A PROGRAM PLAN FOR EARTH ORBITAL SPACE ASTRONOMY

by

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ABSTRACT

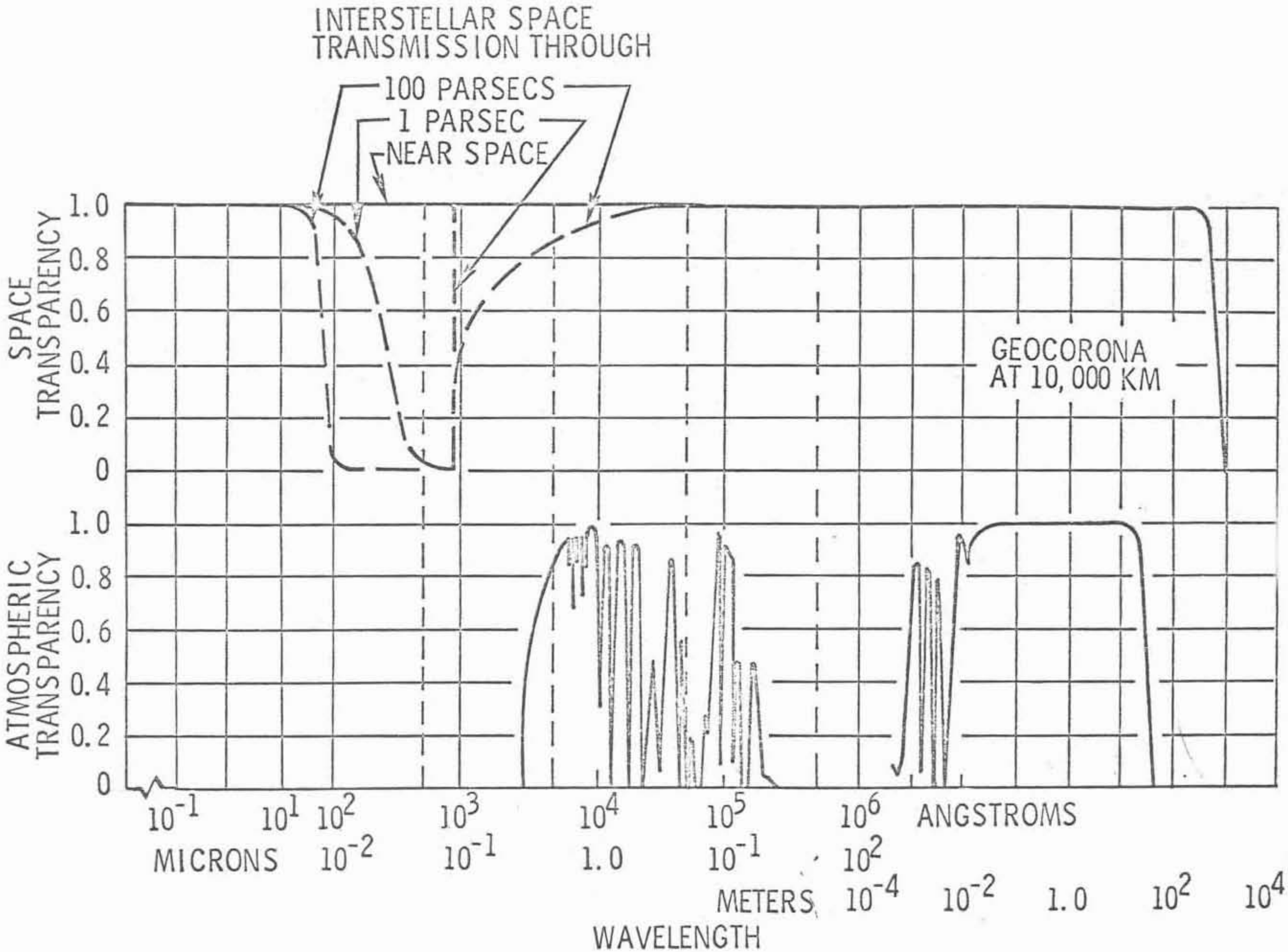
Manned space flight offers the opportunity to couple the astronaut/scientist's ability to select and process data and to calibrate, modify and repair instruments with the vantage point for astronomical observations provided by a platform located above the Earth's atmosphere.

This paper briefly examines the role which manned space flight may play in the 1970-1990 time period in meeting astronomy research needs. The instruments and facilities which appear feasible for that period are described.

INTRODUCTION

The unparalled research opportunities offered by our current capability to launch large payloads into Earth orbit are perhaps nowhere more evident than in astronomy and astrophysics. The terrestrial atmosphere, while essential for life as we know it, is a major hindrance to astronomical observations from the surface of the Earth.

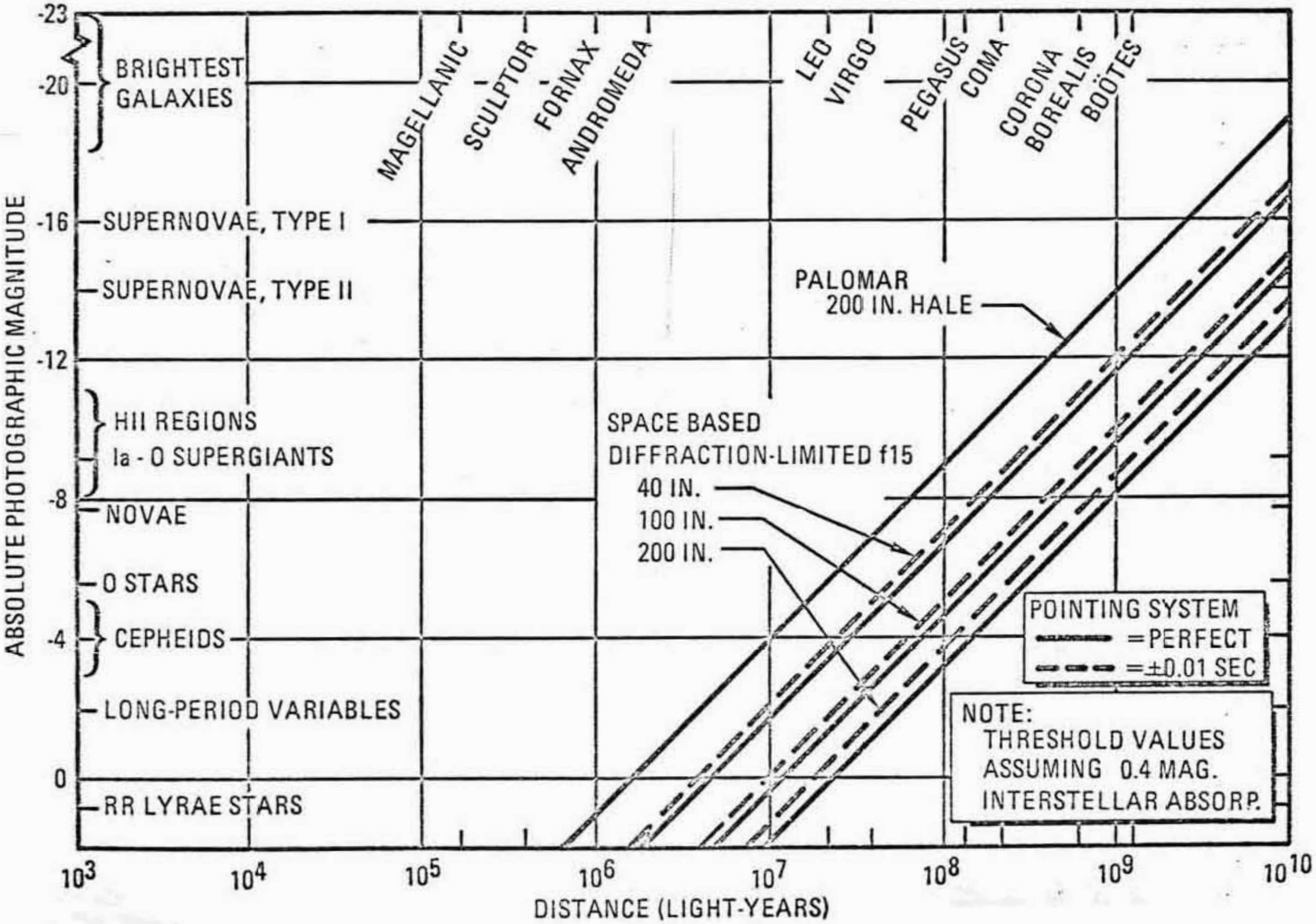
A summary of the transmission properties of the Earth's atmosphere and isonosphere is shown in Figure 1. The atmosphere is totally opaque to radiation of wavelengths shorter than about 2900Å, i.e., the UV, X-ray, and gamma ray bands of the electromagnetic spectrum. This radiation is absorbed by ozone, oxygen, and nitrogen in the atmosphere. As a consequence, astronomical sources which emit strongly in these bands cannot be observed from the ground to full advantage (as in the case of hot, early-type stars), and in some cases cannot be observed at all (e.g., some X-ray sources). In the IR wavelength region (0.7 to 100μ) and in the submillimeter and millimeter region (100μ to about 10 mm), water vapor and carbon dioxide absorb in broad bands leaving scattered wavelength windows of varying transparency. In this large region lies the emission maximum of all stars with effective atmospheric temperatures below 5,000°K, including the interesting pre-main-sequence objects, plus interstellar clouds and sources of synchrotron emission (e.g., quasi stellar objects). The Earth's ionosphere attenuates radio waves longer than 30 m (frequencies less than 10 MHz). The solar corona and the trapped particle belt surrounding Jupiter are known to emit in the VLF radio band.


