Faint Object Spectrograph
Science Verification Report

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FOS Investigation Definition Team and Associates

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Summary

The FOS has been thoroughly tested and calibrated in the extensive Science Verification (SV) phase of the mission for use as one of the two spectrographs on board the Hubble Space Telescope (HST). Through these tests and the associated Guaranteed Time Observations (GTO) of the Investigation Definition Team (IDT), which designed, built and tested the instrument, the FOS has been proven to be a high-quality instrument, capable of carrying out any of the programs for which it was designed. The main limitations to the use of the FOS are those imposed from without by the spherical aberration of the HST, reducing the spatial resolution, decreasing the usefulness of the smallest apertures and requiring longer exposure times than originally planned. Some problems internal to FOS were found, of which the most serious is a geomagnetically-induced image motion, primarily on the Red side, which can be reduced by reducing the readout time. FOS far UV sensitivity has been reduced relative to prelaunch, but there is no loss to the HST response as a whole; the GHRS/FOS sensitivity crossover has moved some 10 nm redwards to 145 nm, and this region is only a small fraction of the 115 - 922 nm FOS spectral range. This end-of-SV report is based upon and contains copies of all the CAL/FOS data analysis reports describing the data obtained during calibration of the FOS and the analysis techniques used in reducing this data to the level of inputs to the various calibration data base files maintained at the STScI.

Cover Note

The spectrum on the cover is from data taken October 29, 1990 with the FOS on the Seyfert II active nucleus galaxy NGC 1068 (ref. Caganoff *et al.* Ap. J. Lett. **377**, L9 - 112, August 10, 1991). The 0.3" aperture was centered within 0.1" of the continuum peak. The complex shape of the line profiles indicates at least several different velocity components. Ground-based observations of polarized light from this object have shown a Seyfert I spectrum with broad permitted lines, interpreted as light from a hidden Seyfert I nucleus being reflected into the line of sight, perhaps indicating that the differences in Seyfert class I and II objects are only a matter of point of view. With HST we did not detect the broad Hβ emission seen in the polarized observations, indicating that the continuum peak is not the "mirror" or that the reflection area is larger than 0.3". Nature is sometimes even more complex than initial theory.

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Acronyms and Abbreviations

Ap, Aper	Aperture
Arcsec, as	Arc-second; 1/3600 of a degree
BS	Binary Search (target acquisition)
C	Centigrade
CAL	Calibration test
CAL/FOS	Calibration Report for FOS
CDBS	Calibration Data Base System
CEI	Configuration End Item
COSTAR	Corrective Optics in Space Telescope Axial Replacement
cts/s/d	Counts/second/diode
Fcn	Function
FGS	Fine Guidance System
FOS	Faint Object Spectrograph
FW	Firmware (FOS Microprocessor program)
FWHM	Full Width at Half Maximum
GHRS	Goddard High Resolution Spectrograph
GIMP	Geomagnetically-induced Image Motion Problem
GTO	Guaranteed Time Observation
HR	High Resolution (~1300 for FOS)
HST	Hubble Space Telescope
HV	High Voltage
IDT	Investigation Definition Team
LR	Low Resolution (~200 for FOS)
min.	minute
Mv	Magnitude, visible range
nm	nanometer, 10^{-9} meter, 10 Angstroms
OTA	Optical Telescope Assembly
OV	Orbital Verification (engineering checkout)
PD	Peak-Down (target acquisition)
PMA	Progress Measurement and Assessment (meetings)
POLSCAN	Polarization Scan (mode of operation)
PSF	Point Spread Function
PU	Peak-Up (target acquisition)
QSO	Quasi-Stellar Object, Quasar
Res	Resolution
RejLim	Reject Limit (setting to suppress background)
Resp	Response
SAA	South Atlantic (magnetic) Anomaly
Spec	Specification
STScI	Space Telescope Science Institute
T	Temperature
T.A., TA	Target Acquisition
TALED	Target Acquisition Light Emitting Diodes
UCSD	University of California, San Diego

UV	UltraViolet
V2/V3	System of coordinates for all instruments on HST
WFC	Wide Field Camera
μ,μm	micro-meter, 10^{-6} meter, 1000 nm, 10,000A°
μs	microsecond
"	Arcsecond; 1/3600 of a degree

I. Objectives of Science Verification for the FOS

The overall objectives of Science Verification (SV) were the on-orbit re-measurement of the scientific specifications of the Science Instruments, comparison with pre-launch values, the population of the Project Data Base and various pipeline data processing reference tables with entries which were valid for on-orbit operation, the analysis and projection of performance trends and the dissemination of these results.

The original technical objectives of SV for the FOS were described in "OV & SV for the FOS", R. Downes, rev 3, July 1989 (198 pages). As OV and SV progressed it became apparent that some goals, such as measurements on the smallest apertures, were irrelevant to the mission, given the HST Point Spread Function (PSF), and could be dropped or deferred until the HST spherical aberration was corrected. Other changes to the SV program and to the modes of operating the FOS were required by the discovery of an excessive penetration of the Earth's magnetic field into the magnetic steering field of the Red side Digicon (see section IV).
A matrix of goals, which are derived from the Configuration End Item (CEI) specifications, vs. the results from the FOS calibrations (SV proposals) performed is given in Table 1. Re-testing the FOS for compliance with the CEI specifications was **not** an objective of OV or SV; the CEI specs were designed for ground testing and were met when the FOS was delivered to the government in 1984. It may be of interest, however, to compare on-orbital performance, where possible, to the CEI specs, as we attempt below.

Table 1 - CEI Specifications and OV/SV Results

CEI Spec	Name	Updated Specification[1]	Results of OV / SV	Reference Section, CAL/FOS #
1	**Detectors**	2; ea. **512** diodes	**2; 512**, minus dead & noisy channels[2]	III, 074
2	**Image Format**	diode size **40+-2** x **200+-10** μm	**40** μm nominal x **204.65** μm[3]	IV, 068
3	**Image Scale**	**140+-10**μm/arcsec	Red: **139.45** μm/" Blue:	IV, 068
4	**Fields of View**	(aper size & loc, no stray light)	**No change from prelaunch**	VI (1319)
5	**Spectral Resolution**	HR:**1000 +500/-0** LR:**200 +/- 50**	~**1300** (variations between ~**250** dispersers)	prelaunch
6	**Resp. Fcn., Scatt. Light**	**60**μ FWHM[4] 10^{-4} @ >**100** diodes[5]	**Masked by HST spher. aberration.**	XI, 067, 070

[1]STE-07 Appendix II, Rev. B (March 1984).
[2]Electronics associated with each diode were expected to become unacceptably noisy or dead at the rate of approximately 2% per year. At turnover to the STScI in January 1992 some 31 or 3% had become dead or noisy in more than 1.5 years, for approximately 2% per year. See Table 3 for details.
[3]Diode widths are as manufactured; 40 microns, on 50 micron centers. Effective heights are affected by diode leads, alternating at each end,

7	**Spectral Ranges**	HR: **114 -900**nm LR: **114 -800**nm pol: **122 -300**nm	**115-922**[6] **115-873** **128-331**	XI, 067, 070 XII, 078
8	**Efficiency**	>1%, **120-700**nm >2%, **120-200**nm 7%, **200-400**nm peak > **10%**	**175-800**[7] **220-780** **200-640** **>25%**	X, 077, 069 and see footnotes.
9	**Instrument Noise**	**<0.002** cts/s/d @ -10C [8]	**0.002** cts/sec/diode[9] detector background	XIII, 076, 080
10	**In-Flight Calibration**	(cal & ff lamps)	Calibration and Flat Field **lamps work**	III, IV, XIII etc.
11	**Exposure intervals**	50 μs exp. duration >1ms intervals 100 exp/sec	Not tested in SV, but minimum 3 ms livetime has worked well.	Various.
12	**Instrument Stability**	1% over 4 hrs 3%/4hr, reconfig 5% within 24 hrs	Wavelength stability masked by GIMP. Efficiency decreasing.	X, 077
13	**Pulse Saturation Error**	1% to 10000c/s 4% to .1Mct/sec	Not tested in SV; ground measurement stands.	CAL/FOS 045.
14	**System Switch Time**	**5** min (4.3as Ap) **30** min (0.1pair)	< **5** min. switch; **20** min. for stabil.[10]	Various[11]
15	**Target Acquisition**	**<0.03** arcsec, if image stab.<0.01	Repeatability to **<0.06"**, but HST image not stable	VII, 081
16	**Photo-cathode Temperature**	**-32C < T < -8C**	Has stayed **within limits.**	OV & Engineering Tracking Data
17	**Polarimetry Optics**	**70%** modulation **10%** tran/122nm	**70%** modulated, **10%** transmitted 128-331 nm[12]	XII, 078

