing and managing a team of Co-Investigators (Co-I's). The Co-I team would assist the PI in discharging his responsibilities. Due to the large quantities of data that will result from a mission, it is important that PI/Co-I teams be capable of reducing and analyzing these data in a timely manner. Thus, each prospective P.I. would be encouraged to organize an investigation team including Co-I's, technicians, etc. that will be capable of meeting this need. Specifically, the basic responsibilities expected to be assigned to the P.I. are:

a. Define the detailed functional requirements of the experiment equipment.

b. Design, develop, and formulate specifications for the equipment.

c. Participate in the test and calibration of the experiment in accordance with the Spacelab functional and environmental constraints.

d. Provide for adequate theoretical support for the experiment.

e. Develop a detailed data reduction and analysis plan.

f. Design and develop any special data processing equipment required.

g. Conduct an adequate research program to develop any aspect of the data reduction and analysis program not clearly within the existing capability.

*Throughout this report (000) is used to indicate thousands of dollars (FY 75). No attempt has been made to adjust the amounts for inflation.

h. Institute timely processing and analysis of the data to insure general dissemination of results to the larger scientific community.

i. Support mission operations as required for successful conduct of the experiment in orbit.

j. Accept responsibility for flight hardware development.

The foregoing activities were assumed in costing the focal plane instruments, small astronomy payloads, and non-facility science payloads. Where there may be an advantage in doing so NASA may elect to handle the hardware development phase.

In arriving at a total mission cost the following mission elements and their associated costs would be involved.

1. Surcharges for Spacelab provided subsystems, i.e., Pallets, C&DH, Power, IPS, etc.
2. Test & Integration at GSFC
3. Transportation to Launch Site
4. Test Support at Launch Site
5. Shuttle & Orbital Operations Surcharges
6. Demating Support at Landing Site
7. Return Transportation to GSFC
8. ASP Project Support

These costs have been included in the following manner.

The costs for items 1 and 5 are not available at this time. Items 2, 3, 4, 6, 7 and 8 were prorated as an ASP Project Cost. No costs for GSFC Civil Service manpower have been included.

For fiscal planning purposes it is often necessary to project costs over the procurement cycle. A common cumulative expenditure curve that can be used for this purpose is shown in Figure 1. For all major facility and focal plane instruments a three year span was assumed. In the preceding schedule section, key dates for these milestones are projected.

The HEA science costs that have been considered have consisted of non-facility class payloads. Each payload is in the main self contained. Cost summary data is shown in Table 1. By way of assumptions it should be noted:

1. The non-recurring costs reflect the costs to take each payload from its current status and modify it for a spacelab flight. This cost also includes the costs associated with the initial flight.

2. The recurring costs are the costs associated with refurbishing the payload for a subsequent flight; it is assumed some payload modifications would be included.

3. A major support requirement would be in the area of pointing. The assumptions are that pointing will be provided by either the orbiter or a Spacelab provided pointing system and the associated costs have not been included.

