SPACE TELESCOPE SCIENCE INSTITUTE

INSTRUMENT SCIENCE REPORT

CAL-002

TITLE: Summary of Space Telescope Science Instrument Performance Characteristics - Preliminary

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ABSTRACT

Estimates of the various science instrument detective quantum efficiencies and optical throughputs are used to estimate bright and faint limiting magnitudes for some of the instrument modes. This data, which is largely collected from existing documentation, may be of use in science planning.

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SUMMARY OF SPACE TELESCOPE SCIENCE INSTRUMENT PERFORMANCE CHARACTERISTICS

PRELIMINARY

compiled by

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Computer Sciences Corporation

under Task Order 19321

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1.0 INTRODUCTION

This document is a compilation of existing information on those aspects of the Space Telescope science instrument performance which may be helpful to those planning the types of science that can be done with the Space Telescope. Since the science instruments are still undergoing assembly, modification, and calibration, this compilation is necessarily incomplete and preliminary. As a result, many of the estimates of instrument performance presented in the form of tables or figures in this compilation reflect the instrument specifications rather than the measured performance of the science instruments, which may differ significantly from the design behavior. Much of the data that is needed to assess such differences from the design behavior of the instruments will only become available during Science Verification.

In addition to the instrumental uncertainties, it should be kept in mind that the performance of the Space Telescope is also dependent upon the performance of the Optical Telescope Assembly and upon the environment of the ST in orbit. In particular, estimates of the faint limiting magnitude achievable with reasonable signal to noise in the various modes of the science instruments are extremely sensitive to the OTA efficiency as a function of wavelength, and to the background sources. The OTA efficiency and background from such sources as straylight, scattered light, terrestrial atmospheric emission, and glow phenomena, are poorly characterized at present. As more information becomes available, estimates of the performance of the ST science instruments will be revised.

This compilation is in two parts. Part I is a summary table of estimated science instrument performance for selected modes and for one type of source, namely an unreddened A0 star. Filter photometry mode sensitivities have been calculated for the U band. Sensitivities for the various spectrographs have been calculated at selected wavelengths. Exposure time estimates represent actual observing time required, and do not include such necessary overhead as slewing and target acquisition or the time required to change the instrument configuration. Also not included is time lost due to instrument inactivity as a result of SAA passage of the spacecraft or due to other orbital or engineering problems.

Part II of the compilation is a collection of figures and tables, taken primarily from existing documentation, which present additional data on each of the science instruments. Where possible, results of laboratory calibration have been included. In the case of the FOS, where planned replacement of the digicons before launch means that existing laboratory calibration data is of limited utility, specification estimates of performance rather than current detector

performance have been used. At present little data is available on the performance of the HSP and FGS. The tables included in Part II reflect this fact.

The following documents have been most heavily used in preparation of this compilation:

- The Space Telescope Observatory, D.N.B. Hall (ed.), NASA CP-2244 (1982)
- Macchetto, F., van de Hulst, H.C., di Serego Alighieri, S., and Perryman, M.A.C., The Faint Object Camera, ESA SP-1028 (1982).

TABLE 2.1

INSTRUMENT AND MODE	BANDPASS (NM)	PIXEL SIZE (ARCSEC)	EFFECTIVE IMAGE AREA (PIXELS)	FILTER/ GRATING	WIDTH (NM)	FAINT LIMIT S/N RATIO	FAINT LIMIT SOURCE TYPE	FAINT LIMIT EXPOSURE TIME (S)	MAGNITUDE LIMIT FAINT	MAGNITUDE LIMIT BRIGHT	INSTANTANEOUS WAVELENGTH COVERAGE (A)
FOC F/96	115-700	0.022	20	U	100	5.3	A0	1000	26	21.7*	----
F/96	115-700	0.022	20	U	100	7.7	A0	36000	28		----
F/48	115-700	0.044	9	U	100	5.5	A0	1000	26	23.2*	----
F/48	115-700	0.044	9	U	100	5	A0	36000	28.5		----
LONG SLIT	360-540	0.044x0.088		FIRST/B		5.4	A0	1000	19	15.5*	1800
	360-540	0.044x0.088		FIRST/B	100		A0	36000	22		1800
	180-270	0.044x0.088		SECOND							900
	115-180	0.044x0.088		THIRD							600
F/288	115-700	0.0075	175	U	100	6.9	A0	1000	20.3	18.3*	----
				U	100	6.57	A0	36000	24.3		----
OBJ. PRISM	115-700 f/96			4370A		6.93	A0	1000	21	19 *	5900
WFPC WFC	115-1100	0.1	6	U	60	3.6	A0	3000*2++	28	13 +	----
PC	115-1100	0.043	15	U	60	5.98	A0	3000*2++	28	12 +	----
OBJ.GRATING	130-220	AS ABOVE		UV SECOND			A0				1100
	160-300	AS ABOVE		UV FIRST			A0				1600
(WFC)	300-600	AS ABOVE		BLUE		4.1	A0	3000*2++	25	9.5 +	3000
	600-1200	AS ABOVE		RED		2.9	A0	3000*2++	26	10 +	6000
HSP VIS-DIGITAL		1	1	U	100	5.7	A0	2000	24	7**	----
VIS-ANALOG		1	1	U	100		A0		12	1	----
UV		1	1				A0				----
POL	NO DATA CURRENTLY AVAILABLE ON THIS MODE										
PMT											
FGS	470-690	3	1	CLEAR	220	TBS	A0	1MIN	17	10	----
				NEUTRAL DENSITY		TBS	A0				

* BRIGHT LIMIT DETERMINED BY 1% COUNT RATE NON-LINEARITY NOT BY EXPOSURE TIME

** BRIGHT LIMIT DETERMINED BY COUNT RATE NON-LINEARITY NOT BY EXPOSURE TIME

+ BRIGHT LIMIT DETERMINED BY CCD FULL WELL POTENTIAL OF 30,000 ELECTRONS

++ WFPC EXPOSURE TIMES MULTIPLIED BY 2 IN ORDER TO REMOVE COSMIC RAY EVENTS FROM THE IMAGES. SIGNAL TO NOISE CALCULATED FOR SINGLE 3000 SECOND EXPOSURE.

TABLE 2.1 (CONT.)

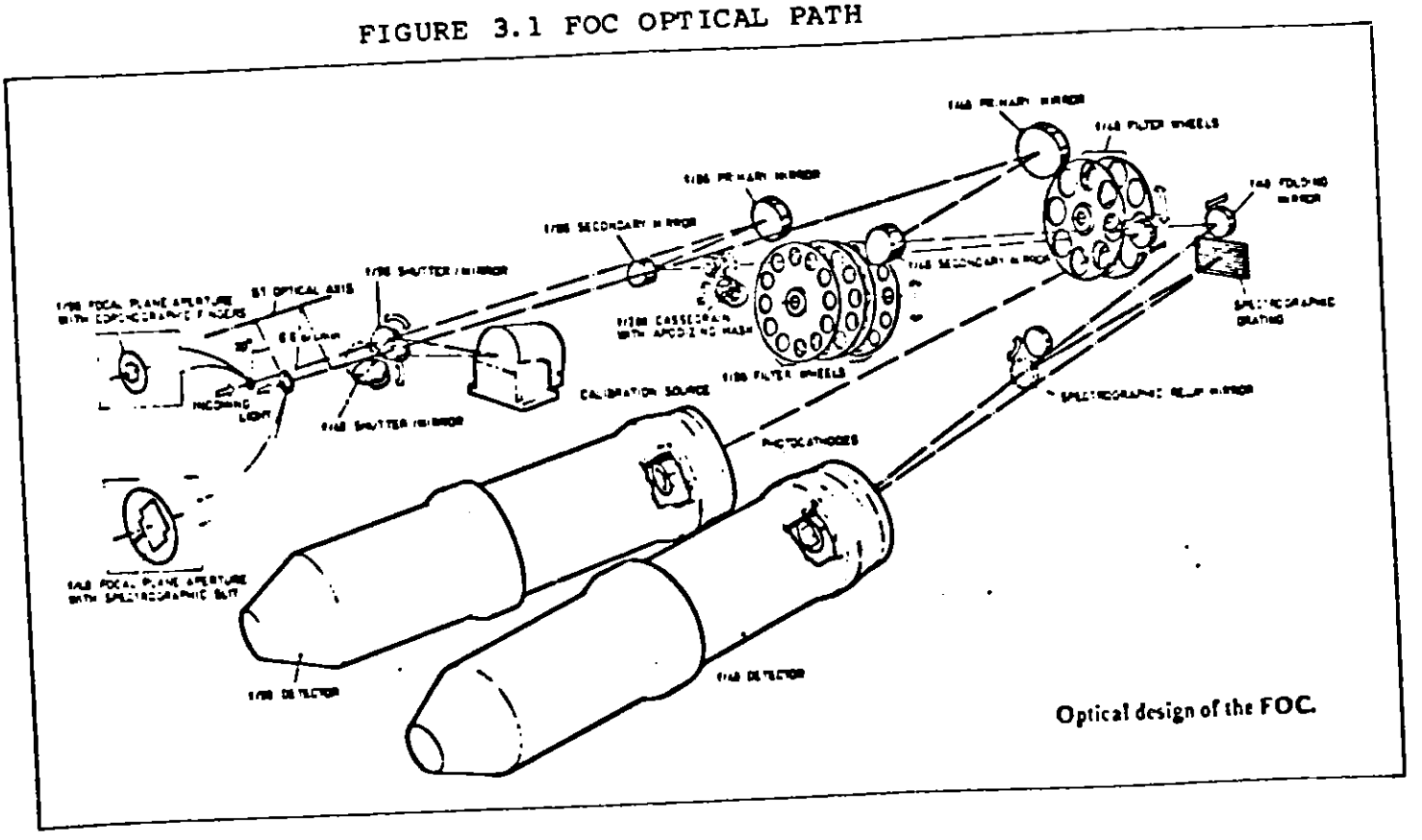
INSTRUMENT AND MODE	BANDPASS (NM)	GRATING/ DETECTOR	WAVELENGTH (A)	FAINT LIMIT S/N	FAINT LIMIT SOURCE	FAINT LIMIT EXPOSURE RATIO TYPE	FAINT LIMIT MAG.	BRIGHT LIMIT MAGNITUDE	INSTANTANEOUS WAVELENGTH COVERAGE (A)
HRS R=2000	115-170	G5/D1	1360	5	A0	3HOURS	15.3	7*	288
R=2000	115-170	G1/D1	1360	5	A0	3HOURS	14.0	4*	25
R=20000	115-210	G2/D2	1360	5	A0	3HOURS	14.0	4*	33
R=20000	160-230	G3/D2	1940	5	A0	3HOURS	14.4	4*	38
R=20000	220-320	G4/D2	2500	5	A0	3HOURS	14.9	4*	43
R= 80000	105-170	G6,7/D1	1360	5	A0	3HOURS	11.7	1*	6-10
R= 80000	170-320	G6,8/D2	2500	5	A0	3HOURS	12.8	1*	9-20
TARG.ACQ.	N2	MIRRORB/D2	-----	--	--	------	21	13*	----
TARG.ACQ.	N1	G5 ZERO/D1	-----	--	--	------	15	7*	----
TARG.ACQ.	A2	/D2	-----	--	--	------	18	10*	----
TARG.ACQ.	A1	/D1	-----	--	--	------	7	-1*	----
POS R=100	250-700	PRISM	@6000	5	A0	1 HOUR	26.5	10*	5500
R=200	110-220	L16/BLUE	@1800	5	A0	1 HOUR	21.5	6*	1100
R=200	400-800	L60/RED	@6000	5	A0	1 HOUR	23.2	6*	4000
R=1200	110-164	H13/BLUE	@1300	5	A0	1 HOUR	NOT TABULATED	6*	540
R=1200	153-228	H19/BLUE	@2000	5	A0	1 HOUR	21	6*	750
R=1200	221-329	H27/BLUE	@2500	5	A0	1 HOUR	21.2	6*	1080
R=1200	319-474	H40/RED	@4000	5	A0	1 HOUR	22.9	6*	1550
R=1200	459-683	H57/RED	@6000	5	A0	1 HOUR	21.8	6*	2240
R=1200	626-931	H78/RED	@7000	5	A0	1 HOUR	21	6*	3050
TARG.ACQ.		MIRROR	-----	-	--	------			----
POL.	NO DATA AVAILABLE ON THIS MODE								

*BRIGHT LIMITING MAGNITUDE DETERMINED BY COUNT RATE NON-LINEARITY WHICH IS INDEPENDENT OF EXPOSURE TIME

3.0 FAINT OBJECT CAMERA

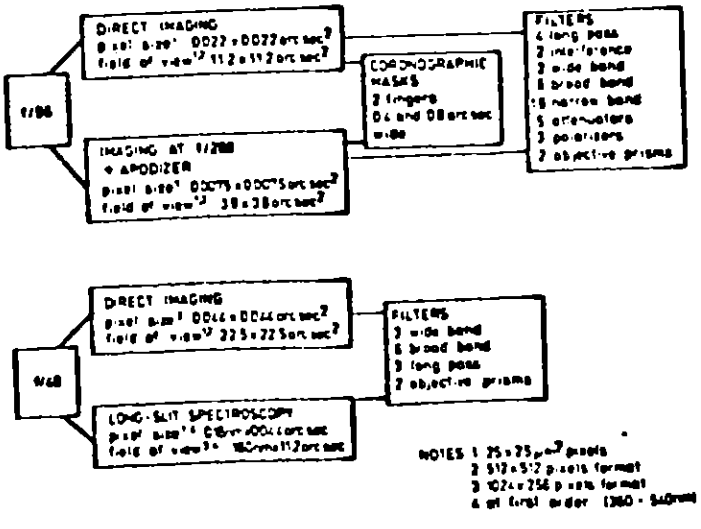
The Faint Object Camera (FOC) consists of two independent optical paths which may be used for direct imaging, objective grating imaging, polarimetric imaging, high resolution imaging as well as long slit spectroscopy. The key instrument characteristics are summarized below:

FIGURE 3.1 FOC OPTICAL PATH



Optical design of the FOC.