[4]The original spec, STE-07 Section 3.2.1 (24 Oct. 1979) shows in Fig 3.2.1-1(a) further specs of 1% of max counting rate at 100 microns from the image center and 0.1% at 300 microns or 6 pixels (diodes).
[5]Fig 3.2.1-1 (b) further specifies 5 10^{-4} of peak counts at 10 pixels (diodes) and 2 10^{-4} at 50 diodes (2.5 mm).
[6]The short wavelength end is determined by the Blue digicon MgF_2 cutoff; see Table 3, CAL/FOS -067.
[7]FOS response in the Blue detector was estimated lower than 1% pre launch and measured in SV at half of prelaunch estimates in the range 115 - 160 nm, (probably due to Al_2O_3 buildup on the grazing mirror while awaiting launch) , ref. Hartig and Kinney "Recommendations for Phase 2 GO Submissions, March, 1991. The Red detector also has a 10% max. drop in efficiency at 185-205 nm (possibly due to on-orbit photocathode degradation by irradiation) ref. CAL/FOS-069.
[8]The CEI ref, ST/SE-35, part 4 incorrectly states that the photocathode noise is measured at 10C, which is well outside the operational temperature limits. The actual spec is at -10C. The detector noise spec does not include the effects of on-orbit background, such as charged particle illumination of the faceplate through the Cerenkov effect.
[9]Using Reject Limit (RejLim)=1, varies with geomagnetic latitude. Red =0.0029, Blue =0.0018 cts/s/d. Without RejLim=1, the average dark count rates are roughly 0.01 and 0.007 cts/s/d for the Red and Blue detectors.
[10]The system can switch over within 5 min, basically as fast as the commands can be sent, but system stability requirements impose a 20 minute H.V. warmup time. The 0.1 Pair apertures are not usable due to the HST spherical aberration problem.
[11]There was no test specifically for system switching time; it was deduced from proposals 1309, 1317, 1318, 1320, 1528, 2195 and their successors, among others.

18	**Magnitude Limit**	Mv=**23** in 3 hr, at **HiRes**, S/N>7/d, @ 400nm	Estimate **20.3** in 3 hr (1.5 on sky) on F5 star, at high resolution.	1316, 1319

[12]The polarimeter modulated 100% polarized light by 70% and transmits > 10% unpolarized light over the full FOS range, exceeding spec, but this range is not usable, given the HST spherical aberration; see CAL/FOS-078.

II. Organization and Dependencies in FOS OV and SV

SV testing was planned to follow and somewhat overlap with the last activities of the engineering or OV tests, with the dependencies shown below (time resolved mode testing was deleted from SV at the request of the Project Office):

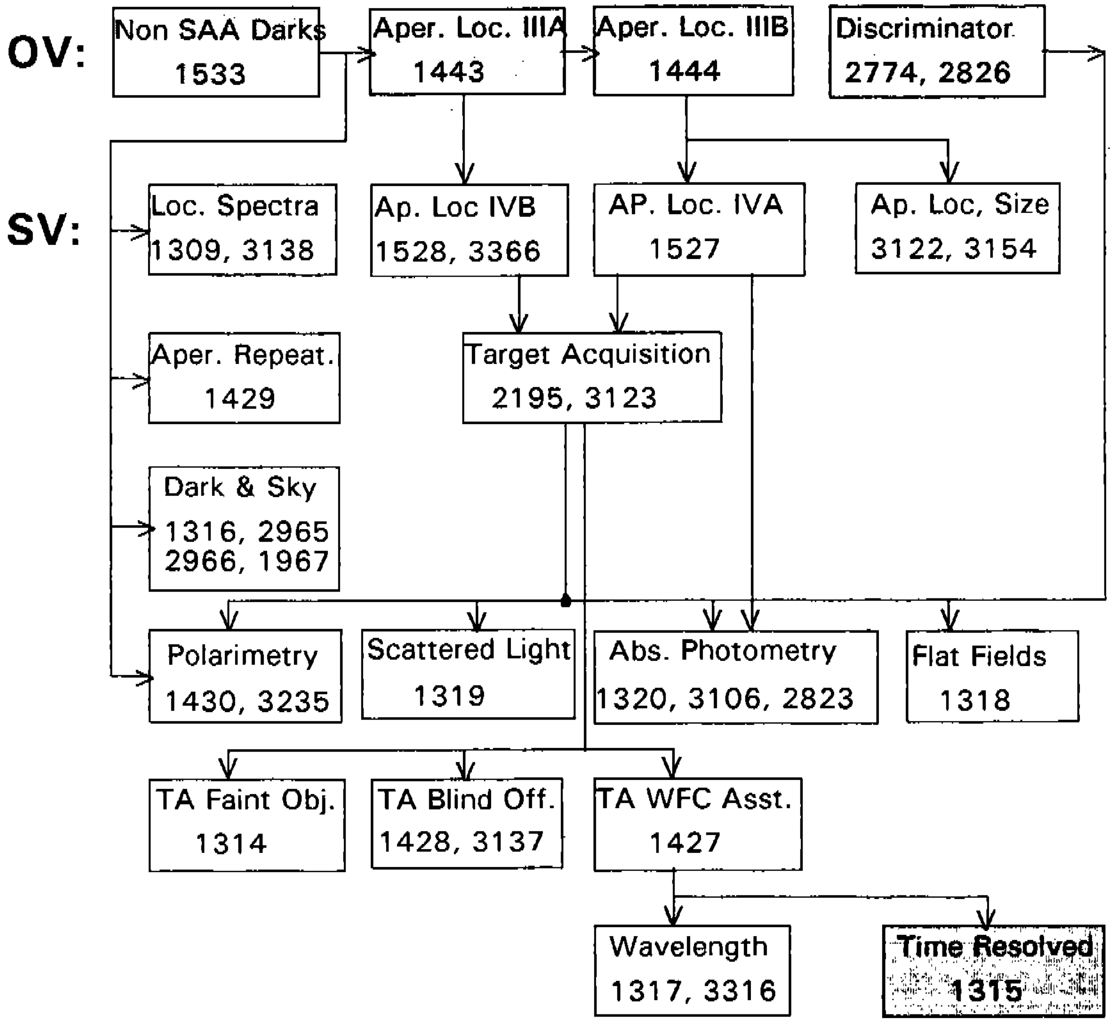

Table 2 - Tests and CAL/FOS Reports

Part 1, by SV Report Section

SV Report Section		SV Proposals	CAL/FOS
III	Discriminator Setting	2774, 2826	074
IV	Location of Spectra - GIMP	1309, 3138	066, 069
V	Aperture Locations and Sizes	1441, 3099, 3122, 3154, 1429	072
VI	Precise Plate Scale and Orientation	1528, 3366	068, 072
VII	Target Acquisition, Mode II	2195, 3123, 1314	081
	Target Acquisition, Mode III	1428, 3137, 1427	081
VIII	Spectral Flat Fields	1318	075
IX	Scattered Light	1319	073
X	Absolute Photometry	1320, 3106, 2823	077
XI	Wavelength Calibration	1317, 3316	067, 069, 070
XII	Polarization Calibration	1430, 3235	078
XIII	Dark Counts and Sky Background	1316, 2965, 2966, 2967	071, 076, 079, 080, 081

Part 2, by Test Number

Prop.	Description	SV Report Section	CAL/FOS
1309	Location of Spectra	IV	066, 069
1314	T.A., Faint Objects	VII	081
1316	Dark Counts	XIII	071, 076, 080
1317	Wavelength Calibration	XI	067, 069, 070
1318	Spectral Flat Fields	VIII	075
1319	Scattered Light	IX	073
1320	Absolute Photometry	X	077
1427	T.A. WFC-Assisted	VII	081
1428	T.A. Blind Offset	VII	081
1429	Aperture Wheel Repeatability	V	072
1430	Polarization Calibration	X	077
1441	Relative Aperture Location, Phase I	V	072
1527	Aperture Location, Phase IVA (never ran)	VI	068, 072
1528	Aperture Location, Phase IVB	VI	068, 072
2195	T.A., Combined Mode II	VII	081
2774	Discriminator Setting	III	074
2817	Y-Base Maps (Cycle 1 CAL, not SV)		
2823	Absolute Photometry (Red), rev 1320	X	077
2826	Discriminator Test	III	074
2965	High Galactic Latitude Sky Background	XIII	080, 082
2966	Low Galactic Latitude Sky Background	XIII	080, 082
2967	Low Ecliptic Latitude Sky Background	XIII	080, 082
3099	FOS/FGS Precise Alignment	V	072
3106	Absolute Photometry (Blue), rev 1320	X	077
3122	Fine Aperture Location, rev 3099	V	072
3123	T.A. Mode II, rev 2195	VII	081
3137	T.A. Blind Offset, rev 1428	VII	081
3138	GIMP Calibration, rev 1309	IV	069
3154	Fine Aperture Location, rev 3122	V	072
3235	External Polarization	XII	078
3316	Wavelength Calibration, Internal/External	XI	069, 070
3366	Aperture Location / Precise Plate Scale, rev 1528	VI	072

III. Discriminator Setting, Dead & Noisy Channels

The task of taking data , analyzing the noise level in each of the 512 channels in each Digicon and later setting the discriminator for each channel to the appropriate level was spread over Orbital Verification (OV) and SV. This work was carried out under the following test plans:
Proposal 2774 - Discriminator Tests (OV)
Proposal 2826 - Discriminator Verification

These tests were performed in August (Red) and October (Blue) of 1990 and quickly analyzed. The results were communicated to the STScI and to the members of the Instrument Definition Team (IDT) and IMDB updates were performed. All usable channels had their discriminators adjusted to meet the CEI background specification. Dead and noisy channels were identified and channels with intermittent problems noted at an early stage (Blue side on 11/7/1990).