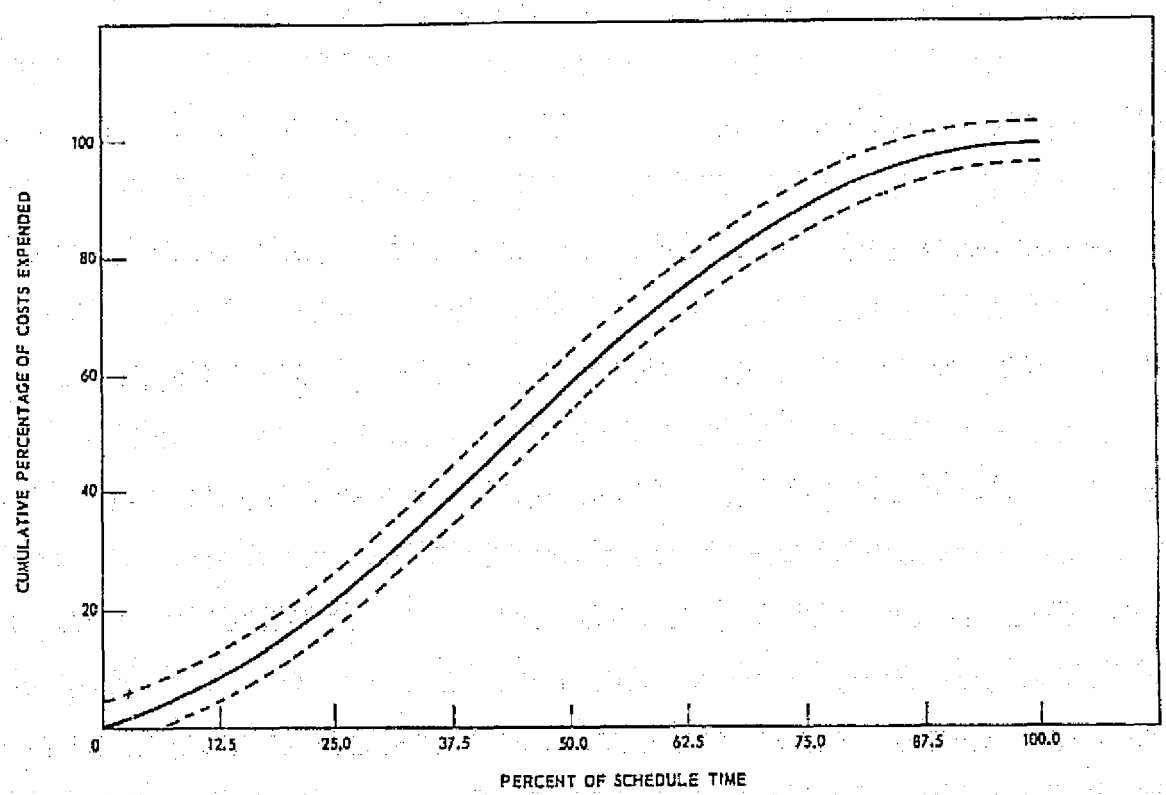

Figure 1. Composite Project Spending Profile (Cumulative Cost Curve) One Sigma Standard Deviation

Reference: "A Quarterly Cost Profile for GSFC Space Satellite Projects," February 1970, GSFC Report X-260-70-46

This cost data is shown in Columns 1, 2 and 3 of Table 1. The Transition Radiation Spectrometer and Ionization Spectrometer Experiment costs are derived from detailed studies of the redesign of existing balloon instruments for Spacelab compatibility. All other figures are primarily first estimates of the instrument cost by the investigator and are not based on detailed studies. The total science costs for the two payloads studied are also shown. A possible funding plan for the High Energy Astrophysics Program is shown in Table 2. This information is taken from the report of the Ad-Hoc Planning Group of the High Energy Astrophysics Management Operations Working Group, July 15-18, 1974; the dates have been shifted by one fiscal year since the schedule could not be met. Limited funding for studies by selected investigators in 1976 have been included. The funding level is to support two HEA Dedicated Missions a year. These missions would be equally divided between new and refurbished experiments. In addition it would enable providing several payloads each year to take advantage of flight opportunities that may occur with other missions.

The UV-Optical Science costs can be divided into two main categories; the costs associated with a facility payload and the costs of small astronomy payloads. For the facility payloads, the non-recurring costs include the design development and initial flight, while the recurring costs include refurbishment. Pointing will be provided by the Spacelab provided IPS. The cost factors are shown in Table 3. Volumetrically the SUOT mounted on the IPS will require two pallets; this would leave up to three additional pallets in configuring a dedicated mission.

One operational mode for the SUOT which would eliminate a large initial funding outlay for focal plane instrumentation would be to conduct a program where initially three focal plane instruments are procured and then new instruments are procured on a regular basis. Table 4 shows the cumulative funding requirements for two flights a year after an initial flight in CY 1981 with a new focal plane instrument being provided annually.