FIGURE 3.2 SUMMARY OF FOC MODES



The minimum efficiency of the instrument is summarized below. It is anticipated that actual efficiency will be considerably higher in the ultraviolet than the minimum figures tabulated here.

TABLE 3.1 Minimum efficiencies in the f/96 and f/48 imaging modes (unfiltered).

Wavelength (nm)	120	150	200	250	300	350	400	450	500	550	600	650	700
ST throughput	0.41	0.43	0.52	0.57	0.58	0.61	0.63	0.64	0.64	0.62	0.62	0.62	0.60
FOC optics throughput	0.50	0.50	0.53	0.57	0.61	0.65	0.69	0.70	0.70	0.70	0.70	0.70	0.70
Detector spectral response	0.05	0.07	0.10	0.13	0.13	0.11	0.09	0.07	0.05	0.03	0.015	0.004	0.0003
Total ST + FOC	0.010	0.015	0.028	0.043	0.045	0.043	0.039	0.032	0.021	0.013	0.0065	0.0018	0.00013

TABLE 3.2 Minimum efficiency in the f/48 spectrographic mode (unfiltered).

	Third order			Second order			First order		
Wavelength (nm)	120	160	180	180	240	270	360	480	540
FOC optics throughput*	0.046	0.057	0.064	0.072	0.12	0.11	0.22	0.35	0.32
Total ST + FOC efficiency	0.0009	0.0018	0.0026	0.003	0.008	0.008	0.015	0.013	0.007

* These values include the efficiencies of the grating and of the folding mirror.

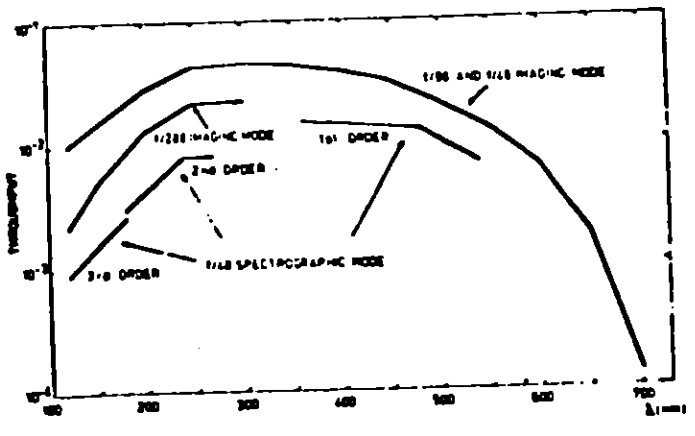


FIGURE 3.3 ST and FOC total efficiency

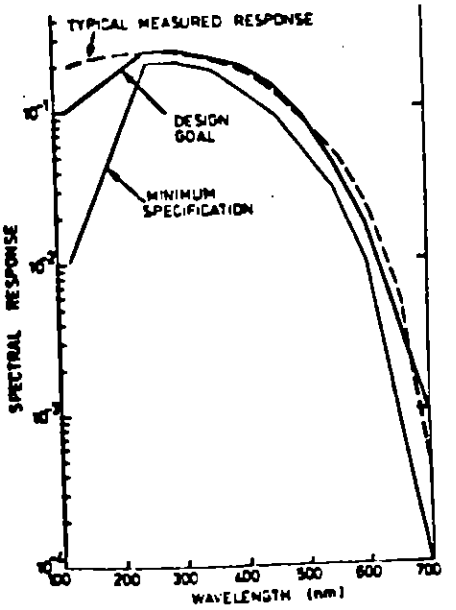


FIGURE 3.4 (right) Spectral response of the FOC detectors.

FILTER TRANSMISSION CHARACTERISTICS TABLE 3.3: The FOC f/96 optical path is equipped with the following filters:

Filters for the f/96 relay.

λ_1, λ_2 are wavelengths at 1/2 of maximum transmission.
$\Delta\lambda_2$ is the bandpass at 1/2 of maximum transmission.
Rejection is normally specified for $\lambda_1 + 6.5\,\Delta\lambda_2$.
$\Delta\lambda_{10}$ is the bandpass at 1/10 of maximum transmission.
$\Delta\lambda_{100}$ is the bandpass at 1/100 of maximum transmission.
1501 can also be used as the Strömgren Hβ continuum filter.

FOC filter name	λ_1 (nm)	λ_2 (nm)	$\Delta\lambda_2$ (nm)	Peak Transmission (%) Min.	Design goal	Rejection	$\Delta\lambda_{10}$ (nm)	$\Delta\lambda_{100}$ (nm)	Remarks
L130	130	∞	NA	90	–	5×10^{-3} at 121.6 nm	NA	NA	Ly α blocking
L370	370	∞	NA	90	–		NA	NA	5 mm GG 375
L480	480	∞	NA	90	90	10^{-5}	NA	NA	$\approx V$ filter
L630	630	∞	NA	90	–	–	NA	NA	
W165	140	200	60	30	35	5×10^{-4} at 400 nm	–	–	
W195	145	260	115	40	45	4% at 400 nm 1% at 600 nm	–	–	
W320	240	365	125	60	70		–	–	
B140	125	155	30±3	25	30	10^{-4}	–	–	
B175	155	195	40±4	25	30	10^{-4}	–	–	
B220	195	245	50±5	30	35	10^{-4}	–	–	
B275	245	305	60±6	30	35	10^{-4}	–	–	
B342	305	380	75	60	60	10^{-4} (up to 650 nm)	–	–	$\approx U$ filter
B430	380	480	100	50	50	10^{-4}	–	–	$\approx B$ filter
N120	115	125	10±1	10	15	10^{-4}	17	30	
N130	125	135	10±1	10	15	10^{-4}	17	30	
N140	135	145	10±1	10	15	10^{-4}	17	30	
N152	145	160	15±1	10	15	10^{-4}	25	45	
N170	160	180	20±2	15	20	10^{-4}	34	60	
N190	180	200	20±2	15	20	10^{-4}	34	60	
N210	200	220	20±2	15	20	10^{-4}	34	60	
N231	220	242	22±2	15	20	10^{-4}	37	66	
N253	242	264	22±2	15	20	10^{-4}	37	66	
N278	264	293	29±3	25	30	10^{-4}	50	87	
N307	293	322	29±3	25	30	10^{-4}	50	87	
N346	325	365	40	40	40	10^{-4}	–	–	u filter
N372	354	390	36±3	40	50	10^{-4}	60	110	
N410	400	420	20±2	40	50	10^{-4}	34	60	v filter
N437	415	460	45±4	50	60	10^{-4}	58	77	
N470	460	480	20±2	45	60	10^{-4}	34	60	b filter
N502	475	530	55±5	50	65	10^{-4}	72	94	
N550	540	560	20±2	50	65	10^{-4}	34	60	y filter
N600	570	630	60±6	50	65	10^{-4}	78	102	
1486	484	488	4±0.4	50	60	10^{-4}	7±0.7	12±0.2	Hβ filter
1501	497.2	504.2	7±0.7	50	60	10^{-4}	9±0.9	12±0.2	(λ_0 = 500.7 nm)

TABLE 3.4: The FOC f/48 optical path is equipped with the following filters:

FOC filter name	λ_1 (nm)	λ_2 (nm)	$\Delta\lambda_2$ (nm)	Peak Transmission (%) Min.	Design goal	Rejection	$\Delta\lambda_{10}$ (nm)	$\Delta\lambda_{100}$ (nm)	Remarks
L130	130	∞	NA	90	–	5×10^{-3} at 121.6 nm	NA	NA	Ly α blocking
L180	180	∞	NA	90	90	–	NA	NA	1st and 2nd order selection
L305	305	∞	NA	90	90	10^{-4}	NA	NA	1st order selection
W150	120	180	60	40	40	10^{-3} at 300 nm	100	180	3rd order selection $\lambda_0 = 150$ nm $\lambda_{10} = 200$ nm. $\lambda_{100} = 240$ nm
W195	145	260	115	40	45	4% at 400 nm 1% at 600 nm	–	–	2nd and 3rd order selection
W215	180	250	70	50	55	7×10^{-3} at 400 nm 10^{-3} at 600 nm	–	–	2nd order selection
B140	125	155	30 ± 3	25	30	10^{-4}	–	–	
B175	155	195	40 ± 4	25	30	10^{-4}	–	–	
B220	195	245	50 ± 5	30	35	10^{-4}	–	–	
B275	245	305	60 ± 6	30	35	10^{-4}	–	–	
B342	305	380	75	60	60	10^{-4} (up to 650 nm)	–	–	$\approx U$ filter
B430	380	480	100	50	50	10^{-4}	–	–	$\approx B$ filter

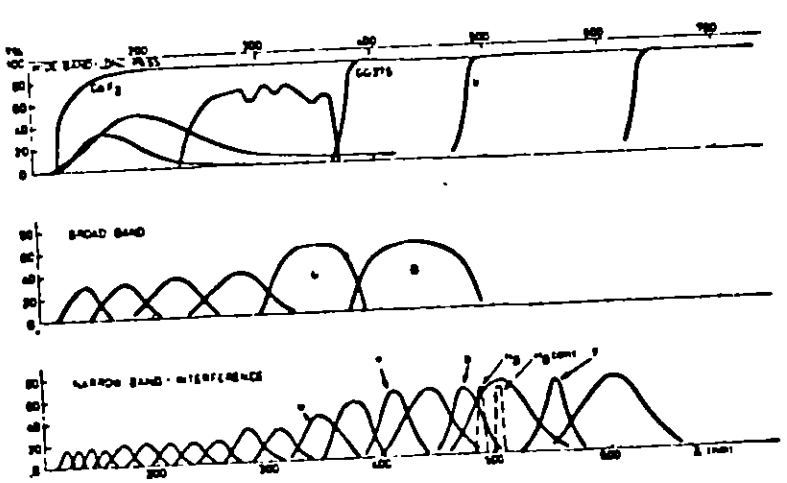
TABLE 3.5: Distribution of transmission elements on the four wheels of the f/96 optical relay.

Filter	Total number	Wheel A	Wheel B	Wheel C	Wheel D
Long pass	4	–	1(L630)	1(L130)	2(L370.480)
Wide band	3	2(W165.195)	–	–	1(W320)
Broad band	6	–	–	–	6(B140–430)
Narrow band	19	8(N120–231)	1(N600)	10(N253–550)	–
Interference	2	–	–	–	2(1486.501)
Objective prisms	2	–	2	–	–
Polarizers	3	–	3	–	–
Attenuators	5	1($\Delta m = 1$)	4($\Delta m = 2.4.6.8$)	–	–
Holes	4	1	1	1	1
Sum	48	12	12	12	12

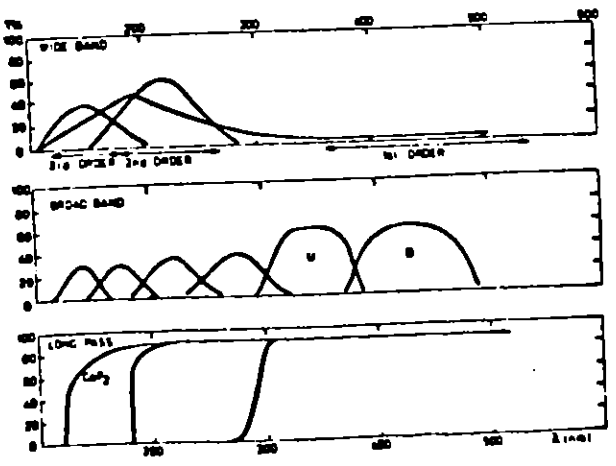
TABLE 3.6: Filters on the f/48 optical path are distributed as indicated in the table below:

Filter	Total number	Wheel A	Wheel B
Long pass	3	2(L130.180)	1(L305)
Wide band	3	–	3(W150–215)
Broad band	6	3(B275–430)	3(B140–220)
Objective prisms	2	2	–
Holes	2	1	1
Total	16	8	8

FIGURE 3.5: Idealized filter transmission curves are plotted below as a function of wavelength:



The f/96 filters.