Table 3, FOS Dead and Noisy Channel Status during SV

Date	Red Noisy	Red Dead	Blue Noisy	Blue Dead	Comments
Prelaunch	7	4	10	4	Red 235, 261, 285, 344, 381, 405 and 409 noisy Red 2, 6, 212 and 486 dead Blue 73, 201, 218, 219, 268, 415 and 427 noisy Blue 49, 223, 284 and 409 dead
May '90	7	4	11	4	Blue 225 disabled
June '90	7	4	10	4	Blue 225 restored
Aug. '90	3	4	10	4	Red 235, 261, 344 and 381 restored
Sep. '90	4	4	10	4	Red 110 disabled
Nov. '90	4	4	15	4	Blue 31, 225,235,241,497 disabled
Dec. '90	4	5	15	4	Red 197 (dead) disabled
Feb. '91	4	5	13	4	Blue 398 disabled, Blue 219, 415, 427 restored
Jun. '91	4	5	13	6	Blue 441, 471 (dead) disabled
Aug. '91	4	5	13	7	Blue 101 (dead) disabled
Oct. '91	4	6	13	7	Red 29 (dead) disabled
Dec. '91	5	6	13	7	Red 189 disabled

Channels on each side have gone dead at the rate of about 2 (or 0.4%) or less per year and this has been roughly the same before and after launch. The hybrid circuits in the preamplifiers are thought to be the cause (GHRS uses other circuitry, with no failures). "Noisiness" is somewhat subjective and the situation is unclear, with channels being restored to usage after testing. In any case, the losses in channels are lower than predicted some years before launch.

Early summaries of channel status were given in CAL/FOS Reports 051 and 064. Recent status is courtesy Bidushi Bhattacharya, STScI. The final write-up of these tests is CAL/FOS 074, *On-Orbit Discriminator Settings for FOS*, R. D. Cohen, February 1992. There is a copy in Appendix 1.

IV. Geomagnetic Image Motion Problem (GIMP)

Several FOS OV and SV tests revealed this problem; the principal ones were:
Proposal OV 2188 - HV Stability & Y-base Measurements
Proposal OV 2189 - Focus, X-pitch and Y-pitch
Proposal 1309 - Location of Spectra
Proposal 1318 - Spectral Flat Fielding
Proposal 2195 *et al.* - Target Acquisition

These early results led to the creation of the following proposal to characterize the problem:
Proposal CAL 3138 - GIMP Calibration, Red Side.

A. GIMP from Spectral Flat Fielding
In analysis of flat-field data in November of 1990, it was noted that for two Red side combinations, G160L/Red and G190H/Red, unusually strong granularity as well as short-term temporal variations were seen. The latter came to be known as the "Geomagnetically-induced Image Motion Problem" or GIMP.

B. GIMP and Aperture Positions
Analysis of aperture positions also revealed the 42-minute (half orbital) periodicity with an amplitude of 50 microns, equivalent to the spacing of the diodes and the resolution of the instrument. This effect was also noted quasi-simultaneously in other SV tests; see below for more discussion.

C. GIMP and Target Acquisition
The image motion on the Red side can have an amplitude of as much as two diodes and can thus significantly affect the Binary Search and Firmware modes of target acquisition. Peak-Up and Peak-Down are not affected because the image of the aperture on the photocathode moves in the same way as the image of the target. Changes were made to the target acquisition procedures to minimize the effect, and these appear to be effective. See section VII and CAL/FOS 081 for details.

D. Resolution of the Problem
Early OV 2188 and OV 2189 test results showing GIMP were communicated within the FOS IDT, presented at the AAS meeting in January 1991, and written up as CAL/FOS 066, *Sensitivity of FOS Red Digicon to the External B-Fields,* V. T. Junkkarinen, E. A. Beaver, R. D. Cohen and R. Lyons, August 1990. There is a copy in Appendix 1.The GIMP effect was found to be due to insufficient shielding of the Earth's magnetic field on the Red digicon (Blue side motion is a factor of 8 less). The primary cause was eventually determined to have been improper fabrication of the second batch of mu-metal shielding, without the required annealing. This is seen in the magnetic field rejection factor, which was specified at 140-160, the first batch measured considerably better (see CAL/FOS 082), while the second batch measured only 16. A second possible cause was improper handling of the shielding during assembly of the spare Red detector in 1985.

After characterization of the problem through testing of flight spare detectors and magnetic shielding components in the laboratory at UCSD, followed by thorough modeling, and after the study of on-orbit results from CAL proposal 3138 by G. Hartig, a work-around involving shorter integrations on-orbit coupled with ground-based corrections was devised. This is expected to be fully implemented in the summer of 1992. Further refinements may result from continuing investigations and modeling. These might include programming the FOS microcomputer to change the deflection currents on the time scale of the orbital change. There appears to be some image motion which is not well correlated to the magnetic field, but which may be a hysteresis effect. Frequent de-gaussing may also minimize hysteresis effects, see CAL/FOS 082 - (UCSD) Lab Test Results of the FOS Detector Performance in a Variable External Magnetic Field, Beaver and Foster, June 1992. There is a copy in Appendix 1.

V. Aperture Location and Size

A. Aperture Location in FOS Coordinates

The rough position of the image of each entrance aperture on the photocathode of each detector was determined through the use of the internal Target Acquisition Light-Emitting Diodes (TALEDs), as described in Proposal 3020 [?]. These positions were then refined through observations of an external source, the elliptical galaxy NGC 4373, as planned in the following OV and SV proposals:
Prop 1429 - Aperture Wheel Repeatability
Prop 1441 - Relative Aperture Location, Phase 1 (OV),
Prop 1527 - Precise Aperture Alignment *[not run, replaced by 3099]* and
Prop 2189 - Focus, X-pitch and Y-pitch (OV)
Prop 3099 - Precise Aperture Alignment, revised.

The end results of SV aperture location testing were placed in CDBS file CYCCS1 - Aperture Position Parameters. The related file CYCCS0 - Aperture Parameters (effective areas or flux ratios) retains the pre-launch values based on direct measurement of aperture sizes as no improvement is deemed feasible with the current Point Spread Function (PSF). Tables of the aperture image centroids are to be found in CAL/FOS 072, *Aperture Calibrations During Science Verification of the FOS,* R. Harms and L. Dressel, July, 1992. This report is currently being revised to include the test results from SV 1528 and SV 3366, so that no copy can be included in Appendix 1 as of this writing. Initial results indicate that there will be little if any change in parameters from results obtained from prelaunch measurements.

B. Aperture Location in Spacecraft Coordinates

Tests used to find the aperture locations in HST V2/V3 coordinates included:
Prop 3122 - Fine Aperture Location
Prop 3154 - Fine Aperture Location, revised.

SV tests 3122 and 3154 were carried out to measure precise locations of the FOS single 0.5" circular aperture and both the upper and lower 0.5" paired apertures. An interactive acquisition was used to center the star to within about 0.1" of the center of each aperture. Then the tests fine-stepped the HST to move the stellar images successively in all four directions across the edges of each of these FOS apertures. The times when the image lay halfway off each edge of an aperture were correlated with the corresponding HST roll angle and pointing data to allow computation of precise locations of the set of aperture edges, and hence the aperture centers, in HST V2/V3 coordinates.

Because the aperture edges serve as a sharp knife-edge, the inherent precision of the test is very high. However, the test relies on FGS measurements of HST pointing. As of this writing, there appear to be unexplained residual errors in FGS #1 data, perhaps indicating a slow drift error of less than 1"/year. Thus, the uncertainty among the FGS pointing determinations for the HST itself may set the ultimate limit on our determination of FOS entrance aperture locations.

Operational experience offers a good estimate of the worst case errors which may remain in the aperture locations currently in the database. Analysis of the target acquisition results for approximately 100 FOS pointings imply that we know the correct locations of the apertures to within at least 0.1". This is already adequate to perform the scientific programs feasible with the FOS with the uncorrected HST PSF.