The Small Astronomy Payload costs include the costs of modifying the existing science, where it exists, to the Spacelab interfaces and the costs of providing thermal protection and satisfying the experiment pointing requirements. The later two requirements will be provided by the combination of the thermal canister and a small instrument pointing system. Table 5 contains the costs associated with the science portion only. The costs were developed independently by each experimenter and are intended to show more the range of costs rather than any absolute number. As in the previous cases the non-recurring costs include the cost to provide the experiment for the initial flight and the recurring costs are for a reflight. In many cases there were no estimates available for the reflight. A factor of 25% was then used; this is higher than the estimates which were available and in line with the sounding rocket reflight experience.

Table 1

Estimated Costs for Typical High Energy Astrophysics Missions — ASP Portion

Science Payloads	1 Non Recurring (000)	2 Recurring (000)	3 Pointing By	P/L "A"		P/L "B"	
				Non Rec. (000)	Rec. (000)	Non Rec. (000)	Rec. (000)
Transition Radiation Spectrometer	1,000	270	Orbiter	1,000	270		
Bragg Spectrometer	7,500	400	IPS	7,500	400		
High Energy Gamma Ray	3,500	250	Orbiter	3,500	250		
Low Energy Gamma Ray & Nuclear Lines	5,000	250	Orbiter	5,000	250		
High Energy Sources	5,000	300	IPS	5,000	300		
Large Area X-Ray Array	10,000	400	IPS			10,000	400
Ionization Spectrometer	2,000	250	Orbiter			2,000	250
Negatron-Positron	5,000	250	Orbiter			5,000	250
Isotope Abundance	2,000	250	Orbiter			2,000	250
ASP Costs	41,000	2,620		22,000	1,470	19,000	1,150

Table 2

Estimated Costs For The High Energy Astrophysics Programs 1976 - 1986 in $M

C.Y.	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Cosmic Ray	0.5	2.0	3.0	4.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
X-Ray	1.0	8.0	10.0	12.0	20.0	20.0	20.0	20.0	15.0	15.0	15.0
Gamma Ray	0.5	2.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Science Total	2.0	12.0	16.0	19.0	28.0	28.0	28.0	28.0	23.0	23.0	23.0
ASP Project Costs	1.67	2.92	4.17	7.42	7.62	9.00	6.55	6.13	6.13	6.13	6.13
Total	3.67	14.92	20.17	26.42	35.62	37.00	34.55	34.13	29.13	29.13	29.13

Table 3

SUOT and Focal Plane Instrumentation Cost Factors

	Non-Recurring (000)	Recurring (000)
SUOT	13,000	700
Focal Plane Instrument	2,000	250

After ten flights a refurbishment of the SUOT at a cost of $750K would be required.

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	

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

To cost a typical UV-Optical Dedicated Mission, the mission shown in the Mission Analysis Section of this report was chosen. The mission costs are contained in Table 6. A possible funding plan for the UV-Optical Astronomy Program is shown in Table 7. The funding level is to support two UV-Optical Dedicated Missions a year starting in CY 1982. These missions would be divided between new and refurbished experiments. In addition it would enable providing several payloads each year to take advantage of any other flight opportunities that may occur.

The Solar Physics costs are shown in Tables 8-10. Table 8 shows estimates of costs for facility telescopes and focal plane instruments. Also included is a list of typical non-facility instruments derived from existing ATM hardware. The estimate $3,000,000 non-recurring costs for these instruments includes a basic refurbishment cost of $500,000-$1,000,000, an additional cost of $1,000,000-$2,000,000 to upgrade the scientific capability of each instrument, and approximately $500,000 in experimenter mission support costs. Included in this table are several examples of rocket instruments whose needs are less because of the typically simpler optical designs of such payloads. The mission costs for the Dedicated Mission shown in the foregoing Mission Analysis section is shown in Table 9. A possible funding plan for the Solar Physics Astronomy Program is shown in Table 10. The funding level is to support mixed missions with the types of early solar spacelab payloads shown on page 4 of the Solar Physics Section in the 1980-1981 time period. This includes the Orbital Flight Test Program. The funding also includes two major instruments being available in 1981 and a dedicated mission in 1981. Thereafter, two flight opportunities per year are assumed.