INTERSTELLAR SPACE
TRANSMISSION THROUGH
100 PARSECS
1 PARSEC
NEAR SPACE
SPACE TRANSPARENCY
ATMOSPHERIC TRANSPARENCY
1.0
0.8
0.6
0.4
0.2
0
GEOCORONA AT 10, 000 KM
10^-1
10^1
10^2
10^3
10^4
10^5
10^6
ANGSTROMS
MICRONS
10^-2
10^-1
1.0
10^-1
10^2
METERS
10^-4
10^-2
1.0
10^2
10^4
WAVELENGTH

In addition to the inherent attenuation of the atmosphere, variable conditions such as cloud cover can block all radiation except the middle radio wavelength band. Poor weather has traditionally driven astronomers to mountaintop locations in the arid regions of the world. Even then, the clear sky varies in opacity and the microfluctuations of the refractive index of air cause scintillation and distortion. Under the best of viewing conditions, the Earth's atmosphere diffusely scatters light from the sun, stars, and artificial sources. It also contains two sources of line emission, the air glow and the aurora. As a result the sky is not black, even on the darkest, moonless nights, and contamination of astronomical spectra occurs.

A final point to be considered is that even in the spectral windows through which "seeing" from Earth is practical, removal of the neutral filtering effect of the atmosphere through use of a platform in space would permit an increase in distance penetration of more than an order of magnitude, i.e., from about 400 m-parsecs or 10^9 light years (the distance to Boötes cluster), to 5,000 m-parsecs (see Figure 2), i.e., greater than 10^{10} light-years. This distance is beyond the limits of the universe as predicted by most cosmologists!

To date, with the exception of high-altitude aircraft and balloon flights, the potential of space has been restricted to unmanned probes and satellites. Sounding rockets have carried radiation detectors to the outermost fringes of the atmosphere with spectacular results even though the observing times are limited to several minutes. Currently, the Orbiting Solar Observatory spacecraft (OSO series) and the Radio Astronomy Explorer (RAE-A) are recording solar phenomena and surveying radio frequencies respectively.



BRIGHTEST GALAXIES
SUPERNOVAE, TYPE I
SUPERNOVAE, TYPE II
HII REGIONS
Ia - O SUPERGIANTS
NOVAE
O STARS
CEPHEIDS
LONG-PERIOD VARIABLES
RR LYRAE STARS
MAGELLANIC
SCULPTOR
FORNAX
ANDROMEDA
LEO
VIRGO
PEGASUS
COMA
CORONA BOREALIS
BOÖTES
PALOMAR 200 IN. HALE
SPACE BASED DIFFRACTION-LIMITED f15
40 IN.
100 IN.
200 IN.
POINTING SYSTEM
=PERFECT
=±0.01 SEC
NOTE:
THRESHOLD VALUES ASSUMING 0.4 MAG. INTERSTELLAR ABSORP.
ABSOLUTE PHOTOGRAPHIC MAGNITUDE
-23
-20
-16
-12
-8
-4
0
DISTANCE (LIGHT-YEARS)
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10

In view of the scientific richness of these programs, it can be anticipated that design and development efforts for unmanned satellites such as the OSO, Orbiting Astronomical Observatory (OAO) and the "Explorer" series will continue in the near term.

With the advent of manned spaceflight, however, the astronaut/scientists' ability to select and process data and to calibrate, modify, and repair instruments can be coupled with the vantage point for astronomical observations above the Earth's atmosphere, to yield an unprecedented opportunity for advanced research and observation.

In spite of its vast potential, manned space astronomy will involve relatively large capital investments and generally be limited to orbits where "standard" recovery and communication facilities can be utilized. Because of this, unmanned satellites may continue to offer attractive advantages for certain classes of observations which require simple, reliable instruments and for observations requiring unique orbital characteristics.

Thus, while the opportunities for important astronomical research from a platform in Earth orbit are clear, significant planning questions arise. For example, what is the role of manned space vehicles in space astronomy? Granted that unmanned probes have demonstrated the value of observation from space, to what degree can the advent of manned operations in space be capitalized upon to further the aims of space astronomy? Considering the real-life constraints of limited fiscal and intellectual resources, is there an orderly plan which can be suggested for the accomplishment of a meaningful and significant research program? The purpose of this paper is to examine the role which manned space flight may play in fulfilling the most critical research objectives of the astronomy community.

THE ELEMENTS OF A PROGRAM PLAN--FUTURE MANNED FACILITIES

In developing a Program Plan for Earth Orbital Astronomy, the authors have drawn heavily upon the recently completed Orbital Astronomy Support Facility Study (OASF) conducted by the McDonnell Douglas Astronautics Company – Western Division for the Marshall Space Flight Center of NASA.* The specific purpose of that study was (1) to identify and analyze elements of a long-range evolutionary plan for the 1974 to 1990 time period that would fulfill the needs of the scientific community to as large an extent as possible, with flexibility for change as new data about the universe stimulate new objectives; and (2) to assess the requirements which such a long-range space astronomy program would place on manned orbital facilities.

In developing the approach to this plan, the study team was faced with several significant challenges. First, it was important to recognize that long-range programs of national scope require considerable time for the development of necessary systems and equipment. Long-range planning is therefore desirable because it offers the promise that necessary long-term fiscal commitments can be made and that the systems and equipment required will be available by the time they are scheduled for use. Yet, the team recognized that in scientific disciplines, unexpected rather than planned events often contribute most significantly to scientific insight, and such unexpected discoveries could well influence subsequent planning.

Furthermore, while rigid research plans may facilitate the design of the space instruments, they may stifle innovative research. Recognizing these

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*Contract NAS8-21023.

aspects, the study team sought to develop an approach that would provide concepts structured well enough for initial planning and for the derivation of instrument and space station designs but flexible enough to permit change and individual contributions and participation.

To accomplish the systematic definition of astronomy program requirements, the OASF Study was organized into three major tasks. Task A was the development of a comprehensive baseline research program and the establishment of space-dependent measurements and mission requirements. Task B was the identification of astronomical instruments, the conceptual design of new instruments, if needed, and the preparation of development plans for time-phased instrument groups. Task C was the definition of orbital facility concepts, the specification of the scientific instrument groupings for each concept, and the definition of the operational interface between ground and flight facilities. Critical supporting research and technology development items to support the evolutionary program plan were also identified.

The OASF baseline research program was prepared by a team of specialists using general and specific recommendations from members of the scientific community. The scientific consultants provided the major source of information for the formulation of research requirements. Their recommendations and advice were used to derive specific research objectives and to determine quantitative requirements for observations and measurements. At several points in the period of information generation, progress was reviewed with cognizant NASA agencies and the scientific contributors. At all times, a diligent attempt was made to produce a research program scientifically valid for the 1974 to 1990 period on the basis of the present understanding of the universe and the anticipated research needs.

At the start of the work, astronomical objectives were defined in terms of research steps or questions, rather than in terms of physical objects. With fundamental research as the starting point, various subobjectives were established, together with their attendant observation or measurement requirements. These requirements were summarized and documented on 91 Observation Requirement Data Sheets (ORDS). Approximately 50 parameters were tabulated on each of the 91 forms. Of these parameters, those considered to be basic in establishing observation requirements were Epoch Span; Wavelength; Radiation Flux; Number and Frequency of Observations; Angular Field of View; Angular Resolution; and Accuracy of Data Required. Other entries were mission-oriented or represented initial estimates of data and of instrument characteristics. These estimates were iterated and augmented during the study to achieve a more refined set of observation parameters.