Further details will be found in CAL/FOS 072, *Aperture Calibrations During Science Verification of the FOS,* R. Harms and L. Dressel, July, 1992. This report is currently being revised to include the test results from SV 1528 and SV 3366, so that no copy can be included in Appendix 1 as of this writing. Initial results indicate that there will be little if any change in parameters from results obtained from prelaunch measurements.

C. Aperture Wheel Repeatability

Prop 1429 - Aperture Wheel Repeatability

In SV test 1429, y-scanned G400H spectra of a calibration star were taken on the Red side through the 0.1"-pair, 0.25"-pair and 0.3" single apertures. Motion in X (along the diode array and dispersion direction) would show up as apparent shifts in wavelength of the various spectral features, while motion in Y (perpendicular to the array and dispersion direction) would vary the y-base values needed to center the spectra or place them on an edge.

Initial analysis of the data indicate, as expected from ground-based measurements, that no motion of the entrance apertures has been detected. The motions due to GIMP are seen very clearly, and residual errors in correcting for GIMP will determine the ultimate limit to which we can rule out entrance aperture motions. [This would probably be true even with no GIMP, as ground-based measurements of aperture repeatability showed variations limited to approximately 1 micron, corresponding to about 0.004".] Operational experience with FOS target acquisition also indicates no detectable entrance aperture motions. No separate test for the Blue side is planned, since all the FOS apertures are etched onto the same ribbon, driven by a single mechanism.More details will be found in CAL/FOS 072, *Aperture Calibrations During Science Verification of the FOS,* R. Harms and L. Dressel, July, 1992.

VI. Precise Plate Scale (Aperture Location, Phase IVB)

On-orbit plate scale factors were determined through observations of the astrometric reference star NGC 188-031 in October 1990 as part of SV Prop 1528 - Precise Plate Scale and later through the tests outlined in Prop 3366 - Precise Plate Scale, revision for the Blue side (using the target GRW+70^{o}582), which was performed in February, 1992. As there were repeated problems with these tests, the test history is recapitulated in Table 4.

Table 4 - Precise Plate Scale SV Test History

SV Test	Date	Side	Result
1527	12/01/90	Both	replace with 3099
1528	10/12/90	Red	replace by 3099
	12/3/90	Blue	failed due to problem with FGS report, replace with 3099
3099	12/10/90	Blue	all failed, replace with 3122
	12/15/90	Red	
	12/16/90	Red	
3122	2/14/91	Blue	3" error
	2/15/91	Red	visit 1 OK, replace visits 2-5 with 3154
3154	3/31/91	Blue	OK
	4/1/91	Red	noise spike
	5/22/91	Blue	OK, not necessary to update PDB
	5/24/91	Red	problem with star coordinates
	6/14/91	Blue	OK
	6/14/91	Red	still have FGS report problem, need 3366
3366	2/22/92	Blue	OK, new target

Given that there were problems of a similar magnitude with Target Acquisition tests, it becomes easier to see why SV lasted approximately 12 months, rather than the 5 months originally planned. These test delays were principally caused by the HST spherically aberrated mirror and the various jitter and pointing problems.

A. Red Side Results

Changes relative to pre-launch values of the plate scale for the Red side were only -0.40% +/- 0.53% along the diode array and 2.9% perpendicular to the diode array, with the latter result affected by uncertainty in the effective diode height. This uncertainty is due to placement of the lead wires, alternating from one end to the other on adjacent diodes. The prelaunch values for plate scale of 1.43 arcsec per 256 y-base units and 0.357 arcsec per diode width are sufficiently accurate and do not require modification.

The orientation of the Red side x-y axis system was found to be rotated by 0.24 +/- 0.32 degrees. The combination of orientation and plate scale changes will result in a maximum offset error of only 10 milliarcseconds over the halfwidth of the 4.3 arcsec target acquisition aperture.

B. Blue Side Results

The SV test 1528 was modified to measure the plate scale and orientation on the Blue side and run on 22 February, 1992 as SV 3366. The data have undergone only preliminary analysis as of this writing. Initial results indicate that there will be little if any change in parameters from results obtained from prelaunch measurements, as was also the case for the Red side.

Details of the calibrations, with full discussion of analysis techniques and tables of results can be found in the two following reports:

CAL/FOS 068, *FOS Red Detector Plate Scale and Orientation,* B. Bhattacharya and G. Hartig, November 1991. There is a copy in Appendix 1.
CAL/FOS 072, *Aperture Calibrations During Science Verification of the FOS,* R. Harms and L. Dressel, April, 1992. This report is currently being revised to include the test results from SV 1528 and SV 3366, so that no copy can be included in Appendix 1 as of this writing.

VII. Target Acquisition

A. Target Acquisition, Mode I

Target acquisition on the HST comes in three modes, I, II and (surprise!) III. Mode I is Interactive Acquisition (INT ACQ), with an astronomer in the loop, taking a pre-planned grid of exposures with the FOS, finding or guessing at the location of the maximum and sending pointing correction maneuver commands. No OV or SV tests were planned for this mode, but due to spherical aberration and pointing problems it has been used extensively and successfully. The exposure grid that is used when INT ACQ is specified in the exposure logsheet has been found to work very well.

B. Target Acquisition, Mode II

1. Description of the Techniques

Mode II is FOS Onboard T.A., a set of methods using only the FOS with no interaction with other instruments or observers on the ground. It could also be termed "fully autonomous FOS T.A.". There are four separate techniques, covered in detail in CAL/FOS 081. We will recap the description of the strategies here:

1) Binary Search (BS) -- Y-stepping with the large 4.3" aperture until the target straddles the edge of the x-oriented diode array.

2) Peak-Up (PU) -- One or more raster scans with FOS flight software in the DF224 HST computer determining the target position from the peak counting rate.

3) Peak-Down (PD) -- Similar to Peak-Up, except that the target is taken to be at the minimum count position.

4) Firmware (FW) -- The 4.3" aperture image is scanned over the diode array and firmware in the FOS microprocessor determines the number and positions of targets.

The following tests were performed to verify FOS Mode II target acquisition methods:

Prop 2195 - Target Acquisition Combined Mode II Test	all 4 techniques
Prop 3123 - Target Acquisition Mode II (revised 2195)	all 4 techniques
Prop 1314 - Target Acquisition, Faint Objects	BS on a field with 4 QSO images
	FW on a faint star

Description of the "acquire image" or ACQIMAGE format -- ACQIMAGE reads out 20 diodes, starting from diode 256 on the Red side and from diode 230 on the Blue side. The data are read in quarter-step mode, such that the pixel size in the x-direction (width) is one quarter of a diode or 0.08 arcsec. In the y-direction, the image is moved in steps of 16 ybase units, which yields a pixel height of 0.08 arcsec. Hence the ACQIMAGE pixels are square. Note that the scanned region of the photocathode is larger than the size of the target acquisition aperture. Binary search reads out only the diodes within the target acquisition aperture, which are the 12 diodes starting with 260 on the Red side and with 234 on the Blue side. Thus Binary Search and ACQIMAGE use some of the same diodes.

2. Results

Translating the results of Table 1 in CAL/FOS 081 from T.A. pixels (0.08 arcsec square) into arcseconds and calculating the accuracy from the known position (48.5, 32.5 in x,y pixel space) of the center of the T.A. working area, we find that by the second step, Peak-up is accurate to within 0.19" in x (along the diodes) and 0.07" in y (across the diodes). The repeatability or precision is within 0.06" in x and 0.03" in y. The term "mean" is used for "accuracy" and "scatter" or "standard deviation" (Sdev) for "precision" in CAL/FOS 081.

Expressing the results of all the Mode II tests in tabular form, we have (bearing in mind that these are the statistics from a small number of tests):

Peak-Up:	x	y
Accuracy	0.19"	0.07"
Precision	0.06"	0.03"

Binary Search :	x	y
Accuracy	0.10"	0.01"
Precision	0.03"	0.05"

Binary Search portion of Peak-Down:

	x	y
Accuracy	0.01"	0.05"
Precision	0.18"	0.10"

Peak-Down:	x	y
Accuracy	0.02"	0.00"
Precision	0.20"	0.08"

Firmware:	x	y
Accuracy	0.14"	0.01"
Precision	0.33"	0.07"

3. Conclusions

Binary Search and Peak-Up are the most precise modes; repeatable to within 0.06 arcsec. The accuracy problem with these two tests is due to the actual center of the science aperture being at (51, 32), rather than at (48.5, 32.5). Since Peak-Up is measuring the light from the target through the science aperture, it knows where the true aperture image center lies, and is going to the correct position, while Binary search is being directed to an incorrect position.

Binary Search is the most time-efficient of the two, but is subject to GIMP errors. Peak-Up is potentially more accurate, depending on final step size, but takes the most time of any Mode II

T.A. The best strategy for a target requiring high pointing accuracy would probably be a Binary search followed by a small, one-stage Peak-Up.