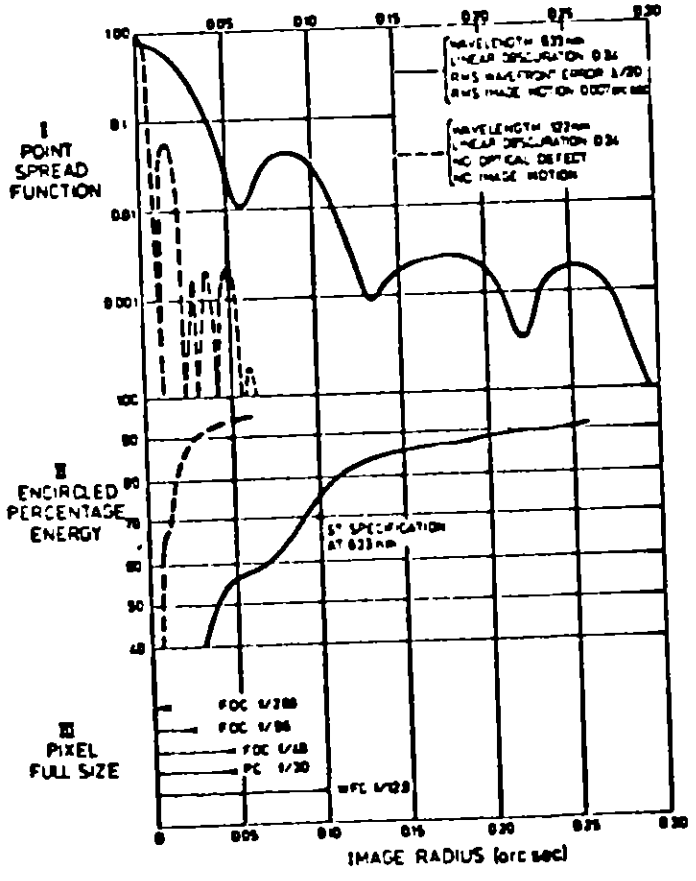
The f/48 filters.

TABLE 3.7: The FOC long slit spectrograph gratings have the following properties:

Table 5. The three orders of the spectrograph.

Order	Spectral range	Projected slit width	Pixel size
1st	360–540 nm	0.40 nm	0.18 nm
2nd	180–270 nm	0.20 nm	0.09 nm
3rd	120–180 nm	0.13 nm	0.06 nm

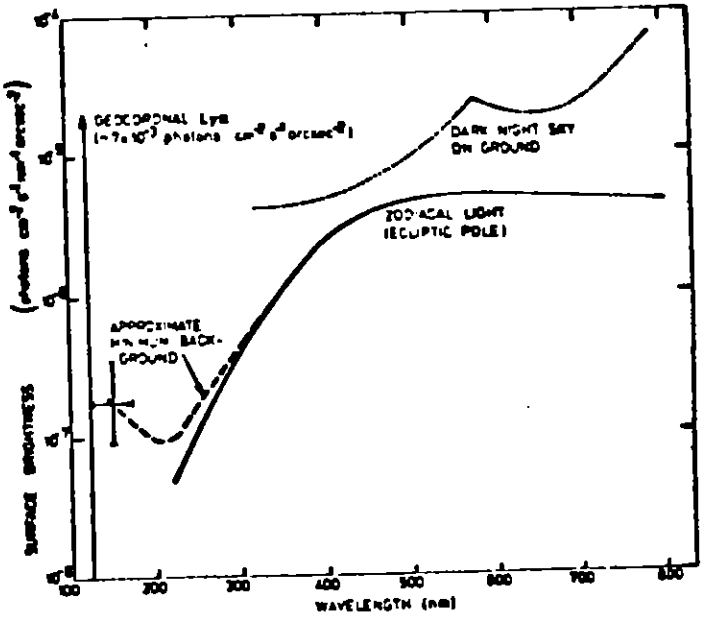
FIGURE 3.6: The FOC point spread function has the following design characteristics:



Each optical path of the FOC is equipped with two objective prisms: one single prism of magnesium fluoride for operation in the far UV with spectral resolution of 50 and efficiency of 90% at 150 nm, and one double prism of silica with spectral resolution of 100 in f/96 and 50 in f/48 and efficiency of 80% at 250 nm. The pass-band of the objective prisms is 120-700 nm for the far UV prism and 200-700 for the near UV prism.

The f/96 optical path is equipped with polarizers oriented in three different position angles (0,60 and 120 degrees) with spectral range from 130-600 nm. The angular separation of the ordinary and extraordinary beam is such that only the image from one of the beams will fall on a single 512x512 format image. The transmission of the plane polarized light is 10% at 130 nm, 50% at 180 nm and 85% at 250 nm.

FIGURE 3.7: The sky background spectrum is characterized below:



Sky spectrum from space and ground. The dashed line joining the zodiacal light spectrum to the mean point derived from various recent measurements around 150 nm is an approximation to the average minimum background.

ASSUMPTIONS IN THE CALCULATION OF THE LIMITING MAGNITUDES
The following assumptions have been made in estimating the limiting magnitudes indicated in the summary table:

- o limiting magnitudes were calculated for the U filter assuming a bandpass of 100 nm. This is larger than the true U bandpass of 75 nm.
- o The source type used is an unreddened A0 star which is assumed to produce 6.1 photons/nm/s at 435 nm at the focal plane of the ST.
- o Detector dark count rates are assumed to be negligible
- o Stray light, scattered light, etc is assumed to be described as in figure 3.7.

TABLE 3.8 BRIGHT LIMITING MAGNITUDES FOR SELECTED MODES

In this table the first row gives the field of view (arcsec); the second row gives the upper magnitude for point sources with 1% photometric accuracy on the central pixel, the third row gives the corresponding magnitude per arcsec^2 for extended sources. Upper magnitudes for about 10% photometric accuracy on the central pixel are about 1.7 magnitude brighter. Numbers in brackets refer to the extended axis of the 1-D zoom mode. In the *f*/48 spectrographic mode the format is limited by the slit length of 20 arcsec.

FOC mode: / Pixel size: / FOC format	*f*/96 Imaging 0.022 × 0.022 (0.044)	*f*/288 Imaging 0.0075 × 0.0075 (0.015)	*f*/48 Imaging 0.044 × 0.044 (0.088)	*f*/48 Spectroscopy 0.18 nm × 0.044 (0.088) (first order)
512 × 512 pixels	11.2 × 11.2 (22.5) 21.0 *V* 15.2 *V*	3.8 × 3.8 (7.6) 18.3 *V* 12.5 *V*	22.5 × 22.5 (45) 22.5 *V* 17.7 *V*	90 nm × 20 15.5 *B* 10.7 *B*
1024 × 256 pixels	22.5 × 5.6 (11.2) 21.0 *V* 15.2 *V*	7.6 × 1.9 (3.8) 18.3 *V* 12.5 *V*	45 × 11.2 (22.5) 22.5 *V* 17.7 *V*	180 nm × 11.2 (20) 15.5 *B* 10.7 *B*
256 × 256 pixels	5.6 × 5.6 (11.2) 19.5 *V* 13.7 *V*	1.9 × 1.9 (3.8) 16.8 *V* 11.0 *V*	11.2 × 11.2 (22.5) 21.0 *V* 15.2 *V*	45 nm × 11.2 (20) 14.0 *B* 9.2 *B*
128 × 128 pixels	2.8 × 2.8 (5.6) 18.0 *V* 12.2 *V*	0.95 × 0.95 (1.9) 15.3 *V* 9.5 *V*	5.6 × 5.6 (11.2) 19.5 *V* 13.7 *V*	22.5 nm × 5.6 (11.2) 12.5 *B* 7.7 *B*
64 × 64 pixels	1.4 × 1.4 (2.8) 16.6 *V* 10.8 *V*	0.47 × 0.47 (0.95) 13.9 *V* 8.4 *V*	2.8 × 2.8 (5.6) 18.1 *V* 12.3 *V*	11.2 nm × 2.8 (5.6) 11.1 *B* 6.3 *B*
1024 × 512 pixels (8 bit)	22.5 × 11.2 (22.5) 21.8 *V* 16.0 *V*	7.6 × 3.8 (7.6) 19.1 *V* 13.3 *V*	45 × 22.5 (45) 23.3 *V* 18.5 *V*	180 nm × 20 16.3 *B* 11.5 *B*

TABLE 3.9 FAINT LIMITING MAGNITUDES FOR SELECTED MODES

Magnitude	Time (s) for S/N = 10	S/N in 1000 s	S/N in 10 h
m_L	*f*/96 (*point sources*)		
21	25	64	380
22	63	40	240
23	160	25	150
24	420	15	93
25	1 200	9.3	56
26	3 600	5.3	32
27	13 000	2.7	16
28	61 000	1.3	7.7
29	330 000	0.55	3.3
30	1 900 000	0.23	1.4

Magnitude	Time (s) for S/N = 10	S/N in 1000 s	S/N in 10 h
m_L arcsec^{-2}	*f*/96 (*extended objects*)		
15	35	58	320
16	89	34	200
17	220	21	130
18	560	13	80
19	1 400	8.4	50
20	3 700	5.2	31
21	9 800	3.2	19
22	18 000	1.9	11
23	91 000	1.1	6.3
24	360 000	0.53	3.2
25	1 800 000	0.24	1.4

Magnitude	Time (s) for S/N = 10	S/N in 1000 s	S/N in 10 h
m_L	*f*/48 (*point sources*)		
21	25	64	380
22	62	40	250
23	160	25	150
24	410	16	94
25	1 100	9.5	57
26	3 300	5.5	33
27	12 000	2.9	18
28	49 000	1.4	8.5
29	250 000	0.63	3.8
30	1 400 000	0.26	1.6

Magnitude	Time (s) for S/N = 10	S/N in 1000 s	S/N in 10 h
m_L arcsec^{-2}	*f*/48 (*extended objects*)		
17	14	84	500
18	36	53	320
19	91	33	200
20	230	21	120
21	610	13	77
22	1 700	7.7	46
23	5 300	4.4	26
24	20 000	2.3	14
25	90 000	1.1	6.3
26	480 000	0.46	2.7
27	2 800 000	0.19	1.1

Magnitude	Time (s) for S/N = 10	S/N in 1000 s	S/N in 10 h
m_B	*f*/48 *spectrographic mode* (*A*0 *point sources*)		
12	5	140	830
13	13	87	520
14	33	55	330
15	83	35	210
16	210	22	130
17	520	14	83
18	1 300	8.7	52
19	3 400	5.4	33
20	8 900	3.4	20
21	25 000	2.0	12
22	77 000	1.1	6.8
23	290 000	0.59	3.5

Magnitude	Time (s) for S/N = 10	S/N in 1000 s	S/N in 10 h
m_B arcsec^{-2}	*f* 48 *spectrographic mode* (*A*0 *extended objects*)		
8	8	120	690
9	19	73	440
10	47	46	280
11	120	29	170
12	300	18	110
13	750	11	69
14	1 900	7.2	43
15	4 900	4.5	27
16	13 000	2.7	17
17	38 000	1.6	9.7
18	130 000	0.89	5.3

4.0 WIDE FIELD AND PLANETARY CAMERA

The Wide Field and Planetary Camera (WFPC) consists of two separate optical paths which have independent detector systems and share filters, calibration lamps, and entrance apertures. The key instrument characteristics are summarized below:

TABLE 4.1

Detector Characteristics:

Readout Noise	11-14 electrons
Dark Current	<0.001 electrons per pixel per sec.
Digitization level bits	12
Electrons/bit	7.5
Exposure Time	0.12-100,000 seconds
Intrascene dynamic range	1500
Capable of observing through South Atlantic Anomaly:	NO

Camera Specific Characteristics:

Parameter	WFC	PC
Field of View	2.63x2.63 arcmin	68x68 arcsec
Pixel Size	0.1 arcsec	0.043 arcsec
Overall dynamic range	0.12-3000 sec	0.12-3000 sec
(spec)	13<m <28.5 (spec)	9.0<m <28.0

FIGURE 4.1 WFPC OPTICAL PATH

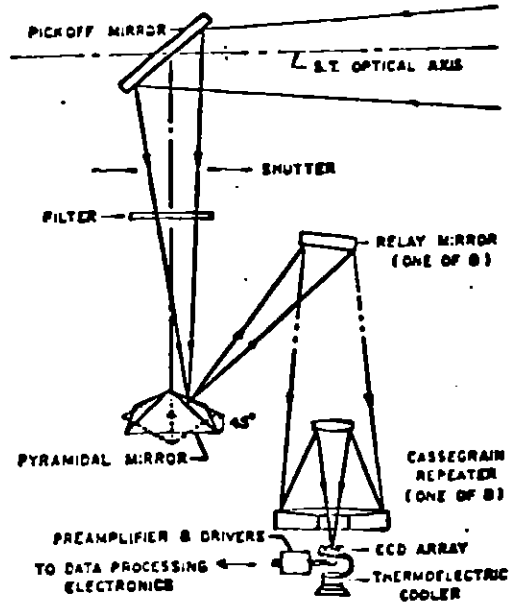
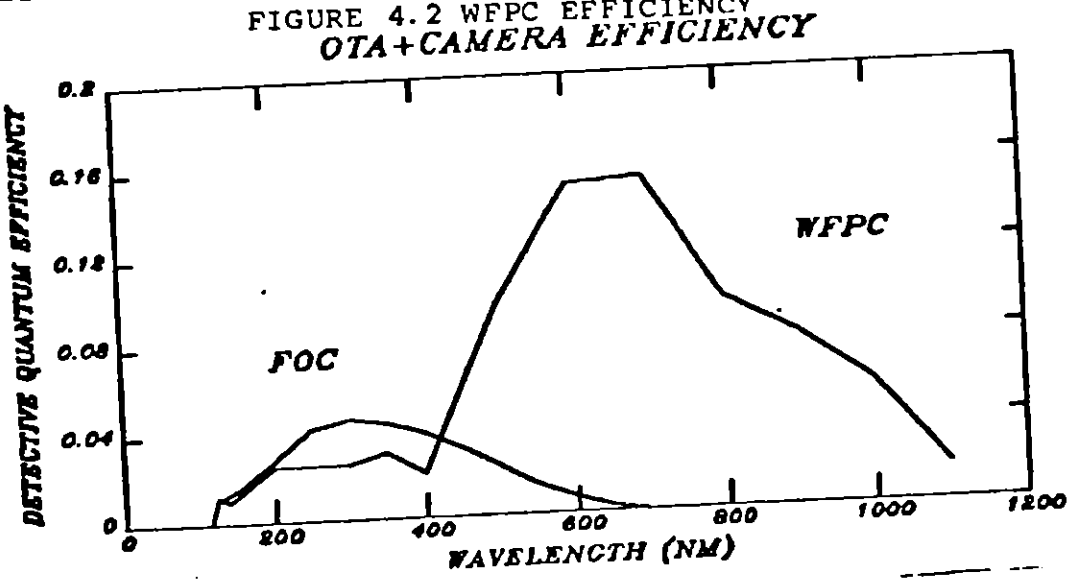