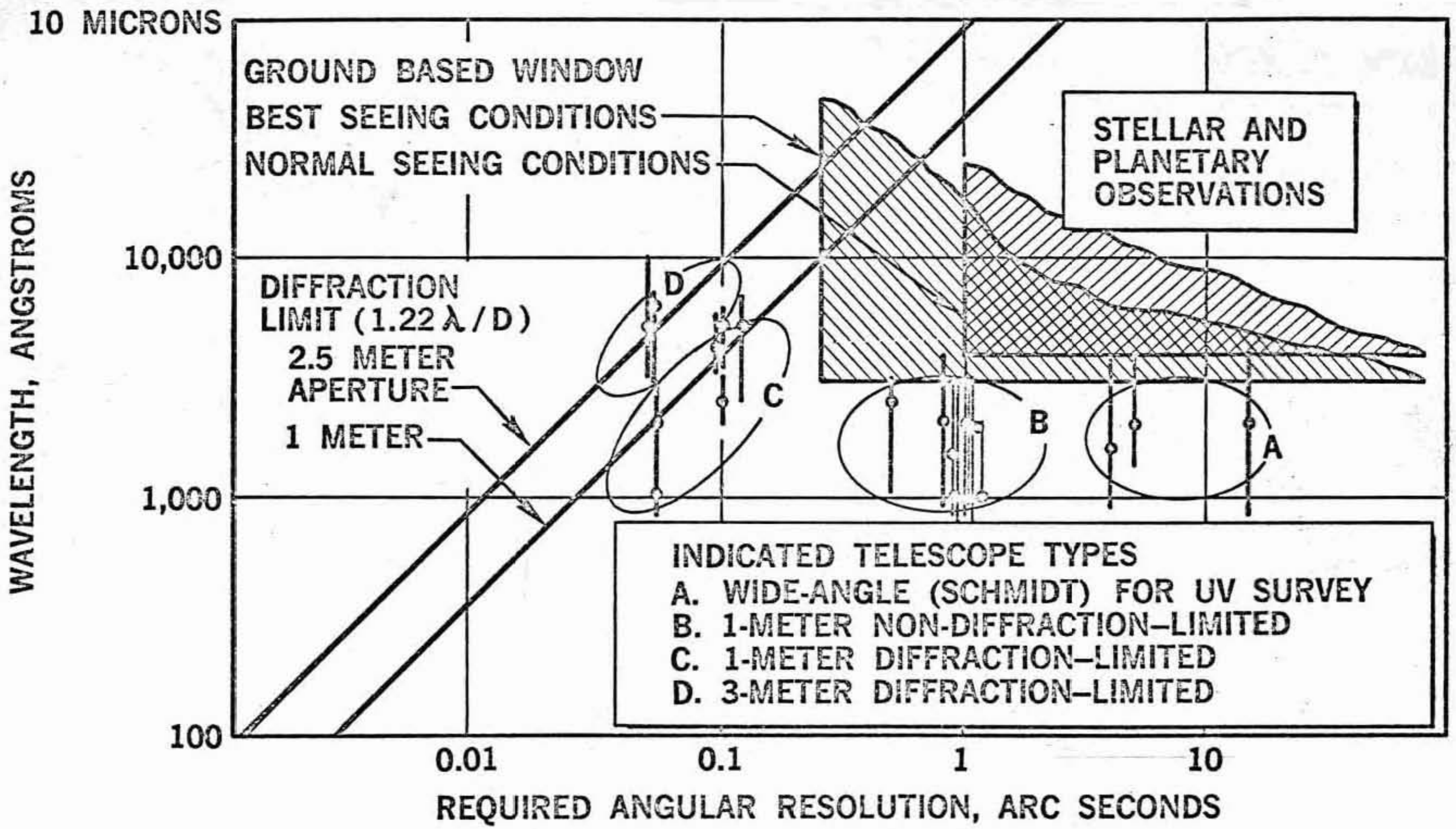
The ORDS described measurements across the electromagnetic spectrum except for two regions. One region was the sector from approximately 1 cm to 20 m in wavelength. This sector was not examined in depth because of the general transparency of the atmosphere in this spectral region. Similarly, it was believed that adequate data in the millimeter and submillimeter regions could be obtained at much lower cost by using ground and aircraft observations.

While the requirements summarized on the data sheets were considered valid examples of potential orbital astronomy activities, they were neither research proposals nor an exhaustive grouping of potential orbital observations. Nevertheless, the measurement descriptions were sufficiently detailed to provide the initial analysis of needs for instrumentation and support facilities and for identification of necessary technological advances.

The measurement requirements defined in the ORDS were grouped into classes according to the degree of similarity of their characteristics. Generic classes of instruments were then identified which could satisfy the discrete groups of measurement requirements. Figure 3 gives an example of this process using stellar and planetary observations for the IR, visible, and UV portions of the spectrum. Each vertical line indicates the wavelength range and the angular resolution required in one of the ORDS; the dot indicates the wavelength at which the angular resolution was specified. Study of the groupings of observation requirements with respect to the diffraction limitations inherent in optical telescope performance (sloping lines) and consideration of the observations available from ground-based observatories (shaded areas), led to the identification of general instrument classes providing the specified capabilities. The considerations illustrated were the first step in a selection process that eventually led to the suggestion for four types of instruments for IR, visible, and UV measurements:

A. A wide-angle telescope (0.3-m aperture UV Schmidt) for sky survey work in the UV region, similar to sky surveys that have been made in the visible region with ground-based Schmidt telescopes, and capable of being upgraded with an advanced version (1-m) in later years for more advanced sky-survey requirements.

B. A telescope of large aperture but less than the highest quality optics (1-m, aperture, non-diffraction-limited, UV-visible) to provide adequate capability for significant spectrographic observation in the UV region and for some UV imaging.


10 MICRONS
10,000
1,000
100
WAVELENGTH, ANGSTROMS
0.01
0.1
1
10
REQUIRED ANGULAR RESOLUTION, ARC SECONDS
GROUND BASED WINDOW
BEST SEEING CONDITIONS
NORMAL SEEING CONDITIONS
STELLAR AND PLANETARY OBSERVATIONS
DIFFRACTION LIMIT (1.22 λ / D)
2.5 METER APERTURE
1 METER
A
B
C
D
INDICATED TELESCOPE TYPES
A. WIDE-ANGLE (SCHMIDT) FOR UV SURVEY
B. 1-METER NON-DIFFRACTION–LIMITED
C. 1-METER DIFFRACTION–LIMITED
D. 3-METER DIFFRACTION–LIMITED

C. A large-aperture, high-quality-optics telescope (1-m, aperture, diffraction-limited, UV-visible-IR) for observations with a finer angular resolution than possible from ground-based telescopes in the visible region, and for fine-angular-resolution observations in the UV.

D. A very-large-aperture telescope (3-m, aperture, diffraction-limited, UV-visible-IR) to extend the angular resolution of both visible and UV observations, which is a generation later than the 1-m diffraction-limited telescope.

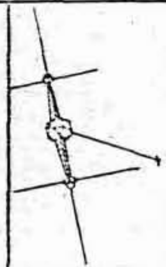
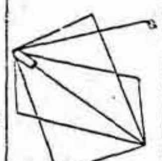
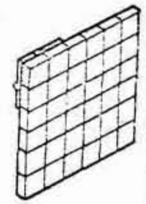
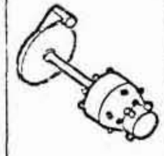
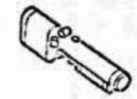
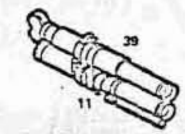
Similar analyses which were conducted for each of the other measurement areas involved a preliminary consideration of over 60 different instruments. NASA-furnished information on instrument concepts and designs was used where possible to take advantage of experience from previous and current design activities; where no data existed, new instrument designs were conceived.

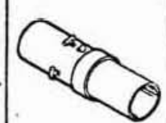
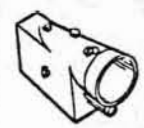
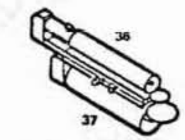
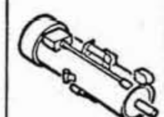
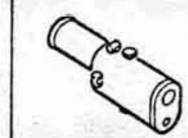
The study team reviewed the instrument designs with scientific contributors and instrument specialists. As a result of these discussions, more promising design approaches were made possible and many design criteria derived from the consultants' collective experience were included; consequently, 29 generic instrument types were defined which are considered as meeting projected orbital observation requirements through the 1990 period.