Those involved with analyzing the test results believe that there is a genuine systematic offset between the Binary Search position and the Peak-Up position, the source of which is not fully understood (it may be a series of systematic errors). Binary Search is currently being updated to go to the same position as Peak-Up, and while these test results do not show it, it is claimed that these two precise methods will henceforth also be the most accurate.

Peak-Down is successful at centering a target behind the occulting bar, but HST spherical aberration leads to a large amount of scattered light, leading to less precision.

Part of test 1314 confirmed the results of 2195 and 3123: Firmware T.A. is not sufficiently precise for use with the HST in its current state, at least for faint objects. SV2145 (Caldwell, in the CTA SV Final Report) has found the Firmware mode to be reliable for acquiring Titan, unless there is abnormal jitter.

The remainder of 1314 was a strenuous test of Binary Search; the apparent second brightest of four very close target images was found on four out of six tries. The two unexplained failures may be the result of the offset discussed above (x center at 51 rather than 48.5); the test is being re-run as a CAL test for Cycle 1 in order to prove this conjecture.

The full write-up of Mode II testing is CAL/FOS 081 *FOS Onboard Target Acquisition Tests,* S. Caganoff, Z. Tsvetanov and L. Armus, March 1992. There is a copy in Appendix 1.

C. Target Acquisition, Mode III

Mode III is a collection of techniques involving slews (blind offsets) from targets found with the FOS or the Wide Field Camera (WFC) on board HST. In the former we validate the ability of the telescope to take a position from FOS and slew to another, nearby, target. In the latter there is a real-time acquisition with the WFC, followed by a telescope slew calculated to center the same target in the FOS field of view.

The following tests were performed to verify Mode III operations:

Prop 1428 - Target Acquisition by Blind Offset
Prop 3137 - Target Acquisition by Blind Offset, revised
Prop 1427 - Target Acquisition with WFC

2. Results

From 3137 (FOS internal test), the mean position after a 10" slew differed from that before the slew as follows:

Difference:	x	y
Accuracy	-0.03"	-0.08"
Precision	0.11"	0.06"

From 1427, the Blue side slew from a WFC target acquisition placed the target close (0.7") to the center of the FOS 4.3" target acquisition aperture on both trials. A slew back to the WFC placed the target within 0.1" of the intended position. This was deemed so successful that the Project canceled Red side tests.

3. Conclusions

There is no evidence for a systematic offset from the target after FOS-originated blind offset slews, but, due partially to HST jitter and FOS GIMP between the measurement times, there is an additional uncertainty (lack of precision) in the final target position on the order of 2.5 pixels, or 0.2". This is acceptable for the larger science apertures, but could be a problem with those smaller than 0.5".

Mode III with the WFC was also successful, given the larger slew and longer time between measurements. The accuracy on two tries was 0.7", and 0.1" for a return to WFC. One can imagine the usefulness of this mode during parallel observations or other special circumstances.

The full write-up for Mode III is also in CAL/FOS 081 *FOS Onboard Target Acquisition Tests,* S. Caganoff, Z. Tsvetanov and L. Armus, March 1992.

VIII. Spectral Flat Fields

Spectral flat field investigations were conducted under SV proposal 1318 - Spectral Flat Fields.

A. Results

The typical structure or "granularity" (standard deviation about the mean response) for most grating/detector combinations is only 1-2%, although there are a few blemishes at the >5% level, particularly one near channel 1490 in several blue side gratings. Blue side flats exhibit less structure than Red side ones. Some flat field information is available for 85 - 95% of the diodes sampling useful wavelength ranges as the result of this SV testing; there are a few narrow spectral ranges of interest for which on-orbit information is still lacking, principally due to spectral features in the calibration targets G191 B2B and KPD0005+5106. See the tables in CAL/FOS 075 for details.

B. Recommendations

As indicated in CAL/FOS reports 069 and 075, further periodic testing of FOS field flatness, especially with the G150L and G190H gratings, has been recommended for Cycles 1-9. In addition, the G780H/Red combination was not calibrated in SV due to lack of time and should be calibrated as soon as possible.

Initial results from SV Flat Field testing were reported in CAL/FOS 069, *"FOS Red Detector Flat Field and Sensitivity Degradation"*, G. Hartig, November, 1991. There is a copy in Appendix 1. The final report for SV Flat Field testing is CAL/FOS 075, *FOS Spectral Flat Field Calibration (Science Verification Phase Data),* S. F. Anderson, February 1992. The full text, with figures, is to be found in Appendix 1.

IX. Scattered Light

The scattering characteristics of the combined HST OTA and FOS optical paths were measured by taking low-resolution spectra of a standard star, BD+75° 325, at a number of selected off-axis positions (at angle θ to the line of sight) and comparing these with the on-axis spectrum. This was accomplished by means of Proposal 1319 - Scattered Light, which was performed early in SV, on March 9, 1991. This test was on the blue side only, in the wavelength range 115 to 250 nm.

A. Results

The analysis of the test data has led to two primary results:
1) The combined (HST + FOS) scattering function exhibits three characteristics: a) the inner core (at $\theta < 4''$) is dominated by the large point spread function (PSF) of the HST; b) the outer wings of the scattering function, $4'' < \theta < 32''$, show a θ^{-3} dependence consistent with predictions for the HST Airy disc; and c) the wavelength dependence of this scattering function follows λ^{-1}, suggesting that the UV micro roughness contribution to the scatter is quite small, and hence the HST primary mirror is very smooth at ultraviolet wavelengths.
2) The FOS scattering contribution is limited only by grating scatter, and is consistent with pre-launch grating calibration measurements.

The scatter contributions from the HST mirror surface micro roughness and the FOS gratings appear to be within their design specifications (i.e. better than planned.)

B. Recommendations

The functional form for the scattering function of the FOS alone will have to be determined by deconvolving the HST point spread function out of the joint function. On the other hand, it is presumably the joint function that is important for observers.

The details of the measurement and analysis by the IDT as well as a description of the implications of these results for FOS on achieving its limiting performance for certain typical observations are given in CAL/FOS - 073, *Scattered Light Characteristics of the HST FOS,* Bartko *et al.* April 1992 (copy in Appendix 1); see also the work of Caldwell and Cunningham (SV Interim Report, in CTA SV Final Report), on Red scattered light, below 2100 Angstroms.

X. Absolute Photometry

Data were taken for more than a year on the photometric standard stars BD+75°325, HZ-44, BD+33°2642 and BD+28°4211 in the following tests:
Prop 1320 - Absolute Photometry, and its successors Prop 3106 - Absolute Photometry, (revision 1) and Prop 2823 - Absolute Photometry (Red only). Data taken prior to the refocusing of the HST in January 1991 were not used, as there is a strong indication that refocusing had a large effect on FOS sensitivity.

1. Red Side

The Red detector seems stable, within the measurement errors, except in the wavelength region around 2000 Angstroms. It is thought that the drop in this region is due to the formation of "color centers" in the fused silica faceplate, caused by radiation damage in the SAA. Tests at a particle accelerator on a flight spare faceplate have not reproduced the on-orbit results however, so this phenomenon is still not understood. The following table is a condensation of the on-orbit test results:

Grating	Wavelength Range	% Change in Quantum Efficiency per year
G190H	1650 - 2312	-12.8 +/- 5.7 (2.24σ)
G270H	2223 - 3278	- 4.5 +/- 1.3 (3.46σ)
G400H	3236 - 4782	+ 0.1 +/- 0.9 (0.11σ)
G570H	4570 - 6818	- 0.8 +/- 0.1 (8.00σ)
G780H	6270 - 8200	- 3.9 +/- 0.7 (5.57σ)
All Hi Res	1650 - 8200	- 4.4 +/- 5.2 (0.85σ, insignificant)

2. Blue Side

The Blue side data taken between 1991.1 and 1992.2 seem to show a loss of about 4.4% per year in efficiency, with possibly a very weak wavelength dependency. The dependence matches neither what would be expected from molecular contamination nor from radiation damage to the photocathode in the Blue digicon. Obvious possible explanations, such as a drift in the discriminator level settings have been investigated, but do not explain the data, which are summarized below. Ohter possible explanations include partial obscuration by the thermal blankets or grating spots, both of which have been seen in the past in ground-based testing.

Grating	Wavelength Range	% Change in Quantum Efficiency per year
G130H	1153 - 1606	-10.9 +/- 0.3 (36.33σ)
G190H	1573 - 2330	-12.8 +/- 5.7 (4.64σ)
G270H	2221 - 3301	- 4.5 +/- 1.3 (10.22σ)
G400H	3240 - 4822	+ 0.1 +/- 0.9 (5.15σ)
All Hi Res	**1650 - 8200**	**- 4.4 +/- 5.2 (4.17σ, fairly significant)**

While the stability of the Red detector, the source of many pre-launch concerns, is gratifying, the diminished Blue detector sensitivity remains a mystery. In checking with IDT groups for the GHRS and the FOC for similar sensitivity drifts, we were informed that their diminished SV testing would be insufficient to reveal changes at the level seen here. We note however that section 3.4.2 of the CTA SV Final Report notes a 6.0 +/- 1.5% decrease per year at 120nm, 5.7 +/- 1.8% per year at 140nm, and 3.6 +/- 1.8% per year at 210nm, as measured in OLT testing of OTA UV throughput.