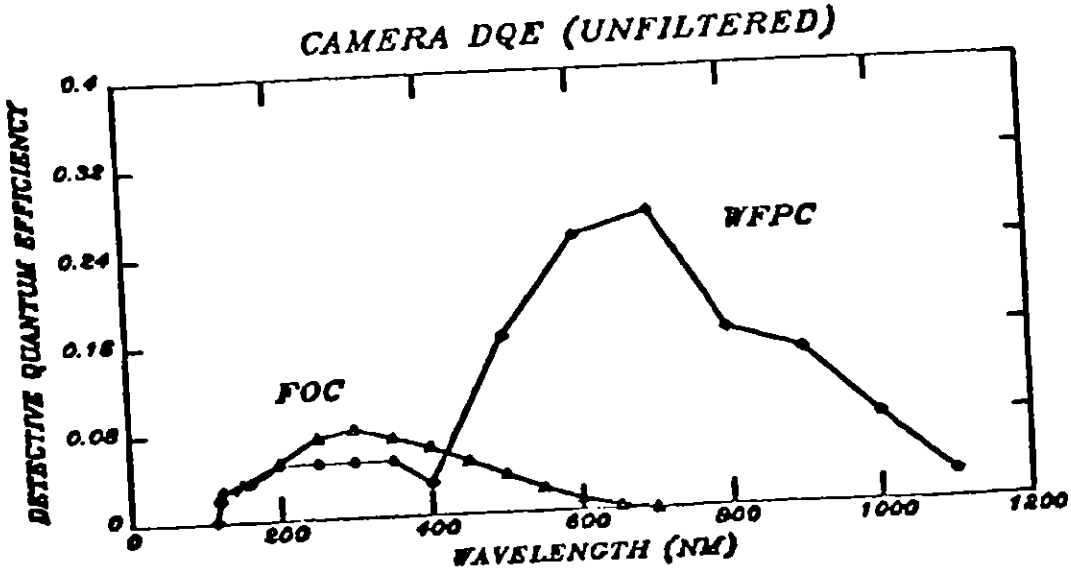
TABLE 4.2 DETECTIVE QUANTUM EFFICIENCY

The estimated detective quantum efficiency of the unfiltered WFPC optical path is given below:

Wavelength (nm)	WFPC (%)	Wavelength (nm)	WFPC (%)
115	0.1	400	16
120	2.5	500	25
125	3.0	600	27
140	3.0	700	16
160	3.5	800	13
200	5.0	900	7
250	5.0	1000	2
300	5.0	1100	
350	5.0		

FIGURE 4.2 WFPC EFFICIENCY





FILTER TRANSMISSION CHARACTERISTICS

The WFPC is equipped with 42 filters, 3 gratings, and 3 polarizers mounted on the 12 filter wheels of the Selectable Optical Filter Assembly (SOFA). The WFPC IDT has identified 137 combinations of filters and polarizer elements which will be most heavily used. The table below summarizes the filter characteristics.

TABLE 4.3 FILTER PROPERTIES

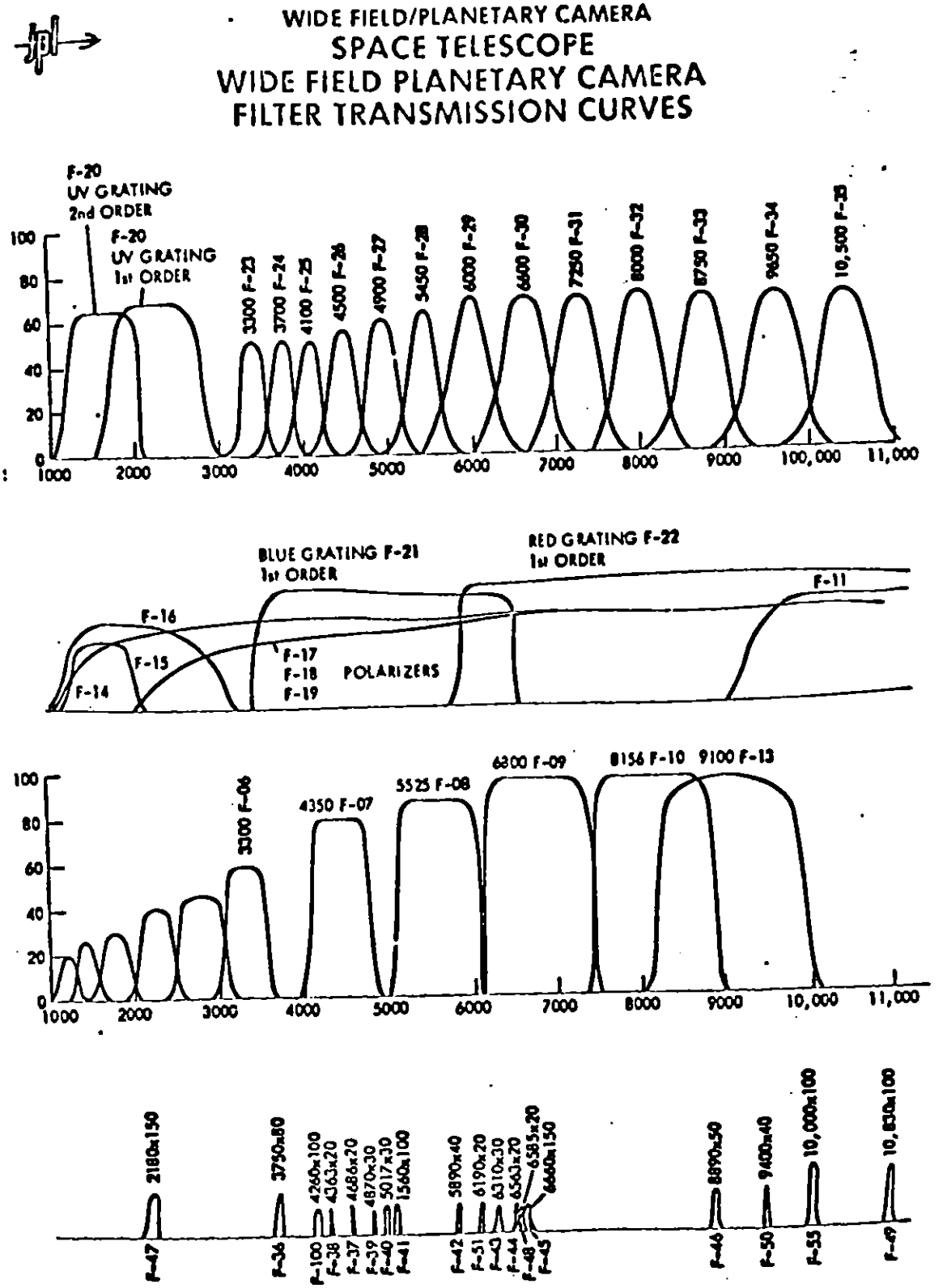
FILTER	CENTRAL WAVELENGTH (A)	WIDTH (A)	COMMENT
WIDE BAND FILTERS			
1	1216	150	WIDE LYMAN ALPHA
2	1450	290	20%
3	1800	360	20%
4	2250	450	20%
5	2800	560	20%
6	3300	600	U
7	4350	900	B
8	5525	950	V
9	6800	1400	R
10	8150	1700	I
11	10000	(9000 TO CUTOFF)	LONG WAVELENGTH PASS
12	5950	2500	WIDE V
13	9100	(7200 TO CUTOFF)	WIDE R
14	1280 TO BLOCKER	LONG PASS	WIDE UV
MISCELLANEOUS ITEMS			
15	-	1280-2000	UV BLOCKER
16	-	1280-3200	UV BLOCKER
17	POLARIZER	-	0 DEGREE
18	POLARIZER	-	60 DEGREE
19	POLARIZER	-	120 DEGREE
20	UV GRATING	-	CALCIUM FLUORIDE
SUBSTRATE			
21	B GRATING	-	ON BG-38 SUBSTRATE
22	R GRATING	-	ON OG-570 SUBSTRATE

TABLE 4.3 (CONTINUED)

FILTER	CENTRAL WAVELENGTH (A)	WIDTH (A)	COMMENTS
10% OF WAVELENGTH FILTERS			
23	3300	330	10%
24	3700	370	10%
25	4100	410	10%
26	4500	450	10%
27	4900	490	10%
28	5450	545	10%
29	6000	600	10%
30	6600	660	10%
31	7250	725	10%
32	8000	800	10%
33	8750	875	10%
34	9650	965	10%
35	10500	1050	10%
NARROW FILTERS			
36	3750	80	3727 REDSHIFTED
37	4686	20	He II
38	4363	20	O III
39	4870	30	H BETA
40	5017	30	O III REDSHIFTED
41	5160	100	C2 AND Mg II
42	5890	40	He I AND Na D
43	6310	30	O I REDSHIFTED
44	6563	20	H ALPHA
45	6660	150	H ALPHA REDSHIFTED
46	8890	50	METHANE (PLANETARY)
47	10830	100	He I
48	6585	20	NII, REDSHIFTED H ALPHA, VIRGO

Idealized filter transmission curves are plotted below with transmission as a function of wavelength. Please keep in mind that the UV filters will be subject to red leaks when viewing late type stars and other red objects due to the very high quantum efficiency of the CCDs in the red.

FIGURE 4.3 WFPC filter transmission curves:



There are three objective gratings mounted in the filter assembly which cover the far UV (130-300 nm) in 2 cross dispersed orders (130-220 nm) and (160-300 nm), the blue (300-600 nm) and the red (600-1200 nm). The table below lists the grating dispersions at selected wavelengths.

TABLE 4.4 GRATING DISPERSION

GRATING/ORDER	DISPERSION (A/PIXEL) WFC	PC
UV AT 2400 A		
FIRST ORDER	12.1	5.2
SECOND ORDER	15.0	6.4
BLUE AT 5000 A	55.5	23.8
RED AT 7800 A	100.8	47.6

ASSUMPTIONS IN THE CALCULATION OF THE LIMITING MAGNITUDES

The WFPC sample limiting magnitudes presented in the summary table were calculated under the following assumptions:

- sky background corresponding to m=23 per square arcsecond contributed 100 electrons per 0.01 arcsecond squared pixel in 3000 seconds
- filter transmission was estimated to be 50%
- U filter bandpass was assumed to be 60 nm.
- dark counts from the detector were neglected
- readout noise was assumed to be 12 electrons
- for the WFC an effective image size for a point source of 6 pixels has been assumed
- for the PC an effective image size of 39 pixels has been assumed.
- no glow phenomena, or other environmental stray or scattered light sources were considered.
- exposure time estimates have been doubled in order to provide 2 images per field for cosmic ray hit removal

5.0 HIGH SPEED PHOTOMETER

The High Speed Photometer (HSP) is designed for high signal to noise, high time resolution photometry and filter polarimetry in the bandpass 110-550 nm. The key instrument specifications are listed below:

TABLE 5.1 KEY INSTRUMENT SPECIFICATIONS

PARAMETER	SPECIFICATION
TIME RESOLUTION (MICROSECONDS)	10
WAVELENGTH RANGE	120-870 (PHOTOMETRY) 210-340 (POLARIMETRY)
ANGULAR RESOLUTION (ARCSEC)	0.4 1.0 10 (ACQUISITION)
DYNAMIC RANGE (MAGNITUDE)	10**7 24-1 IN B
PHOTOMETRIC ACCURACY	0.1%
HSP EFFICIENCY (V BAND)	5%
CAN OPERATE IN SAA	PROBABLY