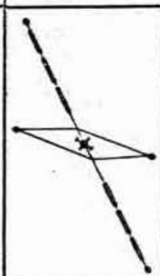
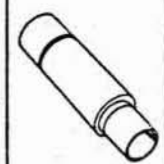
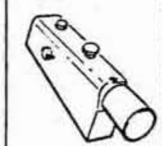
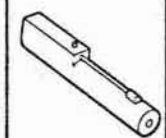
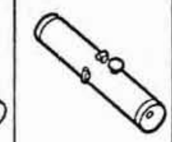
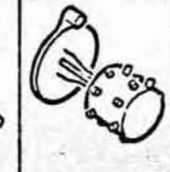
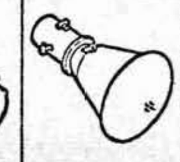
Three time periods were used to categorize the evolving level of sophistication of manned space operation, in general, and astronomical research. in particular. These periods were designated <u>early</u> (1968 to 1973), <u>intermediate</u> (1974 to 1979), and <u>late</u> (1980 to 1990). The early period reflected the short-duration (30-day) Orbital Workshop-Apollo Telescope Mount (ATM-A) mission capability. The intermediate time period reflected a more sophisticated 1- to 2-year space station. The late time period was predicated upon a six- to nine-man extended life (5-year) space station which could be anticipated as evolving into a national multipurpose facility in the late 1980's. These space facility concepts were treated as representing classes of available technology, rather than as fixed configurations modified specifically for astronomy. Because the initial Apollo Telescope Mount (ATM-A) effort has been already defined by NASA, the OASF Study emphasized the ATM-A follow-on or intermediate period (1974 to 1979, i.e., post ATM) and a late period (1980 to 1990). Table 1 describes the characteristics of the 29 generic instrument types suggested for the intermediate and late time periods.

Of the 29 generic instruments identified in Table 1, 22 were based on current instrument-development activities. To provide the information required for Task C, each instrument in the time-phased groups had to be brought to a fairly uniform level of conceptual design. As appropriate, instruments based on known designs were adapted or modified or new conceptual designs were provided. During the conceptual design process, provision for crew participation in the in-orbit operation of the instruments was reflected in the designs wherever this was judged to provide the greatest effectiveness.

Analysis of crew operation of various instruments indicated a significant role for man in the astronomy program. Crew members are expected to participate in orbital astronomy operations with all instruments, but to varying degrees. Radio telescopes are essentially automatic; however, man may prove valuable for corrective or periodic maintenance and modifications.

INSTRUMENT CATEGORY		INTERMEDIATE TIME PERIOD									
		RADIO TELESCOPES		RADIATION COUNTERS					OPTICAL GRAZING INCIDENCE TELESCOPES (SOLAR)		
INSTRUMENT NAME		CROSSED-H TETHERED INTERFEROMETER	TERMINATED-LOOP TETHERED INTERFEROMETER	0.7 KEV TO 20 KEV PROPORTIONAL COUNTER ARRAY	10 KEV TO 300 KEV SCINTILLATION COUNTER	300 KEV TO 1 MEV SCINTILLATION COUNTER	1 MEV TO 5 MEV SCINTILLATION COUNTER	25 MEV TO 1 GEV DIGITIZED SPARK CHAMBER	0.25-METER XUV	0.25-METER IMAGING X-RAY	0.225-METER SPECTROGRAPHIC X-RAY
											
INSTRUMENT NUMBER		32	30	20	22	23	42	43	08	39	11
APPLICABLE AREA OF ASTRONOMY		LONG-WAVE RADIO IMAGERY, SPECTROSCOPY, AND POLARIMETRY	LONG-WAVE RADIO IMAGERY, SPECTROSCOPY, AND POLARIMETRY	X-RAY SKY SURVEY AND SPECTROSCOPY	X-RAY SKY SURVEY AND SPECTROSCOPY	GAMMA RAY SPECTROSCOPY AND PHOTOMETRY	GAMMA RAY SPECTROSCOPY AND PHOTOMETRY	GAMMA RAY SKY SURVEY AND SPECTROSCOPY	XUV HIGH RESOLUTION SPECTROSCOPY	X-RAY IMAGERY OF SOLAR FLARES	X-RAY SPECTROSCOPY OF SOLAR FLARES
COLLECTOR	APERTURE	10 km	40 km	N/A	N/A	N/A	N/A	N/A	0.25 m	0.25 m	0.225 m
	EFFECTIVE FOCAL LENGTH	N/A	N/A	N/A	N/A	N/A	N/A	N/A	3.0 m	2.4 m	2.4 m
	EFFECTIVE COLLECTING AREA	N/A	N/A	1.3×10^5 cm^2	300 cm^2	100 cm^2	100 cm^2	230 cm^2	125 cm^2	50 cm^2	20 cm^2
	SPECTRAL RANGE	0.5 MHz TO 10 MHz	0.05 MHz TO 15 MHz	0.7 keV TO 20 keV	10 keV TO 300 keV	300 keV TO 1 MeV	1 MeV TO 5 MeV	25 MeV TO 1 GeV	170 Å TO >650 Å	2 Å TO 10 Å	1 Å TO 40 Å
	ANGULAR RESOLUTION	1.7°	1°	1°	3°	3°	3°	2.5°	2.5 SEC AT 300 Å	5 SEC AT 6 Å	5 SEC AT 6 Å
	FINE GUIDANCE RESOLUTION	N/A	N/A	± 3.3 SEC	± 1 MIN	± 1 MIN	± 5 MIN	± 30 SEC	± 0.1 SEC	± 1 SEC	
	FIELD OF VIEW	130° X 90°	130° X 90°	3°	6°	6°	6°	60°	2 MIN	30 MIN	10 MIN
	TOTAL SIGNAL COUNT	N/A	N/A	10^4 PHOTON-SEC^{-1}-keV^{-1}	3×10^{-2} PHOTON-SEC^{-1}-keV^{-1}	10^{-6} PHOTON-SEC^{-1}-keV^{-1}	10^{-6} PHOTON-SEC^{-1}-keV^{-1}	10^{-8} PHOTON-SEC^{-1}-keV^{-1}	N/A	N/A	N/A
	EXPECTED COUNT IN TOTAL BAND	N/A	N/A	600 PHOTON/SEC TO 5×10^5 PHOTON/SEC	10 PHOTON/SEC TO 10^4 PHOTON/SEC	0.02 PHOTON/SEC TO 2 PHOTON/SEC	0.02 PHOTON/SEC TO 2 PHOTON/SEC	10^{-2} PHOTON/SEC TO 1 PHOTON/SEC	N/A	N/A	N/A
	SPECTRAL RESOLUTION	50 KHz	50 KHz	10% AT 10 keV	20% AT 50 keV	8% AT 600 keV	5% AT 1 MeV	35% AT 100 MeV	0.5 Å AT 300 Å	N/A	0.1 Å AT 3 Å
COLLECTOR WITH INSTRUMENTATION DEVICES	LENGTH, STOWED POSITION	3.3 m; 10.8 FT	2.4 m; 7.9 FT	4.3 m; 14.1 FT	1.5 m; 4.9 FT	1.2 m; 3.9 FT	1.0 m; 3.3 FT	1.5 m; 4.9 FT	3.2 m; 10.4 FT	3.1 m; 10.2 FT	2.9 m; 9.7 FT
	VOLUME, STOWED POSITION	10 m^3; 353 FT^3	0.75 m^3; 26.4 FT^3	8.8 m^3; 310 FT^3	0.65 m^3; 23.0 FT^3	0.84 m^3; 29.6 FT^3	0.4 m^3; 14.1 FT^3	0.5 m^3; 17.6 FT^3	0.44 m^3; 15.5 FT^3	COMBINED 0.65 m^3; 23.0 FT^3	
	WEIGHT	1,900 kg; 4,200 LB	1,450 kg; 3,200 LB	2,700 kg; 5,950 LB	290 kg; 640 LB	300 kg; 660 LB	200 kg; 440 LB	90 kg; 198 LB	85 kg; 187 LB	COMBINED 80 kg; 176 LB	
INSTRUMENTATION DEVICES		SWEPT-FREQUENCY RADIOMETRY RECEIVER WIDE-BAND RADIOMETRY RECEIVER	SWEPT-FREQUENCY RADIOMETRY RECEIVER WIDE-BAND RADIOMETRY RECEIVER	N/A	N/A	N/A	N/A	N/A	GRAZING-INCIDENCE SPECTROGRAPH PLATE CAMERA, GRAZING INCIDENCE	CINE FRAME CAMERA, 35 mm X-RAY IMAGE INTENSIFIER PLUS VIDICON	CRYSTAL SPECTROMETER X-RAY GRAZING INCIDENCE SPECTROMETER
INSTRUMENT ACTIVITY FROM WHICH DERIVED		LARGE SPACE STRUCTURES EXPERIMENT STUDY	(NEW)	EMR EXPERIMENT NO. 9	EMR EXPERIMENT NO. 3	EMR EXPERIMENT NO. 5	EMR EXPERIMENT NO. 5	EMR EXPERIMENT NO. 8	(NEW)	ATM EXPERIMENT S056	(NEW)