The results of this testing are to be written up in CAL/FOS - 077, *Photometric Calibration of the FOS*, J. D. Neill, R. C. Bohlin and G. Hartig, April 1992. This report has not been released yet, due to the desire to confirm results and test models through further tests.

XI. Wavelength Calibration

Post-launch calibrations of the spectral response of the FOS were conducted according to the following test proposals:
Prop 1317 - Wavelength Calibration
Prop 3316 - Wavelength Calibration, revision 1 (Internal/External Calibration)

A. Summary of Results
After correction for GIMP, the Red-side mean offset ($X_{internal}$ - $X_{external}$) is +0.176 +/- 0.105 diodes. On the Blue-side the offset is -).102 +/- 0.100 diodes. These values are similar to those measured in pre-flight testing. The observed dispersion of +/- 0.1 diode corresponds to a limiting accuracy of roughly 20 km/sec in velocity measurements on single lines in FOS spectra.

The full text of the IDT report on SV wavelength calibration is in CAL/FOS - 067, *In-Flight FOS Wavelength Calibration - Template Spectra,* G. A. Kriss, W. P. Blair and A. F. Davidsen (uncirculated draft 2/1/91) and, more recently, in CAL/FOS - 070, *Internal/External Offsets in the FOS Wavelength Calibration , G. A.* Kriss, W. P. Blair and A. F. Davidsen, February 1992. There is a copy of each in Appendix 1.

XII. Polarization Calibration

On-orbit calibration of the FOS Polarizer and various aperture and filter/grating combinations took place according to the following test procedures:
Prop 1430 - Polarization Calibration
Prop 3235 - Polarization Calibration, revision 1

A. Summary of Results

The main findings from SV polarization modes testing were:
1) The polarizer can be used effectively with the 4.3" target acquisition aperture, with the result that the overall efficiency is only slightly degraded by the spherical aberration of the HST mirror.
2) Due to the geomagnetically-induced image motion problem (GIMP) in the Red side digicon, combined with the need to use large apertures due to the HST spherical aberration problem, polarimetry is best restricted to the Blue side.
3) The polarizer can also be used with the 1.0" circular aperture (B-3) for background rejection or higher spectral resolution.
4) The FOS polarization mode is calibrated in the range 128-331 nm with the B-waveplate (gratings G130H, G190H and G270H).
5) Systematic errors estimates to linear polarization measurements are +/- 3% for G130H and +/- 2% for G190H and G270H. Errors in theta are 1%, with the largest source of uncertainty being an incomplete correction of the oscillation of the plane of polarization with wavelength.

B. Recommendations

1) POLSCAN=8 - Software and mechanical overheads have a big impact on the operational efficiency of the polarizer. A POLSCAN at 8 positions should be used for most observations; at 16 there is more than 13 minutes of data dump, drum rotation and status update overheads.
2) Apertures 4.3" and 1.0" - Only these apertures have enough throughput for astronomical targets. The smaller 0.3" and 0.5" circular apertures are also affected by HST tracking jitter; they may be used for some internal calibrations.
3) Gratings - Use H (high resolution) gratings, specifically G130H, G190H and G270H. Low resolution gratings worsen the low resolution obtained with the larger apertures which must be used due to the spherical aberration problem. Note that the polarizer will be useless when the two mirrors in COSTAR are inserted into the optical path to correct the spherical aberration.
4) Waveplate - Use the B-waveplate, which has better retardation characteristics in the range 128 - 331 nm.
5) Target Selection - The 1.0" aperture may be preferred for targets in extended objects, while the 4.3" aperture may be better for isolated targets such as white dwarfs, QSOs and BL Lacs.

The complete write-up of OV and SV calibrations, as well as a recap of previous ground-based prelaunch calibrations is contained in CAL/FOS 078, *FOS Polarimetry Calibration*, by R. G. Allen and P. S. Smith, March 1992. There is a copy in Appendix 1.

XIII. Dark Counts and Sky Background

A. Tests Performed

The following tests were run, repeatedly, in support of our investigations into the dark and sky background characteristics of the FOS:
Prop 1316 - Dark Counts
Prop 2965 - High Galactic Latitude Sky Background
Prop 2966 - Low Galactic Latitude Sky Background
Prop 2967 - Low Ecliptic Latitude Sky Background

B. Summary of Dark Count Test Results

1. Summary of CAL/FOS-071: (Preliminary) Dark Background Analysis
a) the Red side has a higher count rate than the Blue side,
b) the background count rate is higher at higher geomagnetic latitudes, and
c) the bulk of the dark counts recorded in "good" diode/channels occur in "bursts".

The bursts are attributed to Cerenkov radiation from high energy particle energy deposition in the digicon faceplates lighting up anywhere from a few diodes to the entire diode array simultaneously. The differing attenuation of the Cerenkov light in the faceplates of the two sides explains much of the higher Red background.

2. Summary of CAL/FOS-076: Analysis of FOS On-Orbit Detector Background with Burst Noise Rejection
Test 1316 showed that the "usual" FOS background rate could be reduced by a factor of five (to 0.002 counts/sec/diode) by setting the rejection setting to the lowest possible value of 2 or more counts per array readout (REJLIM=1), with a frame time of 0.25 seconds. Further tests are recommended on the Red side with a frame time of 0.05 sec or less.

3. Summary of CAL/FOS-079: FOS Operation in the South Atlantic Anomaly (SAA)
OV2748 was extended into the SV time frame, after verification that it was safe to leave the HV on through the SAA. These test results were used to determine FOS operational limits in the SAA, so as to increase HST efficiency. The contours determined are similar to those determined previously at UCSD for the GHRS. Both instruments give consistant results, showing that the SAA has shifted westwards a bit with respect to earlier measurements on other spacecraft. The FOS and GHRS show no sensitivity to a previously-reported eastern high-energy tail on the SAA.

4. Summary of CAL/FOS-080: Dark Background Measurements
SV 1316 allowed the characterization of the shape and mean level of the background expected for an FOS exposure. All diode/channels were left on and burst noise rejection was disabled for these test runs .It must be noted that the fits presented below are valid only for the test data set, and not for any particular observation - see CAL/FOS-080.

a) Blue Noise Spectrum
After summing across removed dead and noisy channels, the Blue noise spectrum is relatively smooth, varying from 0.0085 counts/sec/diode at diode 0 (shortest wavelength), through a 15% sag at the middle to roughly the former level by the end of the diode array. The best-fit third-order polynomial fit to our particular runs was:

$$\text{counts} = 0.00847 - 0.00001078d + 0.00000003111d^2 - 0.00000000002153d^3$$

b) Red Noise Spectrum
The Red side varies by only 5%, with a minimum at diode 0 (longest wavelength) of 0.01045 counts/sec/diode and some indication of a two-part distribution, where the best-fit third-order polynomial over diodes 0-235 is

$$\text{counts} = 0.01045 - 0.00001070d - 0.0000001306d^2 + 0.0000000004081d^3$$

while from diode 236 to 511 it is

$$\text{counts} = 0.01527 - 0.00003656d + 0.0000001006d^2 - 0.00000000009062d^3$$

c) Variation with Geomagnetic Latitude
There is evidence of variation of the background rate with geomagnetic latitude, although the fit to previous models is not compelling. The background rate is lowest from +25o to -25o geomagnetic latitude. It is possible that there is also a dependence on geomagnetic longitude, previously undetected. See CAL/FOS-080.

d) Digicon Uniformity
There appears to be reasonable uniformity across both detector faceplates (but we are not using monochromatic light in these tests.)

e) Application to Estimates of Background Noise
Table III of CAL/FOS-080 presents predicted background rates, which may in many cases be compared in with rates from portions of the diode array which are not illuminated by the target, but rather by the background, plus scattered light. Usage of the burst rejection option is also discussed.

C. Summary of Sky Background Test Results

As discussed in CAL/FOS-080, sky background is an important contribution in several instrument configurations, especially when the large TA aperture is used, as is often necessary with the current HST point spread function.

Geocoronal lines are easily seen, particularly relative to Ly α ,and there is clearly O I and possibly some N I. O I is stronger than expected. The effects of this background may be lessened by disabling certain diode/channel ranges. Ly a and O I are fairly well correlated with Sun-Earth angle and may be reduced by operating at low Sun-Earth angles. However, the background rate is also variable, probably depending on solar and/or atmospheric conditions.