FIGURE 5.1 HSP DETECTOR ARRANGEMENT

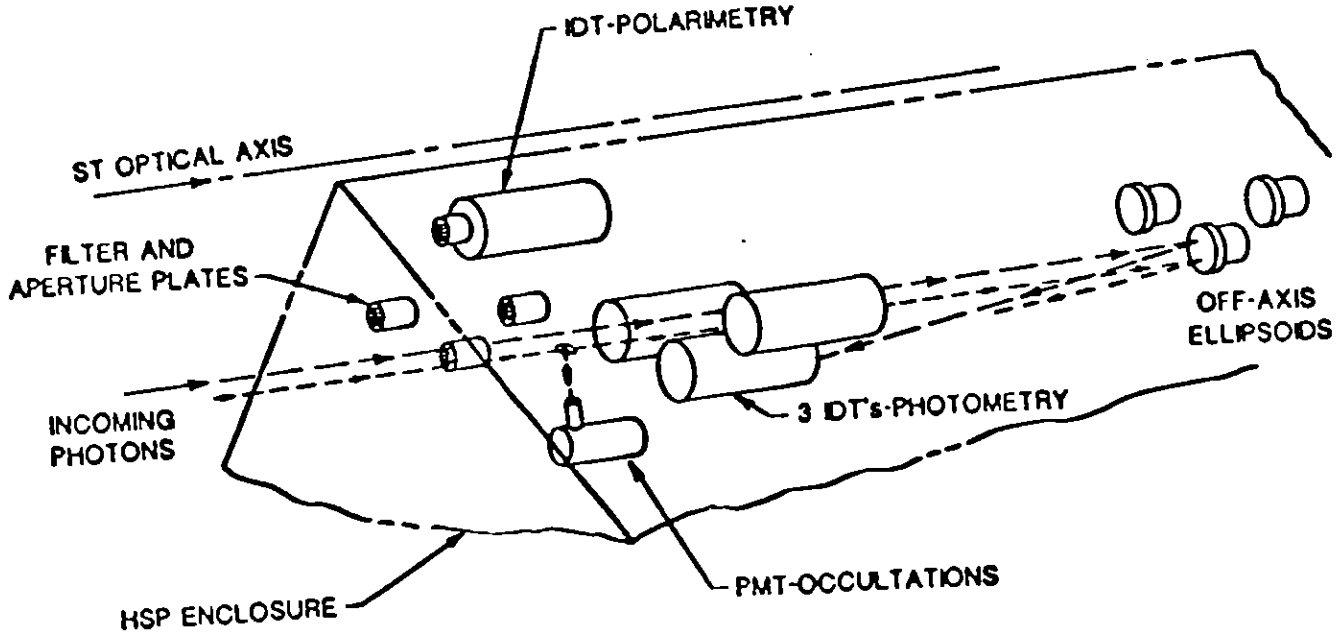
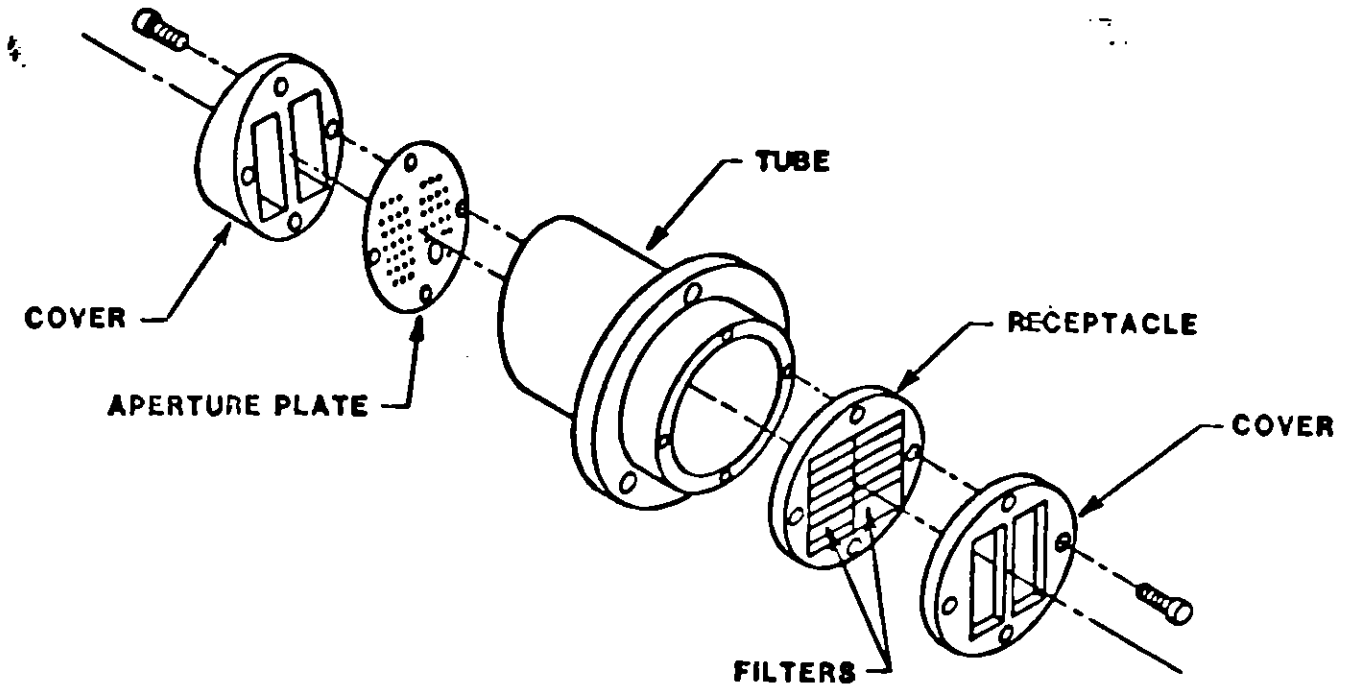


FIGURE 5.2 HSP APERTURE/FILTER ASSEMBLY



The transmission characteristics of the HSP filters are not known at present (the filters still have to be manufactured), but are intended to be the same as the comparable FOC filters.

TABLE 5.2 HSP FILTERS

Photometry		Photometry		Polarimetry	
λ	FWHM	λ	FWHM	λ	FWHM
1200	200	3400	(u)	2175	200
1400	200	4100	(v)	2450	300
1550	200	4700	(b)	2800	300
1700	200	4860	Hβ	3400	300
1800	300	5500	(y)		
2175	200	5500	V		
2450	300	6200	R		
2800	300	1800-7000			
1200-3000					
1800-3000					

FWHM = full-width at half maximum transmission

One important feature of the HSP is the possibility of high time resolution measurement of an object. The minimum time resolution is achieved in the digital mode where integration times of 10 microseconds are possible for one aperture and wavelength. If two apertures are to be monitored (as for target and sky observations) with the same detector at the same wavelength, there is a minimum deflection time (within the image dissector tube) of 1 millisecond between observations. If two detectors are used simultaneously, the minimum time resolution possible is 14 microseconds. In the analog mode the shortest integration time in the 1 nanoamp range is 4 millisec. In the 10 microamp range the shortest integration time is 0.4 millisec. Changes in wavelength (which involve slewing the telescope) may require tens of seconds. All of these factors are important in estimating the time required to obtain science data.

FIGURE 5.3 DISTRIBUTION OF APERTURES ASSOCIATED WITH EACH FILTER

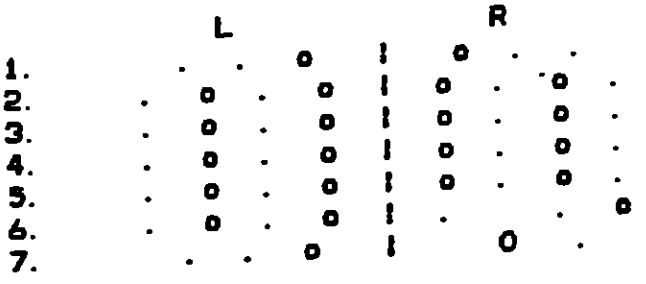
Each filter associated with a particular HSP image dissector tube or the one photomultiplier tube is associated with a number of apertures. The distribution of apertures is indicated schematically below:

1. 0.4 arcsec diameter--.

2. 1.0 arcsec diameter--o

3. 10 arcsec diameter--O

UV1 AND UV2



VIS
identical to UV1 and UV2 except with addition of

for the photomultiplier tube

6.0 FAINT OBJECT SPECTROGRAPH

The Faint Object Spectrograph (FOS) operates as a moderate to low resolution spectrograph in the wavelength range 1200-9000 A. Additional capabilities are spectropolarimetry, and time resolved spectroscopy. The key instrument characteristics are summarized below:

TABLE 6.1 FOS INSTRUMENT PERFORMANCE SPECIFICATIONS

PARAMETER		SPECIFICATION
SPECTRAL RESOLVING POWER	$\lambda/\Delta\lambda$	1200 MODERATE 200 LOW
WAVELENGTH RANGE		120-700 (SPECTROSCOPY) 120-320
(SPECTROPOLARIMETRY)		
ANGULAR RESOLUTION (ARCSEC,APERTURE LIMITED)		0.25
TIME RESOLUTION (MILLISEC)		20
DYNAMIC RANGE		10**6
PHOTOMETRIC ACCURACY		1%

FIGURE 6.1:The efficiencies of the first order gratings are summarized below:

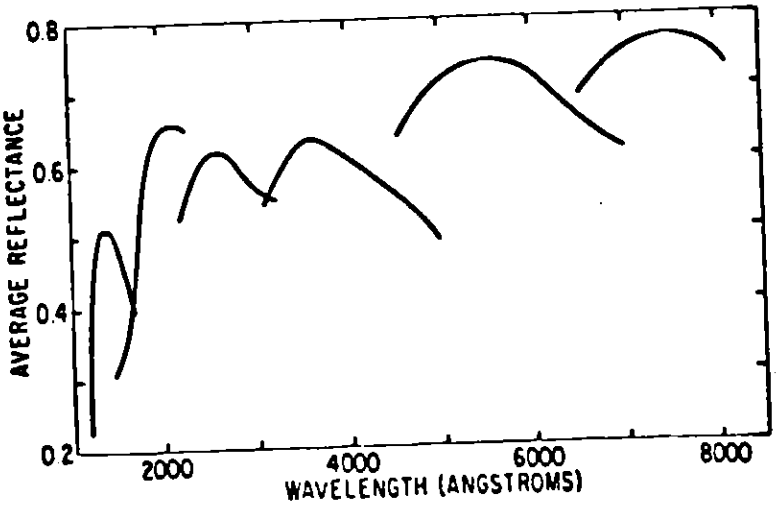


FIGURE 6.2: The efficiencies of the low resolution dispersers are summarized below,left:

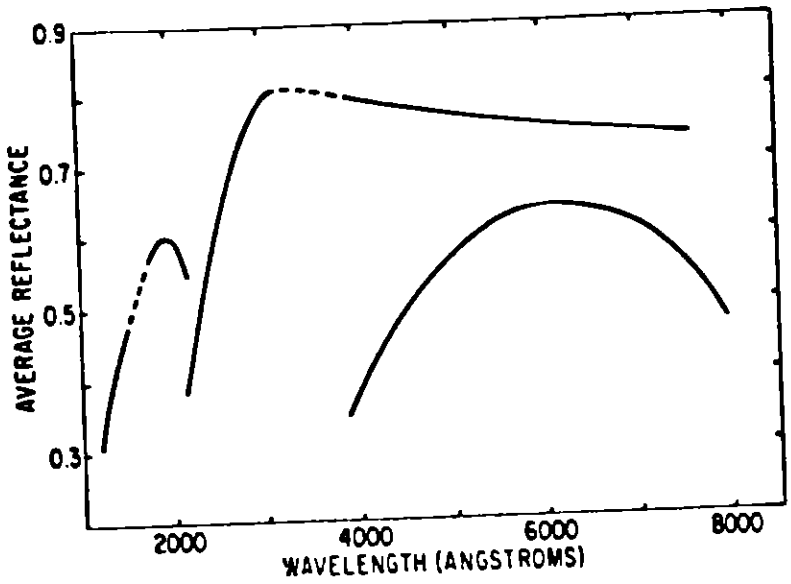
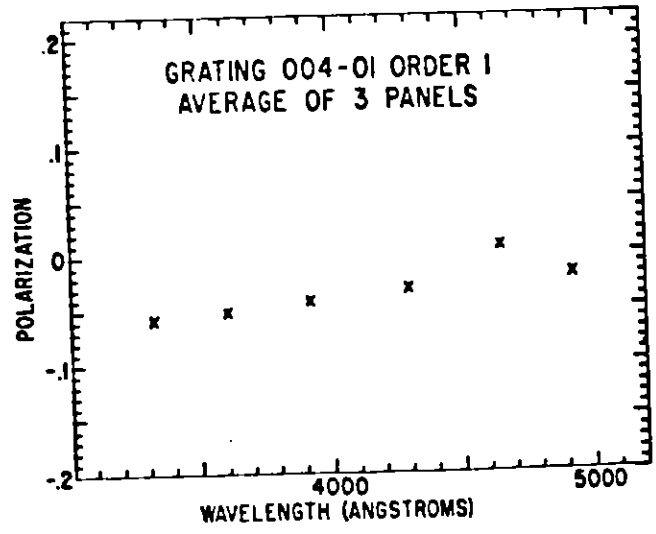


FIGURE 6.3: The polarization produced by a sample FOS flight grating is plotted below.



The FOS is equipped with a number of apertures:

TABLE 6.2: FOS APERTURES

Number	Shape	Size* (arcsec)	Center-to Center Separation (arcsec)	Special Purpose
Single	Round	0.5 dia	N/A	Polarimetry
Single	Round	0.3 dia	N/A	Polarimetry
Single	Round	1.0 dia	N/A	Polarimetry
Single	Round	N/A	N/A	Light Shield
Blank	N/A	N/A	N/A	Target Acquisition
Single	Square	4.3	3.0	Object & Sky
Pair	Square	0.5	3.0	Object & Sky
Pair	Square	0.25	3.0	Object & Sky
Pair	Square	0.1	3.0	Object & Sky
Pair	Square	1.0	N/A	Extended Objects
Single	Rectangular	0.25 x 2.0	N/A	Surrounding Nebulosity
Single	Square**	2.0	N/A	Surrounding Nebulosity
Single	Rectangular	0.7 x 2.0	N/A	
		Failsafe Entrance Aperture		
Pair	Square	0.5 and 4.3	4.4	Target Acquisition & Spectroscopy

* For rectangular apertures, first dimension is along dispersion, second perpendicular to dispersion.