INSTRUMENT CATEGORY		INTERMEDIATE TIME PERIOD								
		OPTICAL TELESCOPE								
		NORMAL INCIDENCE								
		STELLAR				SOLAR				
INSTRUMENT NAME		1-METER INFRARED	1-METER NON-DIFF-LIM UV-VIS-IR	1-METER DIFF-LIM UV-VIS-IR	0.3-METER UV SCHMIDT	1- TO -6-SOLAR-RADII CORONAGRAPH	5- TO -30-SOLAR-RADII CORONAGRAPH	0.8-METER UV-VIS	0.2-METER UV (OFF-AXIS)	0.25-METER XUV SPECTROHELIOGRAPH
						 				
INSTRUMENT NUMBER		14	45	34	33	36	37	44	04	06
APPLICABLE AREA OF ASTRONOMY		IR SPECTROSCOPY	UV IMAGERY AND SPECTROSCOPY	PLANETARY PHOTOGRAPHY AND STELLAR SPECTROSCOPY	UV SKY SURVEY	PHOTOGRAPHY OF CORONA FROM 1 TO 6 SOLAR RADII	PHOTOGRAPHY OF CORONA FROM 5 TO 30 SOLAR RADII	UV-VISIBLE IMAGERY AND SPECTROSCOPY	XUV SPECTROSCOPY	XUV SPECTRO-HELIOGRAPHY
COLLECTOR	APERTURE	1.0 m	1.0 m	1.0 m	0.3 m	0.0245 m	0.040 m	0.8 m	0.2 m	0.25 m
	EFFECTIVE FOCAL LENGTH	10.0 m	5.0 m	10.2 m	0.91 m	0.315 m	0.090 m	39.2 m	2.4 m	3.0 m
	EFFECTIVE COLLECTING AREA	7,050 cm^2	6,290 cm^2	6,930 cm^2	706 cm^2	4.48 cm^2	11.9 cm^2	4,280 cm^2	315 cm^2	490 cm^2
	SPECTRAL RANGE	0.7 μ TO 1,000 μ	<900 Å TO >12,000 Å	900 Å TO 6,000 Å	1,000 Å TO >2,000 Å	4,000 Å TO 10,000 Å	4,000 Å TO 10,000 Å	1,200 Å TO 10,000 Å	300 Å TO >1,500 Å	170 Å TO 750 Å
	ANGULAR RESOLUTION	1 SEC AT 4 μ	0.2 SEC AT 4,000 Å	0.1 SEC AT 4,000 Å	0.25 SEC AT 1,200 Å	10 SEC AT 5,000 Å	30 SEC AT 5,000 Å	0.16 SEC AT 5,000 Å	1 SEC AT 800 Å	1 SEC AT 170 Å
	FINE GUIDANCE RESOLUTION	± 0.1 SEC	± 0.05 SEC	± 0.01 SEC	± 0.5 SEC	± 5 SEC		± 0.02 SEC	± 0.1 SEC	± 0.02 SEC
	FIELD OF VIEW	5 MIN	10 MIN	2 MIN	10°	3.25°	15°	2.6 MIN	2 MIN	32 MIN
	TOTAL SIGNAL COUNT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	EXPECTED COUNT IN TOTAL BAND	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SPECTRAL RESOLUTION	16 Å AT 4 μ	0.2 Å AT 2,000 Å	0.1 Å AT 2,000 Å	2Å AT 1,200 Å	N/A	N/A	0.01Å AT 3,000 Å	0.2 Å AT 300 Å	0.015 Å AT 170Å
COLLECTOR WITH INSTRUMENTATION DEVICES	LENGTH, STOWED POSITION	1.75 m; 5.75 FT (EXCLUDING SHIELD)	2.8 m; 9.2 FT	2.7 m; 8.8 FT	3.1 m; 10.1 FT	3.7 m; 12.15 FT	2.8 m; 9.2 FT	3.6 m; 11.8 FT	3.6 m; 11.8 FT	3.4 m; 11.3 FT
	VOLUME, STOWED POSITION	50 m^3; 1,760 FT^3 (INCLUDING SHIELD)	3.5 m^3; 124 FT^3	4.1 m^3; 145 FT^3	2.5 m^3; 88 FT^3	COMBINED 2.3 m^3; 81 FT^3		3.3 m^3; 115 FT^3	1.6 m^3; 56.5 FT^3	3 m^3; 106 FT^3
	WEIGHT	1,000 kg; 2,200 LB (INCLUDING SHIELD)	1,000 kg; 2,200 LB	240 kg; 530 LB	430 kg; 950 LB	COMBINED 400 kg; 880 LB		800 kg; 1,760 LB	65 kg; 143 LB	300 kg; 660 LB
INSTRUMENTATION DEVICES		INTERFEROMETER RADIOMETER SOLID-STATE DETECTOR MATRIX MAGNETIC TAPE RECORDER	NORMAL-INCIDENCE SPECTROGRAPH ECHELLE SPECTROGRAPH SLITLESS SPECTROGRAPH PLATE CAMERA IMAGE INTENSIFIER SPECTROPHOMETER	ECHELLE SPECTROGRAPH 20-POWER RELAY LENS S.E.C. VIDICON	NORMAL-INCIDENCE SPECTROGRAPH PLATE CAMERA FILTER ASSEMBLY	CINE FRAME CAMERA, 35 mm	CINE FRAME CAMERA, 35mm	ECHELLE SPECTROGRAPH NARROW-BAND LYOT FILTER CINE FRAME CAMERA, 35 mm	NORMAL INCIDENCE SPECTROGRAPH PLATE CAMERA	SLITLESS SPECTROHELIOGRAPH PLATE CAMERA
INSTRUMENT ACTIVITY FROM WHICH DERIVED		(NEW)	GODDARD EXPERIMENT PACKAGE (GEP)	ADVANCED PRINCETON SATELLITE (APS)	NORTHWESTERN UNIVERSITY SCHMIDT	ATM EXPERIMENT S052	ATM EXPERIMENT S052	ATM SOLAR TELESCOPE (JPL)	ATM EXPERIMENT S055	ATM EXPERIMENT S053