The relationship between zodiacal light and ecliptic position is not at all clear, nor is that between the diffuse galactic background and galactic position. Separating out the contributions of zodiacal light and diffuse galactic light has proved difficult: both are overwhelmed by another component, presumably scattered sunlight. These effects are important for optical wavelength observations, and again, they may be reduced by operating at low Sun-Earth angles.

Recommendation: test with smaller apertures and with the polarizer, to facilitate separation of the various sky background components, which may lead to better use of the on-board FOS burst noise rejection software. Allow selective ranges of the Disabled Diode Table to be used, rather than all or nothing, if using REJLIM.

D. References

The following CAL/FOS reports and other publications were generated in the course of FOS Dark and Sky background investigations: There is a copy of each in Appendix 1.

CAL/FOS 071 *An Analysis of FOS Background Dark Noise,* E. I. Rosenblatt et al., April, 1992.

CAL/FOS 076 Analysis of FOS On-Orbit Detector Background with Burst Noise Rejection, E. A. Beaver, R. W. Lyons, April 1992.

CAL/FOS 079 *FOS Operation in the South Atlantic Anomaly,* W. A. Baity, E. A. Beaver, J. B. Linsky and R. Lyons, March 1992.

CAL/FOS 080 *FOS On-Orbit Background Measurements,* R. Lyons, E. A. Beaver, J. B. Linsky and W. Baity, March 1992.

XIV. Liens - Uncompleted SV Activities

In one of the last PMA meetings, which tracked progress through SV, it was determined that the FOS tests performed or scheduled up to that date were sufficient for the purposes of initial calibration and specifically for filling out or updating the various data base tables. In that spirit, we merely point out that the following activities were at one point planned for SV; they have since been deemed un-necessary:

All activities listed as "delta" in the original SV Plan.
SV Test 1315 - Time-Resolved Mode.
From section VII, perform mode III T.A. on Red side, for completeness.
From section VIII, test G780H/Red Digicon combination for field flatness.
From section IX, deconvolve the HST point spread function from the combined HST/FOS results to obtain the separate FOS scattering function. Test Red side, with later type star.

XV. Recommendations for Continued Calibrations

The initial recommendations for continued calibrations of the FOS were made in the report CAL/FOS 062, *Long Term FOS Calibration Plan: Cycle 1,* A. L. Kinney and G. R. Hartig, August 1989. This document was updated in January of 1992. There is a copy in Appendix 1.

It is specifically recommended that tests analogous to SV 1318 - Spectral Flat Fields be continued on a periodic basis, given the temporal instability in some grating/detector combinations (particularly G160L/Red and G190H/Red; see CAL/FOS - 077).

Complete the 5 - 15% of flat-fielding on diodes sampling useful wavelength ranges mentioned in section VIII, part A.

Perform a shorter series of sky background tests with smaller apertures and with the polarizer, to facilitate separation of the various sky background components, which may lead to better use of the on-board FOS burst noise rejection software.

APPENDIX 1 - OV/SV Calibration Reports and Other Documents

A. Post-Launch CAL/FOS Reports

066 - ***Geomagnetic Image Deflection problem in the FOS***
V. Junkkarinen, E. Beaver, R. Cohen, R. Hier, R. Lyons and E. Rosenblatt - April. 1990

067* - ***In-Flight FOS Wavelength Calibration - Template Spectra***
G. A. Kriss, W. P. Blair and A. F. Davidsen - February 1991

068 - ***FOS Red Detector Plate Scale and Orientation***
B. Bhattacharya and G. Hartig - November 1991

069 - ***FOS Red Detector Flat-field and Sensitivity Degradation***
G. Hartig - November 1991

070+ - ***Internal/External Offsets in the FOS Wavelength Calibration***
G. A. Kriss, W. P. Blair and A. F. Davidsen - February 1992

071* - ***An Analysis of FOS Background Dark Noise***
E. I. Rosenblatt, W. A. Baity, E. A. Beaver, R. D. Cohen, V. T. Junkkarinen, J. B. Linsky and R. W. Lyons - April 1992

072 - ***Aperture Calibrations During Science Verification of the FOS***
L. Dressel and R. Harms- (In Revision)

073* - ***Scattered Light Characteristics of the HST FOS***
F. Bartko, G. S. Burks, G. A. Kriss, A. F. Davidsen, R. D. Cohen, V. T. Junkkarinen, and R. Lyons - April 1992

074* - ***On - Orbit Discriminator Settings for FOS***
R. D. Cohen - February 1992

075+ - ***FOS Spectral Flat Field Calibration (Science Verification Phase Data)***
S. F. Anderson - February 1992

076+ - ***Analysis of FOS On-Orbit Detector Background with Burst Noise Rejection (Short Version)***
E. A. Beaver and R. W. Lyons - April 1992

077* - ***Photometric Calibration of the Faint Object Spectrograph***
J. D. Neill, R. C. Bohlin and G. Hartig - April 1992

078* - ***FOS Polarimetry Calibration [update of CAL/FOS 055]***
R. G. Allen and P. S. Smith - March 1992

079* - ***FOS Operation in the South Atlantic Anomaly***
W. A. Baity, E. A. Beaver, J. B. Linsky and R. Lyons - June 1992

080* - ***FOS On-Orbit DarkBackground Measurements***
R. Lyons, J. B. Linsky, E.A. Beaver, W. A. Baity and E. I. Rosenblatt - August 1992

081* - ***FOS Onboard Target Acquisition Tests***
S. Caganoff, Z. Tsvetanov and L. Armus - April 1992

082* - ***Lab Test Results of the FOS Detector Performance in a Variable External Magnetic Field***
E. A. Beaver and P. Foster - June 1992

083* - ***FOS On-Orbit Sky Background Measurements (Preliminary)***
R. Lyons, W.A. Baity, E.A. Beaver, R.D. Cohen, V.T. Junkkarinen and J. B. Linsky - August 1992

Note: + indicates revised version
* indicates not previously released

B. Other Documents

Faint Object Spectrograph Instrument Handbook, Version 1.1
H. C. Ford and G. Hartig - May 1990 (STScI).

Recommendations for Phase 2 GO Submissions
G. F. Hartig and A. L. Kinney - March 1991 (STScI).

Faint Object Spectrograph Instrument Handbook, Version 2.0
A. L. Kinney - April 1992 (STScI).

APPENDIX 2 - Pre-Launch CAL/FOS Reports List

List of all calibration reports issued by the FOS IDT from 1983 to HST launch.
FOS

001 *Photometric Calibration of the FOS Blue Digicon*
J. Wheatley and R. Bohlin - October 1983

002 *Paired Pulse Induced Systematic Errors in the FOS Binary Search Target Acquisition*
H. Ford - October 1985*

CAL/FOS

001 - *Lab. Calibration of the FOS: Absolute Sensitivity (First Results for the Blue Side)*
J. Koornneef, R. Bohlin, and R. Harms - August 1983

002 - *FOS Entrance Aperture Sizes*
J. M. Wheatley, R. C. Bohlin, H. C. Ford - October 1983

003 - *Recent FOS Calibration at GSFC*
J. M. Wheatley and R. C. Bohlin - November 1983

004 - *FOS Wavelength Calibration*
J. M. Wheatley and R. C. Bohlin - December 1983

005 - *FOS-Scattered Red Light (Red Tube)*
Jan Koornneef - January 1984

006 - *FOS Flat Field Calibration (FOS Calibration #15)*
D. Linder and R.C. Bohlin - March 1984

007 - *FOS Scattered Light Measurements (Cal. Plan #12B)*
J. Wheatley and R.C. Bohlin - March 1984

008 - *FOS Aperture Repeatability and Filter-Grating Wheel Repeatability (Calibration Plan 10C and 10D)*
J. Wheatley, H. Ford and R. Bohlin - May 1984

009 - *FOS Firmware Target Acquisition*
H. Ford - June 1984

010 - *High Voltage Settle (FOS Calibration #08)*
D. Lindler & R. Bohlin - December 1984

011 - *Scattered Light Background Perpendicular to the Dispersion - Preliminary Version (Calibration #19)*
D. Lindler and R. Bohlin - January 1985

012 - *FOS Filter Grating Wheel Repeatability (Cal Plan 10D)*
G. Hartig, R. Bohlin, H. Ford and R. Harms - December 1984

013 - *Scattered Red Light - Preliminary Version (Cal Plan 12A)*
M. Sirk & R. Bohlin - January 1985

014 - *Internal FOS Pt-Cr-Ne Calibration Lamps - Performance in the Far UV*
M. Sirk & R. Bohlin - March 1985

015 - *Scattered Light from Bright Emission Lines Preliminary Version (Calibration Plan 12B)*
M. Sirk and R. Bohlin - March 1985

016 - *The Laboratory Absolute Photometric Calibration of the FOS*
George Hartig - June 1985

017 - *Improvements in Filter/Grating Wheel Repeatability*
George Hartig - May 1985