** With occulter bar which is 0.3 arcsec wide in cross-dispersion direction.

TABLE 6.3: GRATING PROPERTIES

Element	Resolution at Central Wavelength ($R = \lambda/\Delta\lambda$)	Wavelength (nm) Min	Max
Grating H13	1200	110	164
Grating H19	1200	153	228
Grating H27	1200	221	329
Grating H40	1200	319	474
Grating H57	1200	459	683
Grating H78	1200	626	931
Grating L16	200	110*	220**
Prism	100	250	700
Grating L60	200	400	800
Mirror	1	110	900

Blocking Filters

Element	Wavelengths (nm) T=1%	T=90%	Minimum Wavelength (nm) Mode	Transmission at Min. Wavelength
FH27 = fused silica	>165	<200	221	93%
FH40 = WG 305	290	340	319	87%
FH57 = GG375 G34	355	425	459	91%
FH78 = OG 530	510	550	626	91%
FL60 = CG375 G34	355	425	400	85%

* Resolution is about 400 at 250 nm.

** Resolution is about 25 at 700 nm.

POLARIZATION DATA The transmission efficiency of the FOS for spectropolarimetric observations is a function of the detector and grating sensitivities, as well as the Wollaston prism transmission efficiency and the efficiency of the waveplate as a function of angle. The Wollaston transmission efficiency can be summarized as follows:

TABLE 6.4 POLARIZER TRANSMISSION

wavelength (A)	1200	1600	2400
transmission (%)	20	60	80

TABLE 6.5: The efficiency of the waveplate as a function of retardation angle is given below:

Retardations of the Flight Waveplates

λ(Å)	Waveplate A δ	Waveplate A Efficiency linear	Waveplate A Efficiency circular	Waveplate B δ	Waveplate B Efficiency linear	Waveplate B Efficiency circular
1175	-108°	.65	.95	-93°	.53	1.00
1200	100°	.59	.98	0°	0	0
1216	215°	.91	.57	90°	.50	1.00
1250	360°	0	0	161°	.97	.33
1300	460°	.59	.98	228°	.83	.74
1350	482°	.76	.85	247°	.70	.92
1400	485°	.79	.82	250°	.67	.94
1450	480°	.75	.87	241°	.74	.87
1500	468°	.65	.95	238°	.76	.85
1600	439°	.85	.98	226°	.85	.72
2537	251°	.66	.94	123°	.77	.85
3650	163°	.98	.29	84°	.45	.99
6328	95°	.54	.99	43°	.13	.68

TABLE 6.6: The polarization accuracy for a sample A0 star is given below:

Polarization Accuracy for A0 Star, V=15, Exposure Time = 20 Minutes

(Å)	% Accuracy For Linear*	% Accuracy For Circular**
1216	6.4	5.8
1500	1.9	1.5
2000	0.89	0.74
2500	0.66	0.54
3000	0.63	0.58

* Standard deviation in Stokes parameter ratios Q/I and U/I
** Standard deviation in Stokes parameter V

FIGURE 6.4: OVERALL SYSTEM SENSITIVITY

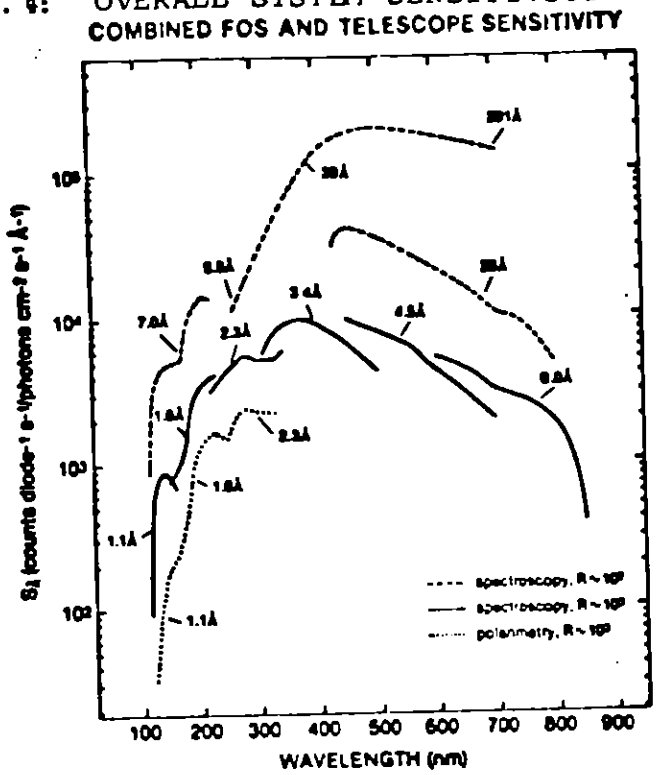
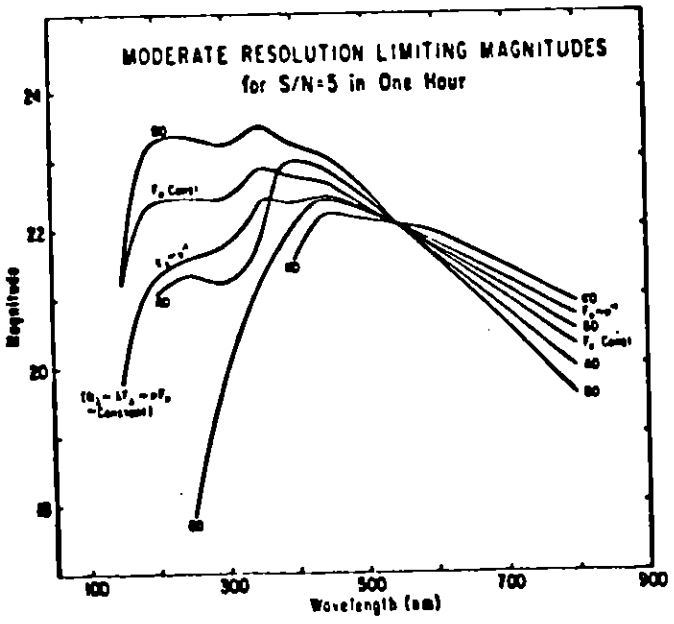
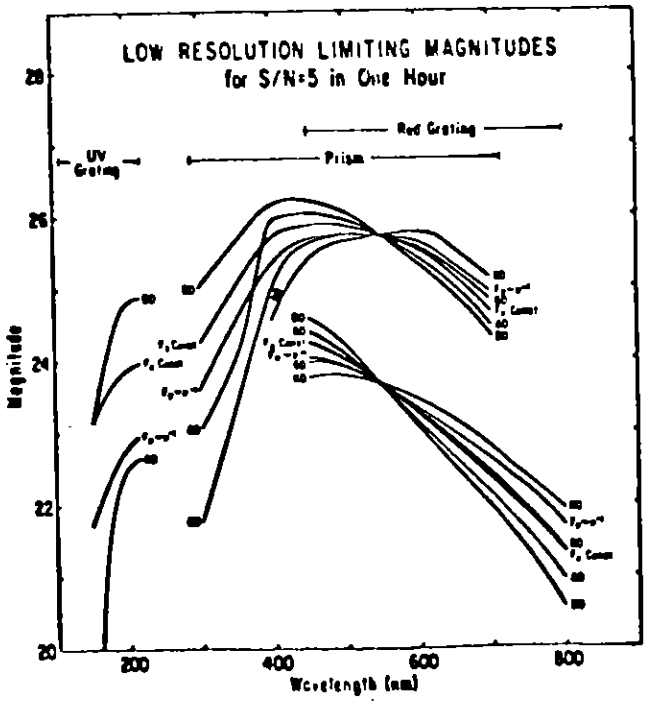


FIGURE 6.5: FAINT LIMITING MAGNITUDES



Limiting V Magnitudes for several flux distributions which produce 0.01 counts/sec/diode for moderate-resolution FOS spectroscopy (R=1200). With quarter-arcsecond aperture, night sky is negligible.



Limiting V magnitudes for low resolution FOS spectroscopy (R=200 for gratings, R strongly varying for prism). With quarter-arcsecond aperture, sky is significant only with the prism between 400 and 500 nm (e.g. for observing 25-26 magnitude objects).

7.0 HIGH RESOLUTION SPECTROGRAPH

The High Resolution Spectrograph (HRS) is designed for moderate to high resolution vacuum ultraviolet spectroscopy. The key instrument specifications are listed below:

TABLE 7.1: HRS SPECIFICATONS

PARAMETER	SPECIFICATION
SPECTRAL RESOLVING POWER	10**5, 2x10**4, 2x10*3
WAVELENGTH RANGE	110-320 NM
PRECISION OF WAVELENGTH CALIBRATION	APPROX. 0.5 RESOLUTION ELEMENT (1.5 KM/S FOR ECHELLE)
ANGULAR RESOLUTION (ARCSEC, APERTURE LIMITED)	0.25 2.0
INTEGRATION PERIOD	50 MS
INTEGRATION TIME	50 MS <DELTA T<12.75S
DYNAMIC RANGE	10**6
PHOTOMETRIC ACCURACY	1%
CAN OPERATE IN SAA	MAYBE
FORMAT	500 DIODES IN LINEAR ARRAY
MAXIMUM ACCUMULATED COUNTS/INTEGRATION	65,535