The costs associated with mounting the ATM instruments in the Multiple Telescope Mount (MTM) in lieu of using the SIPS approach have been developed by MSFC and are included in the Solar Physics Volume.

Finally, it should be remembered the estimates given may be incomplete or of questionable accuracy. They are presented as being representative of estimates available at this time. The Astronomy Spacelab Payloads Project will welcome any information which will minimize these faults in the cost data base.

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	700		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
Swarzschild Camera	200	50			
Schmidt Camera (2)	100	10	1	SIPS (1)	250
Pointing Costs	750	750			
Total ASP Mission Costs	23,250	2,739			

Table 7

Estimated Costs For The UV — Optical Astronomy Program — in $M

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
Science Total	0.7	4.0	9.0	12.0	14.0	13.5	15.0	15.0	15.0	16.0	15.0
ASP Project Costs	1.67	2.92	4.17	7.42	7.62	9.00	6.55	6.13	6.13	6.13	6.13
Total	2.37	6.92	13.17	19.42	21.62	22.50	21.55	21.13	21.13	22.13	21.13

Table 8

Estimated Costs for the Solar Physics Science — ASP Portion

Solar Physics Science Costs	Non Recurring (000)	Recurring (000)
One Meter Class Helioscope Facility	15,000	1,500
Birefringent Filter & Camera	3,000	300
Hi Resolution Spectrograph	6,000	600
XUV Telescope Facility	20,000	2,000
Filter/Camera	500	50
Slitless Spectrograph	2,000	200
Spectroheliograph	4,000	400
Line Profile Spectrometer	6,000	600
X-Ray Telescope Facility	20,000	2,000
Filter/Camera	500	50
Objective Grating	500	50
Crystal Spectrometer-Spectroheliograms	2,500	250
Crystal Spectrometer-Line Profiles	2,500	250
Crystal Spectrometer-Spectroheliograms	3,000	300
Crystal Spectrometer-Line Profiles	3,000	300
Polarimeter	1,500	150
EUV Telescope Facility	9,000	900
Spectroheliograph	3,100	310
Line Profile Spectrometer	6,000	600
Magnetometer	6,000	600
Hard X-Ray Imaging System Facility	5,000	500
X-Ray Polarimeter	3,000	300

Table 8 (Continued)

Solar Physics Science Cost	Non Recurring (000)	Recurring (000)
Typical Non-Facility Instruments		
X-Ray Telescope[1]*	3,000	500
X-Ray Spectrometer[1]*	500	50
HE-1 Line Profile[1,2]*	3,000	500
UV Spectrometer[1]*	3,000	500
EUV Spectroheliograph[1]*	3,000	500
XUV Spectroheliograph[1]*	3,000	500
XUV Monitor[1]*	3,000	500
X-Ray Burst Detector[1]*	3,000	500
White Light Coronagraph[1]*	3,000	500
Gamma Ray Spectrometer[1]	500	50
Small Rocket Class Non-Facility Instruments		
High Cost Instruments	500	50
Low Cost Instruments	100	20

[1]Non Recurring Costs are to update existing ATM/OSO-7, Balloon and Rocket Experiments and modify them to Spacelab Interfaces.
[2]If flown to be provided by CNES.
*Costs listed are gross average, not based on detailed plans.