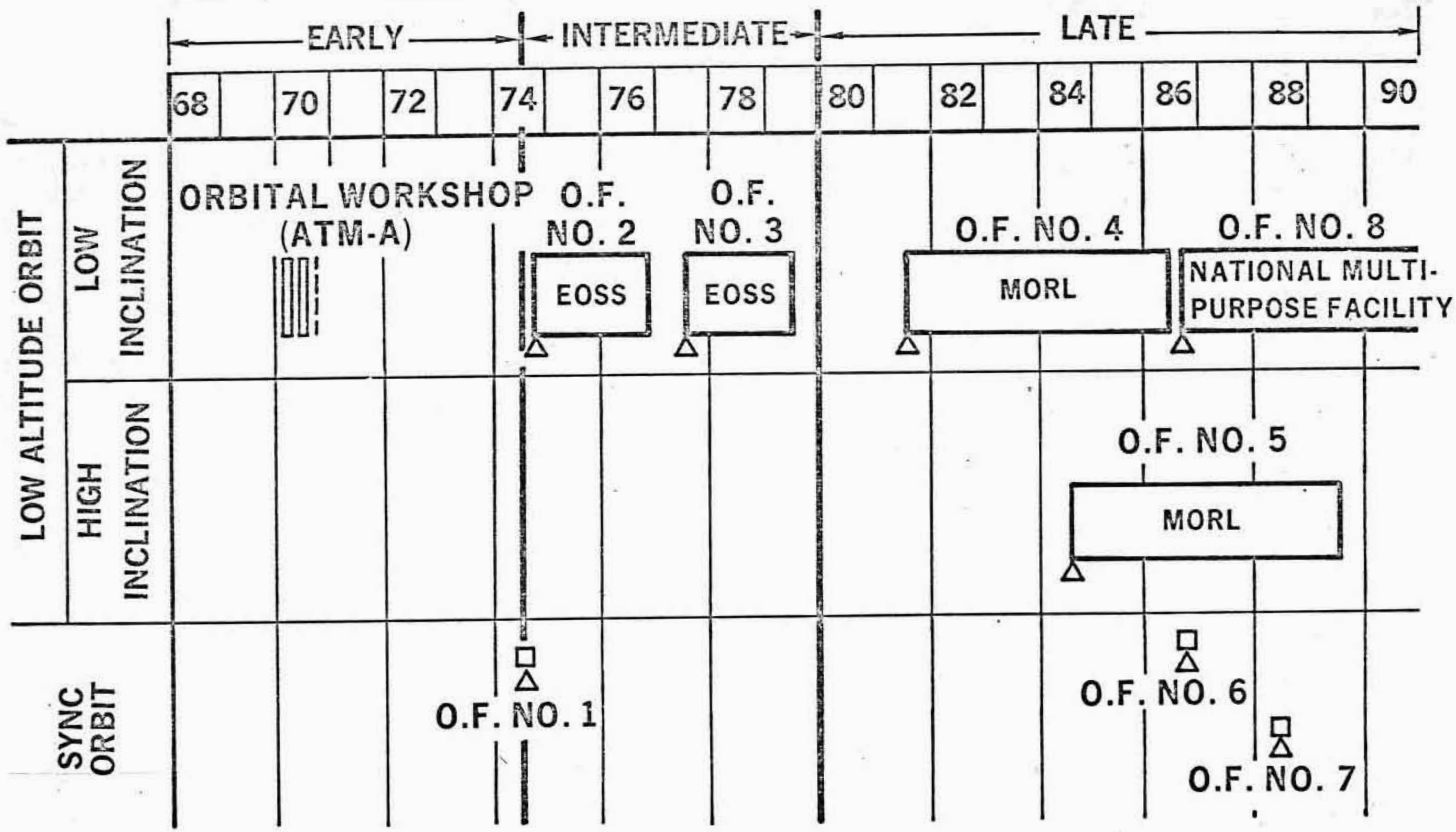
INSTRUMENT CATEGORY		LATE TIME PERIOD									
		RADIO TELESCOPE	OPTICAL TELESCOPES							RADIATION COUNTERS	
			NORMAL INCIDENCE					GRAZING INCIDENCE			
			STELLAR		SOLAR			STELLAR	SOLAR		
INSTRUMENT NAME		KILOMETER WAVE ORBITING TELESCOPE (KWOT)	3-METER DIF-LIM UV-VIS-IR	1-METER UV SCHMIDT	1.5-METER DIF-LIM UV-VIS	0.5-METER UV (OFF-AXIS)	0.125-METER XUV HIGH-DISPERSION SPECTROHELIOGRAPH	1-METER X-RAY	0.5-METER XUV	10 KEV TO 20 MEV SOLID STATE COUNTER	20 MEV TO 100 GEV GAS CERENKOV COUNTER
											
INSTRUMENT NUMBER		41	35	13	46	05	07	19	09	25	27
APPLICABLE AREA OF ASTRONOMY		LONG-WAVE RADIO IMAGERY, SPECTROSCOPY, AND POLARIMETRY	IMAGERY AND SPECTROSCOPY OF FAINT SOURCES	UV SKY SURVEY	UV-VISIBLE IMAGERY AND SPECTROSCOPY	XUV SPECTROSCOPY	XUV SPECTRO-HELIOGRAPHY	X-RAY IMAGERY AND SPECTROSCOPY	XUV HIGH RESOLUTION SPECTROSCOPY	X-RAY AND GAMMA RAY SPECTROSCOPY AND PHOTOMETRY	COSMIC RAY FLUX, SPECTROSCOPY, AND POSITRON/ ELECTRON RATIO
COLLECTOR	APERTURE	10 km	3.04 m	1.0 m	1.5 m	0.5 m	0.125 m	1.0 m	0.5 m	N/A	N/A
	EFFECTIVE FOCAL LENGTH	N/A	45 m	4.0 m	75 m	6.0 m	2.5 m	10.0 m	6.0 m	N/A	N/A
	EFFECTIVE COLLECTING AREA	N/A	63,200 cm^2	7,850 cm^2	17,200 cm^2	1,360 cm^2	122 cm^2	500 cm^2	500 cm^2	1,000 cm^2	500 cm^2
	SPECTRAL RANGE	0.1 MHz TO 10 MHz	900 Å TO 12,000 Å	1,000 Å TO 5,000 Å	<1,300 Å TO >12,000 Å	170 Å TO >1,500 Å	304 Å TO 1,216 Å	2 Å TO 100 Å	170 Å TO >650 Å	10 keV TO 20 MeV	20 MeV TO 100 GeV
	ANGULAR RESOLUTION	1.7°	0.04 SEC AT 5,000 Å	0.1 SEC AT 4,000 Å	0.1 SEC AT 6,200 Å	0.5 SEC AT 800 Å	1 SEC AT 600 Å	5 SEC AT 6 Å	0.5 SEC AT 300 Å	3°	8 MIN
	FINE GUIDANCE RESOLUTION	N/A	± 0.005 SEC	± 0.05 SEC	± 0.05 SEC	± 0.05 SEC	± 0.02 SEC	± 0.25 SEC	± 0.02 SEC	N/A	± 15 SEC
	FIELD OF VIEW	80°	15 MIN	5°	1.1 MIN	2 MIN	10 MIN	10 MIN	2 MIN	6°	60°
	TOTAL SIGNAL COUNT	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10^{5} PHOTON - SEC^{-1} - keV^{-1}	10^{5} PARTICLE - SEC^{-1} - MeV^{-1}
	EXPECTED COUNT IN TOTAL BAND	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2 PHOTON/SEC TO 20 PHOTON/SEC	0.05 ELECTRON/SEC TO 50 ELECTRON/SEC AT 0.1 GeV
	SPECTRAL RESOLUTION	NOT AVAIL.	0.5 Å AT 2,000 Å	N/A	0.002 Å AT 3,000 Å	0.02 Å AT 800 Å	0.015 Å AT 600 Å	6% AT 2Å	0.1 Å AT 304 Å	3 keV AT 1 MeV 8 keV AT 20 MeV	10% AT 1 GeV
COLLECTOR WITH INSTRUMENTATION DEVICES	LENGTH, STOWED POSITION	3.1 m; 10.2 FT	15.6 m; 51.2 FT	9.1 m; 29.6 FT	12.3 m; 40.4 FT	9 m; 29.6 FT	3.4 m; 11.3 FT	5.7 m; 18.8 FT	6.4 m; 21.0 FT	1.2 m; 3.9 FT	3.7 m; 12.1 FT
	VOLUME, STOWED POSITION	1.5 m^3; 53.5 FT^3	270 m^3; 9,520 FT^3	53 m^3; 1,870 FT^3	32.5 m^3; 1,150 FT^3	10.8 m^3; 38.1 FT^3	3 m^3; 106 FT^3	200 m^3; 7,050 FT^3	2.3 m^3; 81 FT^3	0.4 m^3; 14.1 FT^3	9 m^3; 318 FT^3
	WEIGHT	640 kg; 1,410 LB	12,000 kg; 26,500 LB	930 kg; 2,050 LB	1,600 kg; 3,530 LB	1,800 kg; 3,970 LB	320 kg; 710 LB	1,220 kg; 2,690 LB	400 kg; 880 LB	350 kg; 770 LB	800 kg; 1,760 LB
INSTRUMENTATION DEVICES		WIDE-BAND RADIOMETRY RECEIVER	NORMAL-INCIDENCE SPECTROGRAPH PLATE CAMERA FILTER ASSEMBLY 2-POWER FIELD LENS VIDICON	PLATE CAMERA FILTER ASSEMBLY	ECHELLE SPECTROGRAPH NARROW-BAND LYOT FILTER PLATE CAMERA MAGNETOGRAPH	NORMAL-INCIDENCE SPECTROGRAPH SLITLESS SPECTRO-HELIOGRAPH PLATE CAMERA	SLITLESS SPECTRO-HELIOGRAPH PLATE CAMERA	PLATE CAMERA, GRAZING INCIDENCE CRYSTAL SPECTROMETER X-RAY IMAGE INTENSIFIER CHANNEL SPECTROMETER	GRAZING INCIDENCE SPECTROGRAPH PLATE CAMERA, GRAZING INCIDENCE	N/A	N/A
INSTRUMENT ACTIVITY FROM WHICH DERIVED		KWOT	MANNED ORBITAL TELESCOPE (MOT)	(NEW)	ATM SOLAR TELESCOPE (JPL)	ATM EXPERIMENT S055	ATM EXPERIMENT S063	LARGE SPACE STRUCTURES EXPERIMENT STUDY	(NEW)	EMR EXPERIMENT NO. 7	(NEW)

With optical telescopes, man is involved in nearly all functions; i.e., from updating or retrofitting sensors or changing film cassettes, to locating specific observational objectives such as areas of high solar activity. The crew may not be required for operating and monitoring radiation counters.