FIGURE 7.1 HRS OPTICAL PATH

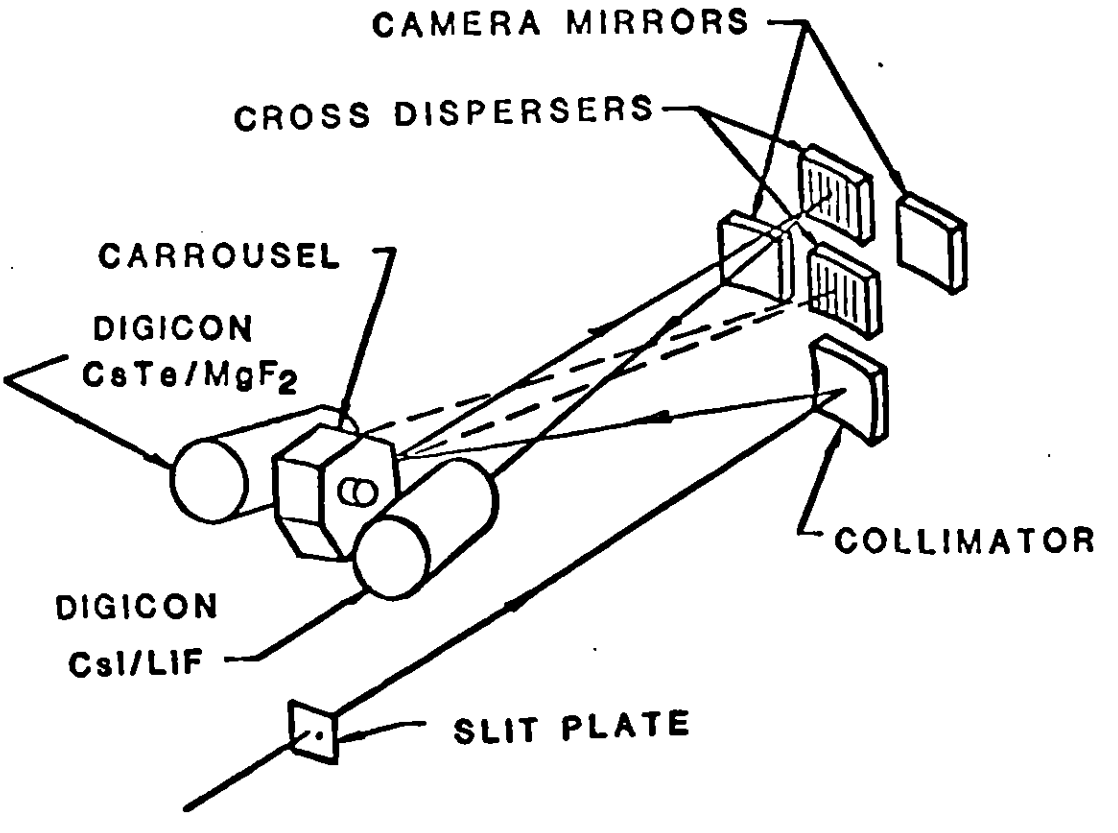


FIGURE 7.2: LABORATORY CALIBRATION MEASURED SENSITIVITY

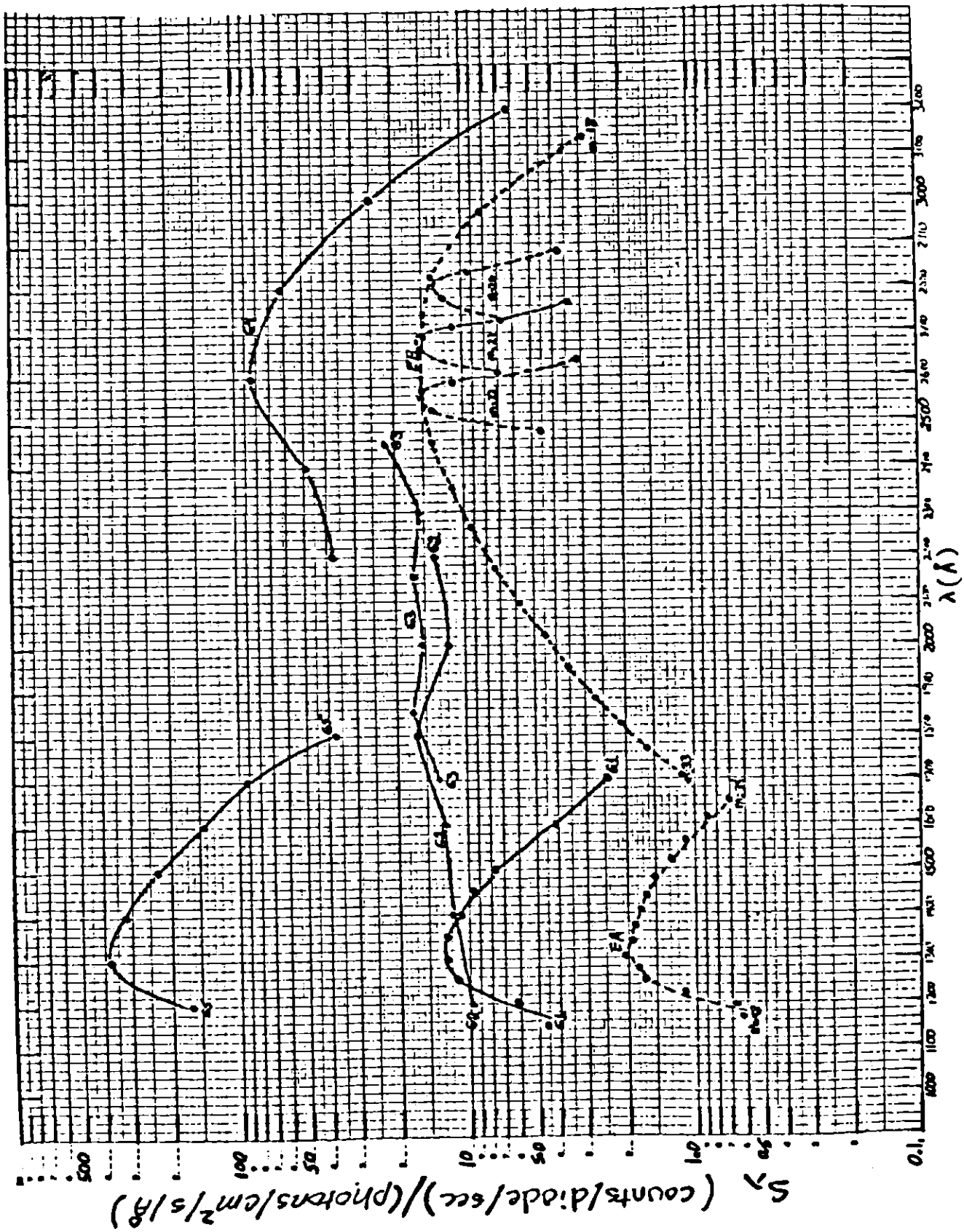
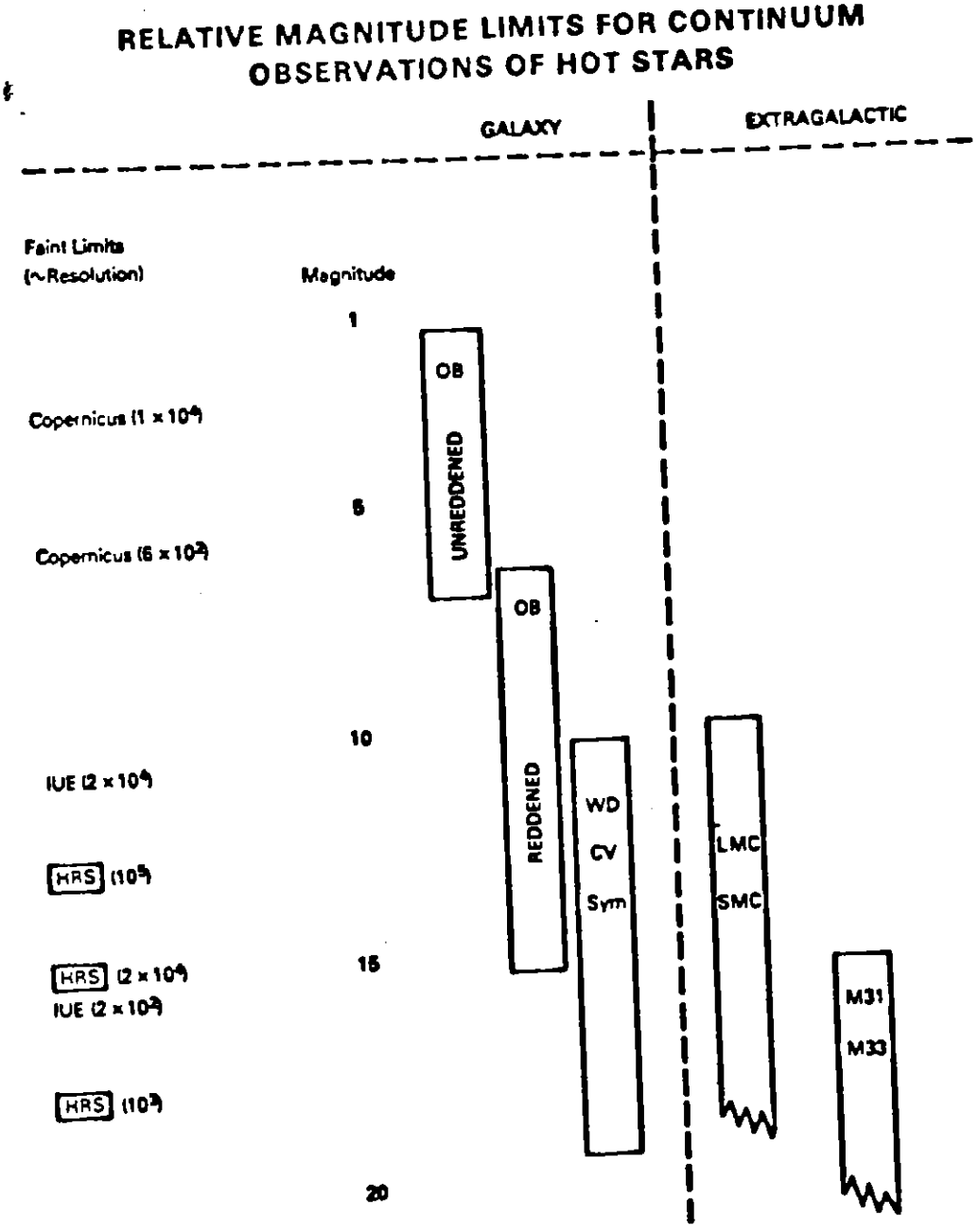
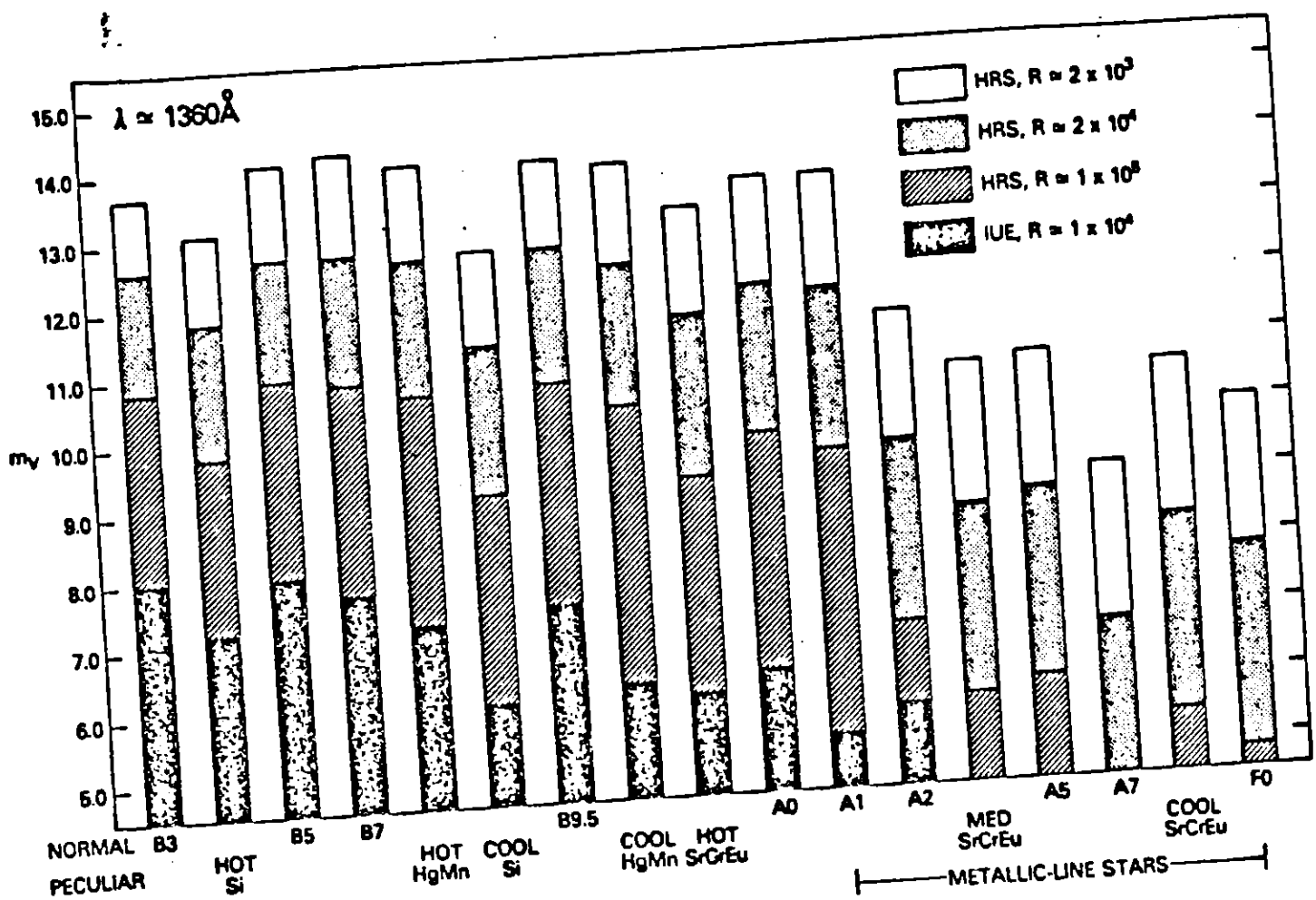


FIGURE 7.3: RELATIVE MAGNITUDE LIMITS (CONTINUUM)



Limiting ultraviolet magnitude diagram for hot stars (after J.B. Hutchings).

FIGURE 7.4: FAINT LIMITING MAGNITUDES AT 1360 A



Apparent visual magnitudes of normal and peculiar B and A-type stars which can be obser
at 1360 A in the various HRS modes (and IUE) with S/N = 20 in 3 hrs assuming 0.8
magnitudes/kpc average visual extinction (D.S. Leckrone).