Table 9

Estimated Costs for a Typical Dedicated Solar Physics Mission - ASP Portion

	Non-Recurring (000)	Recurring (000)	Pointing Provided By
One Meter Class Helioscope Facility	15,000	1,500	SIPS (1)
Birefringent Filter & Camera	3,000	300	
Hard X-Ray Imaging System Facility	5,000	500	SIPS (1/4)
X-Ray Polarimeter	3,000	300	
Non-Facility Instruments			
X-Ray Telescope	3,000	500	SIPS (1/2)
X-Ray Spectrometer	500	50	SIPS (1/4)
HE-1 Line Profile	To Be Provided By CNES		SIPS (1/4)
UV Spectrometer	3,000	500	SIPS (1/2)
EUV Spectroheliograph	3,000	500	SIPS (1/4)
XUV Monitor & Spectroheliograph	3,000	500	SIPS (1/2)
X-Ray Burst Detector	3,000	500	IPS or Orbiter
White Light Coronograph	3,000	500	SIPS (1/2)
Gamma Ray Spectrograph	500	50	IPS or Orbiter
Pointing Costs			
4 SIPS @$250K	1,000	1,000	
Total ASP Mission Costs	46,000	6,700	

Table 10

Estimated Costs For The Solar Physics Astronomy Program in $M

	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
Solar Telescope	0.1	0.2	1.2	2.2	4.5	7.5	7.0	2.8	1.5	1.5	1.5
XUV Telescope	0.04	0.7	3.3	7.0	9.5	7.0	5.0	3.0	1.5	0.5	
X-Ray Telescope	0.04	0.3	0.5	0.7	1.2	2.3	6.5	11.0	8.0	4.5	1.0
EUV Telescope	0.02	0.2	0.3	0.3	0.4	1.0	1.1	4.0	8.0	9.0	2.0
Hard X-Ray Imaging Sys.	0.08	0.6	4.0	4.5	1.9	1.0					
Special Purpose Non-Facility Instruments	0.1	2.0	6.0	6.0	6.5	4.5	4.5	4.5	4.5	4.5	4.5
Science Totals	0.38	4.0	15.3	20.7	24.0	23.3	24.1	25.3	23.5	20.0	9.0
ASP Project Costs	1.67	2.92	4.17	7.42	7.62	9.00	6.55	6.13	6.13	6.13	6.13
Total	2.05	6.92	19.47	28.12	31.62	32.30	30.65	31.43	29.63	26.13	15.13

CONCLUSIONS

At this stage of the Astronomy Spacelab Payload Study, several conclusions about astronomical investigations and the effective methods of using the Spacelab for research in astronomy during the early 1980's have been identified. In each of the scientific areas of the study, solar physics, UV and optical astronomy, and high energy astronomy, a substantial and valuable scientific program has been identified based on the experience of our past research in space, from recommendations from available studies and from consultations with scientists in the fields. The direct utilization of instruments operated from balloons, sounding rockets and satellites appears readily feasible and, in many cases, desirable in the pallet mode of the Spacelab missions. Furthermore, the huge volume and weight available with the Space Shuttle affords the opportunity of incorporating large instruments and, in fact, facilities in the Spacelab program. The costs for the design and construction of such instruments for use with Spacelab appear very reasonable; significantly less than instrument costs used in satellite payloads as the development of these instruments in many ways appears to parallel the techniques used with sounding rockets, balloons and aircraft.

The methods of carrying out experiments with Spacelab are of a special nature with many similarities and disparities with the past techniques. Although the Spacelab missions represent full scale satellite-of-the-Earth operations, the missions are relatively shortlived, they may be amended by the crew of specialists on hand, and the return to Earth of the scientific equipment for maintenance and modifications is a guaranteed aspect of this mission mode. In addition, the flight-into-orbit schedule is like the streetcar approach of the old Orbiting Geophysical Observatory, with an expected launching schedule of two space shuttles a month and probably about ten launches a year which may be available for some astronomical research. In effect, in about five years from now, the capacity for carrying instruments into Earth orbit will be increased by more than an order of magnitude and certainly more than the increase in the number of scientists, funds and other resources for carrying out research. It is essential that the methods for utilizing Spacelab match and adjust to such constraints.