The manned orbital facilities (O. F.) assumed to be available in the time periods of interest are illustrated in Figure 4. They included two of the Earth orbital space station (EOSS) class, 2-year, six-man space stations in low-altitude (200-nmi), low-inclination (30° to 50°) orbits in the intermediate period. As noted above, in the late time period, the stations were visualized as evolving into 5-year, six- to nine-man manned orbital research laboratory (MORL) class stations in low-altitude, low-inclination, and polar orbits; then, into a long-duration, national multipurpose facility in a low-inclination, low-altitude orbit. Also considered were a series of short duration, non-resuppliable missions to synchronous orbit. The orbital facilities utilized have been numbered from one to eight, in approximate order of launch sequence.

The alternatives for housing and operating instruments in the various orbital facilities can be classified into three general categories:

1. Integrated--The instrument is attached to, and wholly dependent on, the manned space-station subsystems (propulsion, power, data management, crew systems).
2. Semidetached (Intermittently-Detached)--The instrument module can operate for limited times, independently (free-floating) of the manned space station and must have all subsystems required to support itself as an independent satellite. This module's normal mode of operation is attached to the space station.



EARLY
INTERMEDIATE
LATE
68
70
72
74
76
78
80
82
84
86
88
90
LOW ALTITUDE ORBIT
LOW INCLINATION
HIGH INCLINATION
SYNC ORBIT
ORBITAL WORKSHOP (ATM-A)
O.F. NO. 2
EOSS
O.F. NO. 3
EOSS
O.F. NO. 4
MORL
O.F. NO. 8
NATIONAL MULTI-PURPOSE FACILITY
O.F. NO. 5
MORL
O.F. NO. 1
O.F. NO. 6
O.F. NO. 7

3. Detached--The instrument's mode of operation is as an independent, free-floating satellite, station-keeping with the manned space station and dependent on it for maintenance, repair, resupply of consumables (e.g., propellants and film), modifications of instruments, possibly some data management, communication, and experiment program sequencing commands.

To determine general guidelines in optimal operations-mode (integrated, semi-detached, detached) selection, the unique requirements for radio, optical (IR-visible-UV-XUV--longer than 1Å), and high-energy radiation (X-ray to cosmic ray--shorter than 1Å) observations, were examined in some depth.

Earth-based and low-altitude radio telescopes are limited in their usefulness below roughly 30 MHz by the reflection, absorption, refraction, and polarization rotation effects of the ionosphere. The most highly ionized part of the ionosphere is the F-region. Above the F-region ionization maximum, the electron density falls off, to merge eventually with that of the plasma surrounding the sun. A long-wave radio astronomy antenna placed above the F-region can both receive signals from outside the Earth, and be freed from radio noise generated on Earth by the shielding of the ionosphere.

The orbit altitude should be such that the local number of electrons must be $\leq 9\ cm^{-3}$ and the plasma frequency ($f \cong 9\ H_e^{1/2}$ kHz) must be ≤ 0.5 times the minimum operating frequency (50 kHz). These conditions exist only above the 12,500-mi (20,000-km) altitude.

Besides the requirements for very-high-altitude orbits, which would seriously limit the time available for manned operations, radio noise interference can be expected to increase near any manned spacecraft. For these reasons, an unmanned, detached antenna configuration was suggested as the normal operating mode for radio astronomy.

Because high-energy radiation devices can tolerate coarse attitude control and are not subject to appreciable degradation by spacecraft effluents, it appeared that this class of instrumentation could be integrated into the basic space-station configuration, or operated while attached to the station, without the need for sophisticated mounting provisions.

The selection criteria for the operations mode of the optical group were less obvious and it was necessary to examine the factors which could influence operations-mode selection for the optical instruments in greater detail.

Selection and recommendations for optical telescope operations modes were based on (1) scientific and technical performance, as affected by such factors as optical environment contamination, radiation effects, attitude hold (dynamic isolation), thermal stability, and data management; (2) operations, as affected by flexibility for modifications, maintainability, reliability, useful life, multipurpose missions impact, discretionary payload, and schedule flexibility; and (3) cost. In general, the optical group of instruments was characterized by precise attitude-hold requirements (1 arc-sec or lower) and sensitivity to spacecraft effluent environment.

Figure 5 summarizes the criteria which were investigated in attempting to evaluate the potential of integrated, semi-detached, and detached modes of operations for the optical instruments. Each mode carried certain advantages and penalties. The potential problem of environment contamination in the

CRITERIA	OPERATIONS MODE: INTEGRATED	OPERATIONS MODE: SEMI-DETACHED	OPERATIONS MODE: DETACHED	
PERFORMANCE (SCIENTIFIC/TECHNICAL)				
OPTICAL ENVIRONMENT CONTAMINATION			✓	▨
ATTITUDE HOLD – DYNAMIC ISOLATION			✓	▨
THERMAL STABILITY			✓	
DATA MANAGEMENT	✓			▨
OPERATIONS				
FLEXIBILITY FOR MODIFICATIONS		✓		
MAINTAINABILITY	✓			▨
RELIABILITY	✓			
USEFUL LIFE		✓		
MULTIPURPOSE MISSION IMPACT			✓	▨
DISCRETIONARY PAYLOAD	✓			
SCHEDULE FLEXIBILITY		✓	✓	▨
COST	✓			▨
INDICATED MODE	5	3	5	

SIGNIFICANT IMPACT ON MODE SELECTION: ▨

FAVORED MODE ✓

vicinity of a manned space station favored detached module operation. The potential need to store data on film to avoid saturating the data transmission capabilities, favored integrated operation (in view of the potential for better shielding provisions on a manned space station using ecological water). Dynamic isolation of instruments can be achieved in any operational mode but may be easier to accomplish in a detached module. Detached and semi-detached modes obviously offer advantages in improved schedule flexibility (equipment does not need to be launched with a space station), and reduced impact on station operations when several different observation programs must be accomplished simultaneously. Although no one factor could be determined which would make one mode of operation mandatory for optical instruments, examination of the factors considered to be most critical (i.e., environment contamination, dynamic isolation, data management, maintainability/reliability, multipurpose mission impact, and schedule flexibility) suggested that a detached module concept for housing optical instruments offered considerable potential and should be explored in greater depth.

The generic classes of instruments proposed for each of the eight orbital facilities is shown in Figure 6. The observation programs and their associated instruments generally evolve from simpler survey or gross data-collection tasks to detailed observations of faint, small sources requiring larger apertures or more sensitive detectors. The demands on orbital-facility resources correspondingly evolve to more precise pointing, greater data-handling capability, stricter thermal control, less optical environment contamination, and specialized orbits for long-term uninterrupted viewing of celestial objects. This growth is reflected in the distribution of instruments among the orbital facilities.

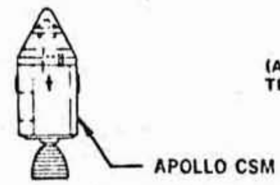
ORBITAL FACILITY NO. 1
(SYNCHRONOUS ORBIT)

INSTRUMENT

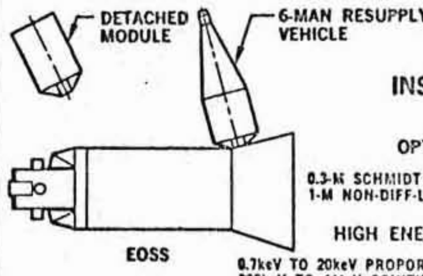
RADIO

CROSSED-H TETHERED INTERFEROMETER (32)

(ALTERNATE: TERMINATED-LOOP TETHERED INTERFEROMETER) (30)



ORBITAL FACILITY NO. 2



INSTRUMENTS

OPTICAL STELLAR

0.3-M SCHMIDT TELESCOPE (33)
1-M NON-DIFF-LIM UV-VIS-IR TELESCOPE(45)