FIGURE 7.5: FAINT LIMITING MAGNITUDES AT 1650 A

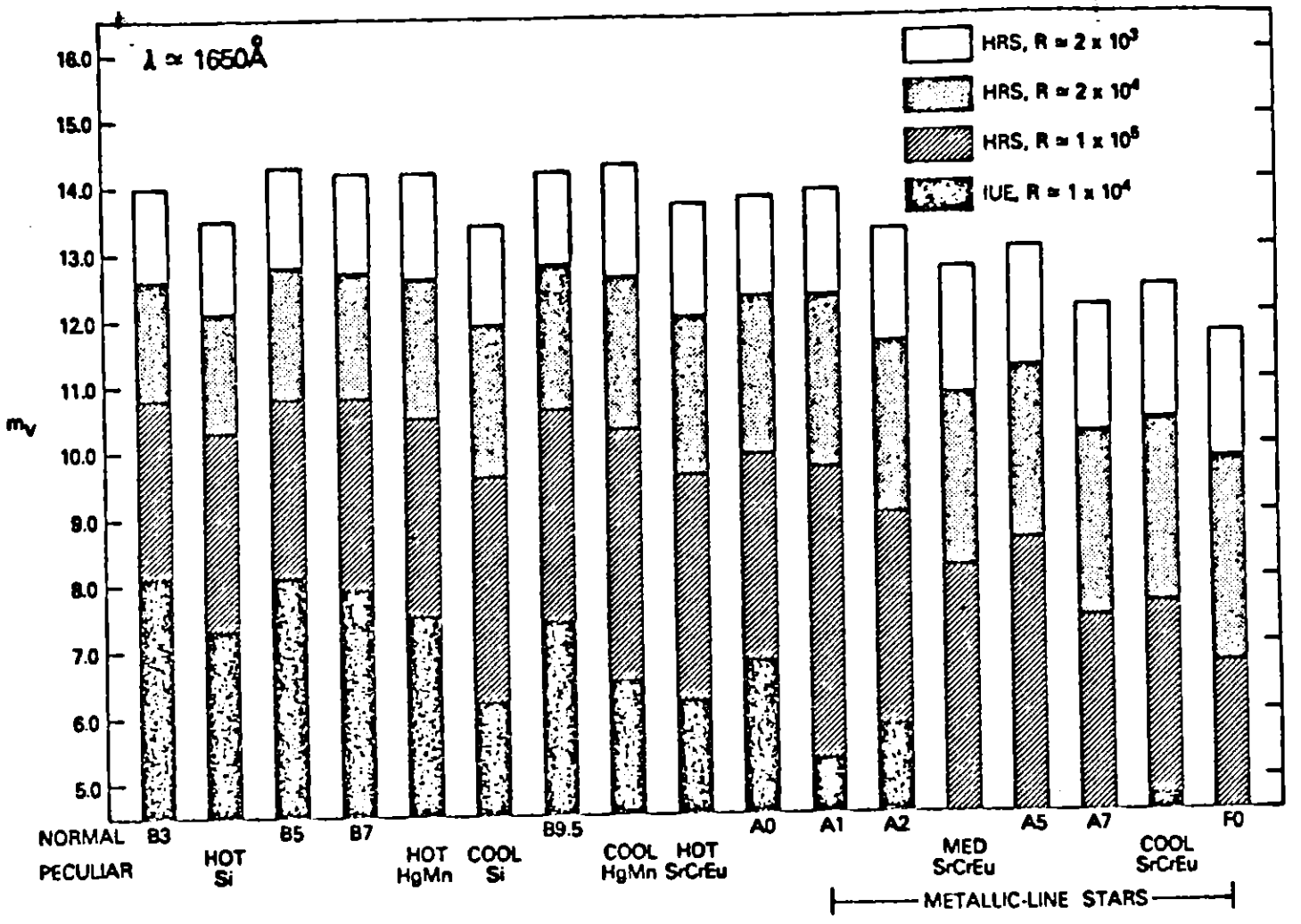


FIGURE 7.6: FAINT LIMITING MAGNITUDES AT 1940 A

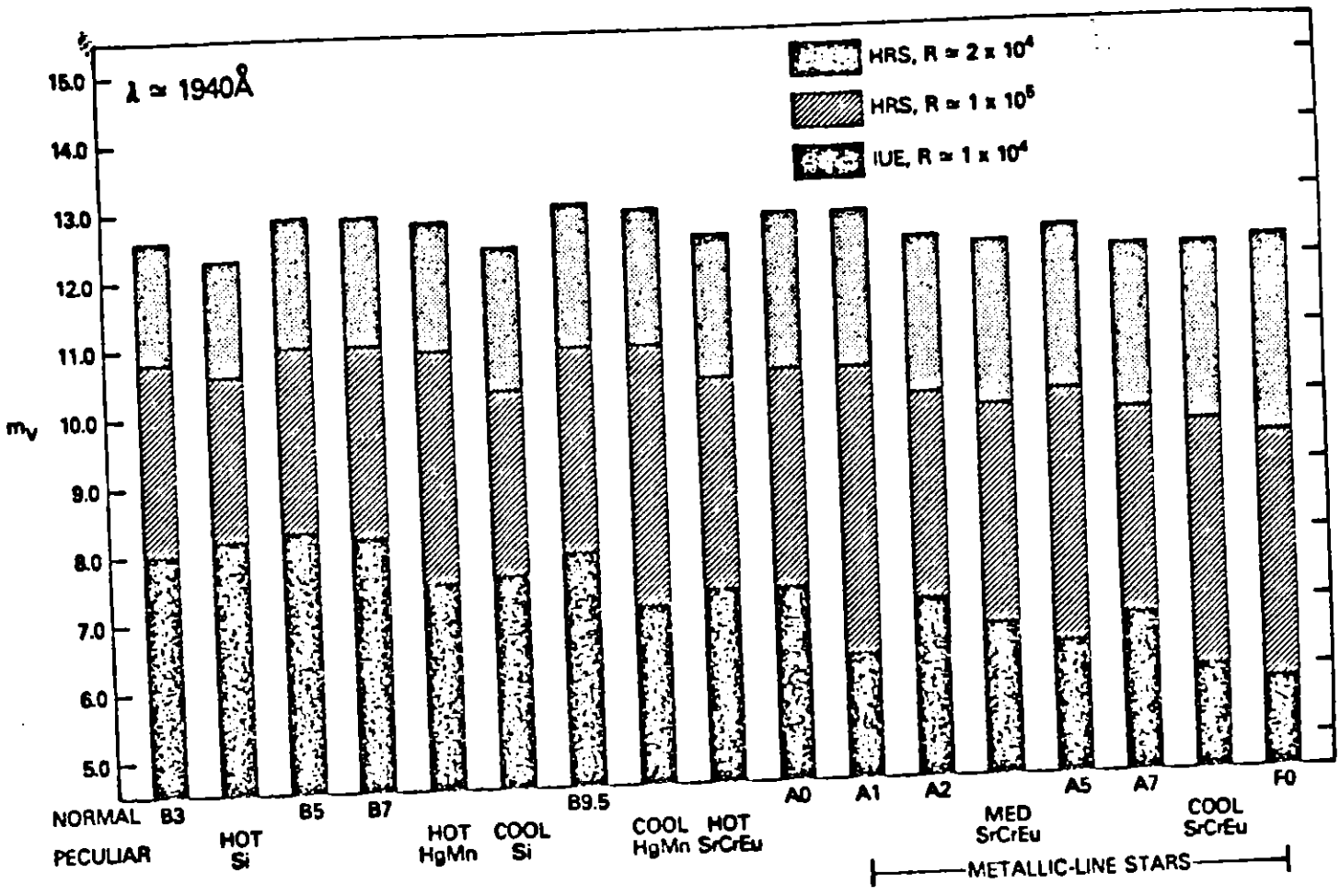


FIGURE 7.7: FAINT LIMITING MAGNITUDES AT 2500 A

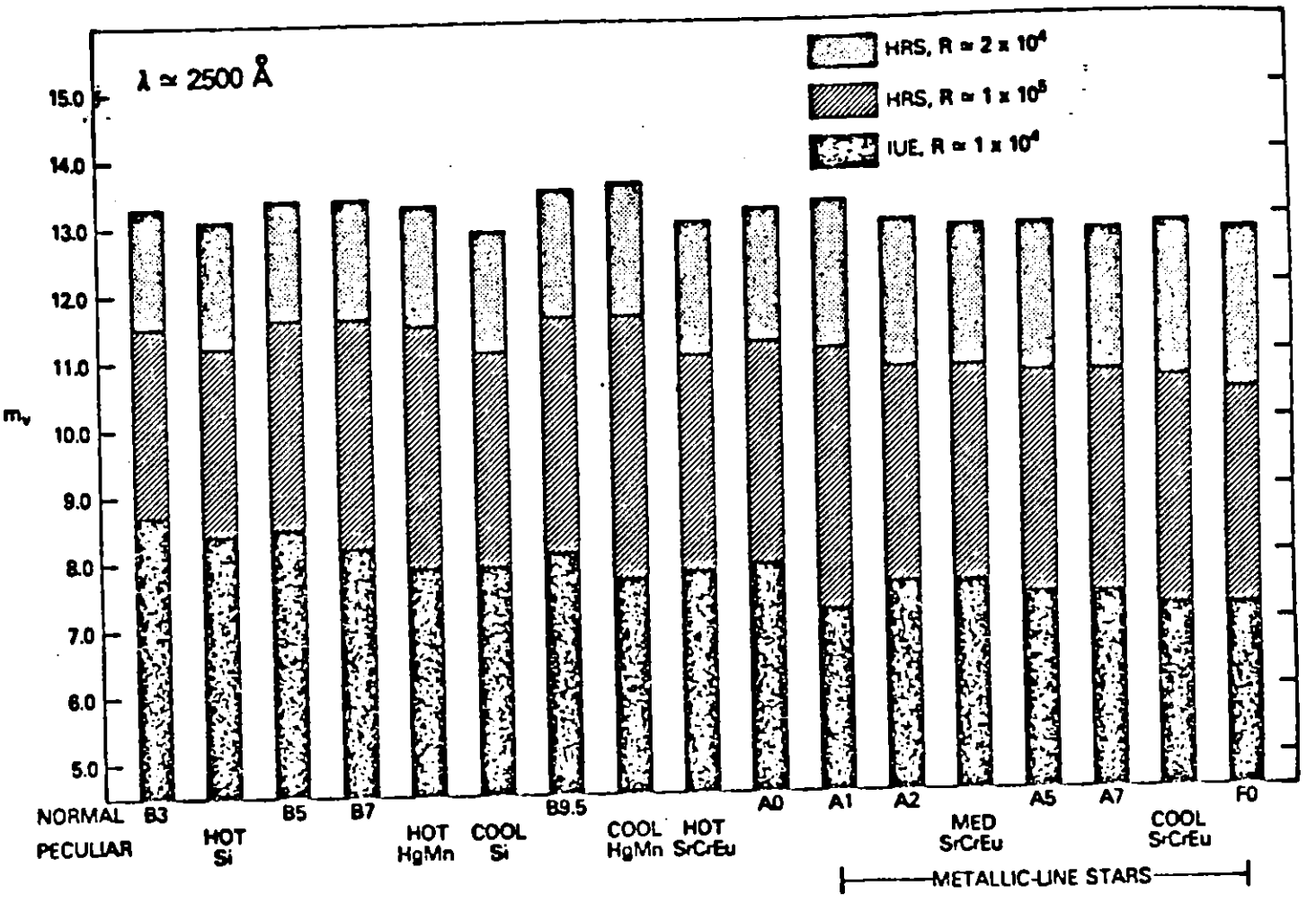
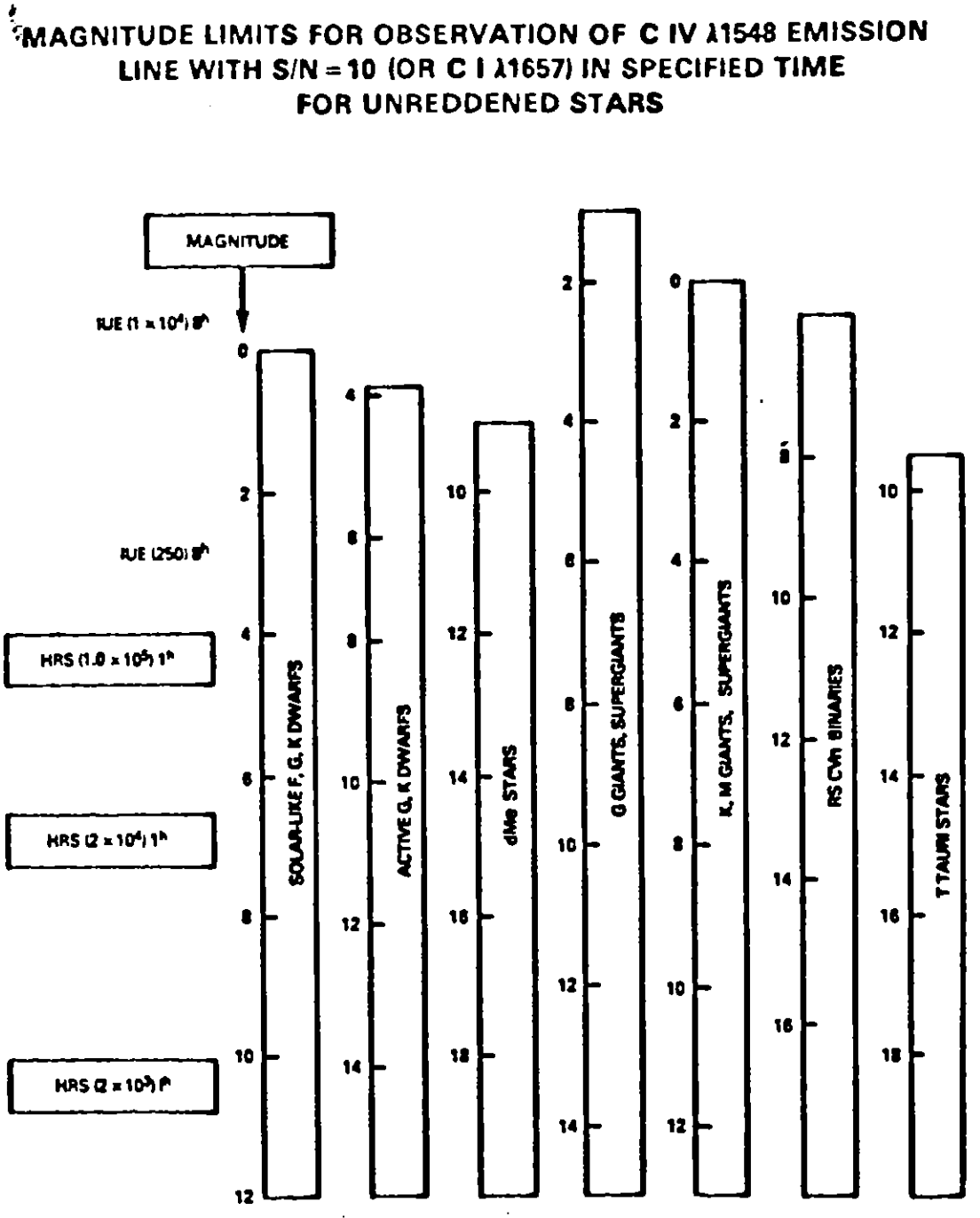


FIGURE 7.8: FAINT LIMITING MAGNITUDES FOR EMISSION LINES

(prepared by J.L. Linsky) gives limiting magnitudes for an emission line in various cool stars. The assumptions used are stated on the figure.



Visual magnitude limits for observation of selected emission lines in cool stars (J.L. Linsky).

8.0 FINE GUIDANCE SENSORS FOR ASTROMETRY

In addition to being used for guidance purposes, the Fine Guidance Sensors (FGS) are also intended for use in relative astrometric measurements. The key instrument specifications are listed below.

TABLE 8.1 INSTRUMENT SPECIFICATIONS

parameter	specification
positional accuracy	2 milliarcsec for 3 or more stars in a single field of view
Magnitude range	10-17 m in V (unfiltered)
Rate of measurements at m=17	10 stars in 10 minuites (no slewing)
Availability of specified rate of measurement at m=17	Continuous throughout typical orbital night
Photometric accuracy	1%
Wavelength Band	4700-6900 A