The Astronomy Spacelab Payloads Study has, from the engineering and mission analysis investigations, found several requirements to effectively use the Spacelab for astronomy. These requirements include a set of pointing platforms for a variety of instruments, special instrument containers for rapid and easy integration of scientific instruments, some standardization of power, telemetry and operational functions, and modular overall integration into pallets at the integration center for the scientific program. The conclusions so far derived from this study are listed below. They are divided into groups defined by scientific areas and by required subsystems to integrate the scientific instruments and by the cost of such integration and schedule procedures.

Scientific Program

1. Astronomers may have available simple and regular access to extended wave lengths into ultraviolet, superb image quality and a dark sky with a one meter class Spacelab UV Optical Telescope (SUOT). This ultraviolet facility can provide regular opportunities for a great number of astronomers, and with the wide field and regular access to focal plane instruments it would complement the Large Space Telescope. The SUOT should be developed for early Spacelab operation in 1981.

2. A solar telescope of large aperture for diffraction-limited observations extending over near UV and visible wavelengths can be of great value in studies of the heating of the solar chromosphere, for studying mass transport, magnetic field configurations, fine scale phenomena in sunspots and abundance distributions of elements in solar structure. Such a spectroheliograph or One-Meter Telescope Facility should be developed for the 1980-1981 Spacelab program in solar physics.

3. A Solar EUV-XUV Soft X-ray Facility covering the solar spectral region from 2000Å to 2Å and a Hard X-ray Imaging Facility consisting of instruments to study X-ray, gamma ray and neutron emissions from the flaring and nonflaring sun, should be constructed for the early 1980 period of Spacelab operations. These facilities will be used for observations and studies of processes in the tenuous transition region and the corona, and studies of the physics of flares.

4. The field of high energy astrophysics encompassing X-ray, gamma ray and cosmic ray astronomy includes an outstanding group of scientists with the developed technologies, instrumentations and experiments that can fully utilize the expanded capability of the early Spacelab modes. One of the first Spacelab missions should be devoted to high energy astrophysics and regular opportunities for about two dedicated missions a year should be planned.

5. A wide variety of experiments derived from experiments using sounding rockets, balloons and satellites have been identified in each of the astronomy disciplines. Considerable flexibility exists in combining experiments and integrating instruments on pallets and segments of pallets and these experiments are compatible with many Spacelab missions. An organized instrument preparation, integration and scheduling system for effectively and fully using each Spacelab mission would give scientists a powerful, productive and continuing means for carrying out research in astronomy and astrophysics.

Experiment Integration and Mission Management Operations

1. Three classes of pointing systems have been identified to fulfill the scientific requirements for astronomical observation with Spacelab.

(1) For facilities and large high energy instruments, the Instrument Pointing System (IPS) using an inside-outside gimbal, is under development by the European Space Agency. A pointing accuracy and stability in the one arc second range with limited roll is required for solar and astronomical observations. For several of the X-ray experiments more modest, near one arc minute pointing, and instrument capacities of close to three tons are needed. Based on the preliminary projected scheduling of this pointing system for astronomy and applications, a total of three (3) IPS's are required.

(2) For pointing instruments of moderate weight a double-mount Small Instrument Pointing System (SIPS) has been under study. The SIPS can accommodate the moderate weight ATM class of solar instruments and the great majority of solar and astronomical instruments with a pointing accuracy and stability approaching the one to two arc second range. Four SIPS units are required for astronomy.

(3) A low-cost, one arc minute accuracy and 10 arc second stability system is needed for the many rocket-class instruments. This system may readily be developed in-house by personnel of the Sounding Rocket Division of GSFC. Six of these units are needed.

2. Instrument canisters are required for thermal control and ease of integration of the wide variety of instruments considered for Spacelab astronomy flights. Canister configurations for compatibility with the SIPS and various instrument and mounting requirements can be developed. Contamination control is available with the instrument canister. The flexibility of the instrument canister is substantial, as it not only is used to control the environment of the instrument, but it also may afford a means of remote integration and becomes a shipping container for the instrument on Earth and in space.