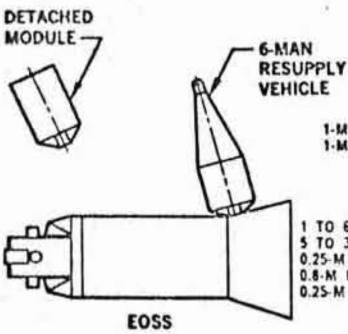
HIGH ENERGY RADIATION

0.7keV TO 20keV PROPORTIONAL COUNTER ARRAY(20)
300keV TO 1MeV SCINTILLATION COUNTER(23)
1MeV TO 5MeV SCINTILLATION COUNTER(42)

OPTICAL SOLAR

0.8-M UV-VIS TELESCOPE(44)
0.2-M UV OFF-AXIS TELESCOPE(04)
0.225-M SPECTROGRAPHIC GRAZING INCIDENCE X-RAY TELESCOPE(11)
0.25-M IMAGING GRAZING INCIDENCE X-RAY TELESCOPE (39)

ORBITAL FACILITY NO. 3



INSTRUMENTS

OPTICAL STELLAR

1-M IR TELESCOPE(14)
1-M DIFF-LIM UV-VIS-IR TELESCOPE(34)

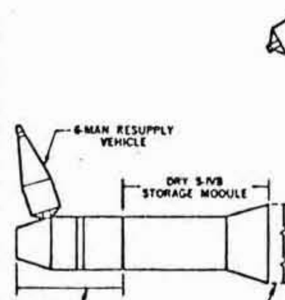
OPTICAL SOLAR

1 TO 6 SOLAR-RADII CORONAGRAPH(36)
5 TO 30 SOLAR-RADII CORONAGRAPH(37)
0.25-M GRAZING INCIDENCE XUV TELESCOPE (08)
0.8-M UV-VIS TELESCOPE(44)
0.25-M XUV SPECTROHELIOGRAPH(06)

HIGH ENERGY RADIATION

10-keV TO 300-keV SCINTILLATION COUNTER (22)
25MeV TO 1GeV DIGITIZED SPARK CHAMBER(43)

ORBITAL FACILITY NO. 4



INSTRUMENTS

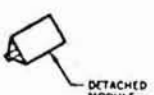
OPTICAL STELLAR

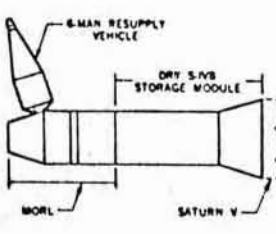
1-M GRAZING INCIDENCE X-RAY TELESCOPE (19)
1-M UV SCHMIDT TELESCOPE (13)

HIGH ENERGY RADIATION

10keV TO 20 MeV SOLID-STATE COUNTER (25)

ORBITAL FACILITY NO. 5
(POLAR ORBIT)





INSTRUMENTS

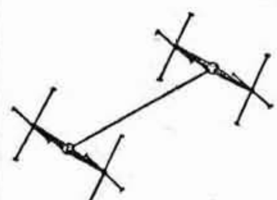
OPTICAL SOLAR

1.5-M DIFF-LIM UV-VIS TELESCOPE(46)
0.5-M UV OFF-AXIS TELESCOPE(05)
0.125-M HIGH DISPERSION XUV SPECTROHELIOGRAPH(07)
0.5-M GRAZING INCIDENCE XUV TELESCOPE (09)

HIGH ENERGY RADIATION

20MeV TO 100GeV GAS CERENKOV COUNTER (27)

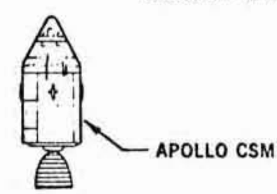
ORBITAL FACILITY NO. 6
(SYNCHRONOUS ORBIT)



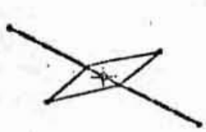
INSTRUMENT

RADIO

ADVANCED VERSION –
CROSSED-H TETHERED INTERFEROMETER (32)



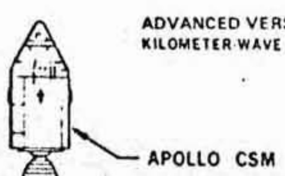
ORBITAL FACILITY NO. 7
(SYNCHRONOUS ORBIT)



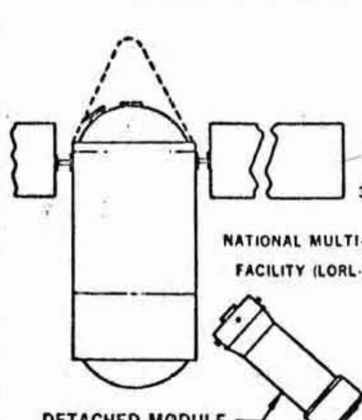
INSTRUMENT

RADIO

ADVANCED VERSION –
KILOMETER-WAVE ORBITING TELESCOPE (KWOT) (41)



ORBITAL FACILITY NO. 8



INSTRUMENT

OPTICAL STELLAR

3-M DIFF-LIM UV-VIS-IR TELESCOPE (35)

NATIONAL MULTI-PURPOSE FACILITY (LORL-CLASS)

The synchronous missions (No. 1, 6, and 7) are utilized in this plan only for radio astronomy because of the unique requirements of radio observations. If man is present, crew duties might involve radio telescope deployment, checkout, and monitoring of initial operations. The crew would then return to Earth after 14 to 28 days, leaving the automated instruments behind. A possible alternative would be to conduct the entire radio astronomy mission in an unmanned mode. Determination of the optimal degree of involvement of the crew in these synchronous missions remains to be investigated.

The low-altitude, low-inclination missions (No. 2, 3, 4, and 8) would be visualized as supporting evolving groups of instruments in other regions of the electromagnetic spectrum, from gamma ray detectors through IR detectors through IR telescopes. It is anticipated that other instruments besides the 3-m telescope (Reference 10) will probably orbit with the national multipurpose facility (No. 8). The design of other instruments for use in this time period, however, must wait for the results of the earlier astronomy programs.

The polar mission (No. 5), if placed in a sun-synchronous orbit (98°), would offer a unique opportunity for continuous viewing to an array of advanced solar instruments. The gas Cerenkov counter would be planned for polar orbit to allow observation of cosmic ray electrons down to 0.1 GeV.

The synchronous orbit is most desirable for general observations of the celestial sphere. From synchronous orbit, any portion of the celestial sphere can be continuously viewed for periods of at least 24 hours. In lower altitudes, a 98° orbit provides continuous viewing for most of the ecliptic plane, relatively small portions of the galactic plane, and short viewing periods for both the center of the Galaxy and the galactic poles. A 50^{o} orbit provides limited continuous-viewing capability for a small portion of the ecliptic plane, and for the plane, poles and center of the Galaxy. Each of the low Earth orbits can view all of the celestial sphere for short periods of time.

Long-duration solar viewing can be obtained only in a sun-synchronous, or near-polar orbit. For each orbit altitude, there is only one orbit inclination that yields the required precession of 0.986^{o}/day to achieve a sun-synchronous orbit. Deviations from this ideal would reduce the time for continuous viewing. For example at 200 nmi, the optimal orbit would be 98^{o}. In this orbit, however, only about 210 days would be available for continuous viewing, assuming a 100 km critical atmosphere height; this reduces to less than 30 days of continuous viewing in a 200 nmi orbit at inclinations of 90^{o}. Longer periods of continuous viewing would be possible in higher-altitude orbits (above 500 nmi).

CONCLUSIONS--EARLY MISSIONS ARE TECHNOLOGICAL STEPPING STONES

The emphasis in manned solar and stellar astronomy in the early time period should be primarily directed toward conducting coarse surveys in the UV, X-ray and gamma-ray and toward the development of operational capability with manned vehicles. Ultimately, the highest probabiltity of significant scientific return can be realized if the ATM-follow-on missions are directed toward obtaining a better understanding of the role and primary contributions of man before large-scale commitments are made to the more sophisticated facilities of the late time periods. These early missions would provide a needed platform to answer the many technology-oriented questions upon which future design will be predicated, such as those relating to design criteria and operational techniques for space servicing operations, evaluation of candidate operating modes, determination of man's role in data taking, and demonstration of precision pointing and control techniques. Based upon early mission success, it can be anticipated that the first major long-term scientific facilities for astronomy which are capable of effectively utilizing man's working participation would become available in the intermediate time period.

While the views presented herein may be somewhat optimistic and it is recognized that achievements are more highly dependent upon budgetary than upon technical limitations, the tremendous potential before us does indeed stagger the imagination. Coupling man's capabilities with the vantage point of space will provide a dynamic and viable platform for unprecendented opportunities to learn more of the universe and even, perhaps, of our eventual destiny.

REFERENCES

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