3. Astronomical research with Spacelab involves mission planning and scheduling, instrument integration and mission operations, and requires Payload Operations Control Center (POCC) at the GSFC. The experimenters would use the POCC during the installation and check out of instruments on pallets and later during the operation of the instruments in orbit. The POCC would incorporate in-flight experiment operations, Spacelab communications, and data reduction operations. Investigator Stations would be incorporated into POCC for the operation and control of individual and sets of experiments during the mission.

4. For Spacelab mission planning, the assignment of prime mission goals to a particular astronomical discipline, a "dedicated mission", is scientifically and operationally efficient because the orbit, orientation, and mission sequences may be optimized. Solar physics, UV/optical astronomy and High Energy Astrophysics are generally mission compatible and combinations of experiments in these fields also would be scientifically productive. The interrelationships among mission parameters are complex and necessitate iterative and continuing mission analyses studies and operations.

The Astronomy Spacelab Payload Study has identified the mode for astronomical research using scientific facilities and instruments evolved through research using sounding rockets, balloons, aircraft, and satellites and the large instruments and instrument evolution making use of the Space Shuttle capacity and instrument return capability. The use of the pressurized module, the interface with free-flyers and space stations, and the general effects of working with the Spacelab mode requires further study. Of special concern is the ordering of the developments of facilities, the focal plain instruments and the support for experiments for the early missions.

Although the actual selection of experiments will be made from proposals submitted according to the NASA Announcements of Opportunity, early guidance in the relative value and comparison factors for the scientific and technological program is required. This is the initial year for Astronomy Spacelab Payload Study -- in the next year the start and the ordering of the facilities will be made, the critical engineering subsystems for pointing, environment, power and data handling will be under development and the evaluation of experiment proposals and the selection of early experiments will be initiated.

The newly evolving capabilities of the Space Shuttle will not only permit a new approach to scientific investigations; but can influence lowering the costs of scientific instruments and their supporting subsystems. The availability of the shuttle as an Engineering test bed, the substantial payload carrying capacity, the presence of man in the operation and the capability to return the instruments should permit the development of ASP payloads in an evolutionary manner and enable the scientist and engineer to take risks. Cost savings should be expected. In addition the capability to refurbish and fly payloads should further increase the cost effectiveness of the ASP payloads. To take full advantage of this new potential cost consciousness and constantly look for the "cost drivers" will continue to be a prime concern.

APPENDIX

MEMBERSHIP OF FACILITY DEFINITION TEAMS FOR SOLAR PHYSICS SPACELAB PAYLOADS

I. One-Meter Solar Telescope Definition Team

R. Dunn (Leader)	- Sacramento Peak Observatory
R. Fisher	- Sacramento Peak Observatory
J. Harvey (prime)	- Kitt Peak National Observatory
W. Livingston (backup)	- Kitt Peak National Observatory
P. Lemaire	- L.P.S.P. du C.N.R.S.
R. Milkey	- Kitt Peak National Observatory
R. Smithson	- Lockheed Palo Alto Research Labs.

II. EUV-XUV-Soft X-Ray Telescopes Definition Team

G. Withbroe (Leader)	- Harvard College Observatory
A. B. C. Walker (Deputy Team Leader)	- Stanford University
W. Behring	- Goddard Space Flight Center
G. Brueckner	- Naval Research Laboratory
A. Gabriel	- Appleton Laboratory (England)
A. Krieger	- American Science and Engineering
W. Neupert	- Goddard Space Flight Center
J. G. Timothy	- Harvard College Observatory

III. Hard X-Ray Imaging System Definition Team

L. Peterson (Leader)	- U. of California/San Diego
H. Hudson (Alternate)	- U. of California/San Diego
G. Garmire	- California Inst. of Technology
R. Lin	- U. of California/Berkeley
Z. Svestka	- American Science & Engineering
H. van Beek	- Space Research Lab. (Utrecht)

IV. Quick Reaction and Special Purpose Facility Definition Team

L. Acton (Leader)	- Lockheed Palo Alto Research Labs.
J. Beckers	- Sacramento Peak Observatory
R. Blake	- Los Alamos Scientific Labs.

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