018 - *FOS Line Widths (FWHM) as a Function of Aperture Size*
A. Kinney and H. Ford - May 1985
019 - *FOS Entrance Aperture Sizes (Calibration Plan 10B)*
D. Lindler, R. Bohlin and G. Hartig - July 1985
020 - **Scattered Light from Bright Emission Lines (Cal Plan 12B)**
M. Sirk and R. Bohlin - September 1985
021 - *LMSC NSSC-1 Target Acquisition Tests of Feb. 1985*
D. Lindler, A. Kinney and H. Ford - September 1985
022* - *Locating Spectra on the FOS Digicons and the Photometric Consequences of Errors in Position*
J. Wheatley and R. Bohlin - October 1985 (incomplete)
023 - *Mode 2 Target Acquisition: Binary Search Parameters*
A.L. Kinney and H.C. Ford - October 1985
024 - *Results of Binary Search Target Acquisition Tests of August 1985*
A. L. Kinney and H. C. Ford - November 1985.
025 - *FOS Linearity Corrections*
D. Lindler and R. Bohlin - January 1986
026 - *FOS Wavelength Calibration (Laboratory Calibration Plan 13B)*
M. Sirk and R. Bohlin - January 1986
027 - *Firmware Target Acquisition*
A. L. Kinney, R. G. Hier, - June 1986
028 - *FOS Wavelength Calibration Exposure Times (Laboratory Calibration Plan 13G)*
R. Bohlin and M. Sirk - April 1986
029 - *FOS Entrance Aperture Offsets (Calibration Plan 13G)*
M. Sirk and R. Bohlin - May 1986
030 - *Limiting Magnitudes for FOS Target Acquisition*
A. L. Kinney - April 1986
031 - *Commanding FOS Target Acquisition*
T. M. Gasaway and A. L. Kinney - June 1986
032 - *An Automated Method for Computing Absolute Instrumental Sensitivity Curves for FOS: Results of Testing on IUE Spectra*
D. Lindler and R. Bohlin - August 1986
033 - *Thermal Vac Measurements of the FOS Filter-Grating Wheel Repeatability*
George Hartig - August 1986
034* - *FOS Throughput Optical Test Results*
George Hartig - August 1986 (NOT to be completed.)
035 - *Results of TA Tests at LMSC; Feb. 1986*
Anne L. Kinney - August 1986
036 - *TV Monitoring of the F8 Detector Red Sensitivity (Test Segment YMONTHLY)*
George Hartig - August 1986
037 - *Ambient QE Measurements of the FOS Red Side*
George Hartig - October 1986
038 - *FOS Wavelength Scale Below the Calibration Lamp Cutoff at 1239 Angstroms (Laboratory Calibration Plan 13B)*
M. Sirk and R. Bohlin - October 1986
039 - *FOS Entrance Aperture Transmittance for Point Sources*
George Hartig - November 1986
040 - *Results of Target Acquisition Tests; February, 1987*
A.L. Kinney - March 1987
041 - *Wavelength Offsets Among Internal Lamps and External Sources*

M. Sirk and R. Bohlin - April 1987
042 - ***FOS Target Acquisition for Moving Targets***
A.L. Kinney - June, 1987 (never completed)
043 - ***FOS Target Acquisition Handbook***
A.L. Kinney and H. C. Ford - May 1988
044 - ***Limiting Accuracy of FOS Wavelength Calibrations***
R.C. Bohlin, M. Sirk, and G. Hartig - October 1987
045 - ***FOS Linearity Corrections (Revisited)***
D. Lindler and R. Bohlin - August 1988
046 - ***FOS Aperture Wheel Repeatability***
R. Harms and R. Downes - October 1988
047 - ***FOS Exposure Limits***
G. Hartig - October 1988
048 - ***FOS Wavelength Calibration Exposures***
G. Hartig - October 1988
049 - ***FOS Filter Grating Wheel Repeatability (Revisited)***
G. Hartig - October 1988
050 - ***FOS Discriminator Settings***
R. Cohen, E. Beaver - May 1990
051 - ***Dead and Noisy Channel Summary***
R. Cohen, D. Tudhope & E. Beaver - April 1989
052 - ***Results Tests Related to Target Acquisition, March-August 1988***
A. Kinney - February 1989
053 - ***Laboratory Calibration of FOS Throughput***
G. Hartig - January 1989
054 - ***Revised FOS Wavelength Calibration***
G. A. Kriss, W. P Blair, and A. F. Davidsen - November 1988
055* - ***FOS Polarimetry***
R. G. Allen and P. S. Smith - November 1988
056 - ***FOS Internal/External Wavelength Offsets***
W. P. Blair, G. A. Kriss, and A. F. Davidsen - December 1988
057 - ***FOS Stability After Short HV Off***
E. Beaver, R. D. Cohen, D. Tudhope & W. Baity - February 1989
058* - ***Scattered Red Light in the FOS***
W. P. Blair, A.F. Davidsen, and A. Uomoto - March 1989
059 - ***Scattered Light Perpendicular to the Dispersion in the FOS***
A. Uomoto, W. P. Blair, and A. F. Davidsen - March 1989
060 - ***Filter/Grating Wheel Repeatability: Dependence on Motor Selection***
G. Hartig - May 1989
061 - ***FOS Optical Focus and Resolution***
T.E. Smith and G. Hartig - October 1989
062 - ***Long Term FOS Calibration Plan: Cycle 1***
A.L. Kinney and G.F. Hartig - August 1989
063 - ***FOS Project Data Base Aperture Files***
A.L. Kinney and C. Cox - October 1989
064 - ***FOS Dead and Noisy Channel Update***
R. Cohen, E. Beaver and V. Junkkarinen - October 1989
065* - ***Rotation Matrix for Mode 2 FOS TA***
A.L. Kinney and G.F. Hartig - March 1990

APPENDIX 3 - Anomalistic Behavior and Performance-Limiting Characteristics

A. List of FOS-related CCRs

CCR #	Date	Title and Comments
527	9/83	Elim aperture door closure flags
1073	7/84	CEI spec SCN error
323R1	10/84	SI differential pressure decay rate Note: although FOS & HRS pressure gauges are different, readings inside each instrument compartment were consistent in initial orbital checkout.
1041	7/84	Change of FOS fuses; see also 1185 "< 3 amp fuses in FOS"
1105	11/84	In-line heat pipes Note FOS flight heat pipes are stainless steel, replacing copper ones. The amount of ammonia inside them is NOT life threatening, no matter what the EPA thinks! These stainless steel pipes are more efficient than the original ones, so that the FOS preamps and photocathodes may run on the cold side, near previously defined limits. The caution during servicing mission is even more valid: sunlight on the radiators will result in the photocathode and preamps rapidly heating up, to probable damage limits.
1046	12/84	Global event flags. Note FOS does not use take data flag.
1124	12/84	Automatic dump; note not implemented due to almost certain conflicts with other HST elements & contention for data channels.
1145	1/84	Composite SI safing sequence Note we had some objection: letter LKR to Beyer 2/19/85. Possibly time too short to ensure FOS door closing fully.
1083	1/85	Acoustic test; note some impact.
1164,6	2/85	Other SI (and STAR) emissions, ripple, noise may cause problems.
1336	9/85	Magnetic field strengths of other SIs; we are less well shielded than called for in the FOS design, so there may be more susceptibility than we previously thought to other SIs. GIMP.
1351	10/85	Minimum fine lock step size
990	9/85	SI C&DH Sci Data/Clock Timing
1377	10/85	Axial SI Forward Guide Block limits; changes made
1395		Initial Safing Sequence Bit in SSM PIT; FOS will have 4.5 sec wait before any safing is initiated

1427 et al		Preparation of Spare Digicons
1494		New General Equations for FOC & FOS; revised response
1687		Ops of Survival Heaters; add details here on just how our heaters work
		Envelope for FOS: did we have any trouble on insertion?
2177		FOS minor refurbishments; anything of note?
2305		Critical Commanding: FOS "arming" commands are not to be included in data base. Arm and "Blow" (=Burn) commands are not to be sent without full discussion, which MUST include PI.
2382		FOS microprocessor Commanding; approved with comments -look them up!
2398		FGWA Commanding: any long-term test suggestions? Note: FGWA motor drive teeth in motor showed sufficient wear that the motor was refurbished (gear wheel replaced) in 1985, at the time of shipping to LMSC. Commanding is in forward direction only to alleviate positioning problems. Ref G. Hartig, CALFOS reports #17, #33
2607	2/21/90	Mechanism Lifetimes / Cycles Limits Change
2682	5/15/90	Baseline Thermal Constraint/Action Values Changes

B. Historical Microprocessor Reset Events:

(Ref Baity/Randall summary 5, rev 7/25 1990)
1st at 04:28 on July 14, 1984 (notebook 00512, p11)
2nd 14:30-19:00 on July 14, 1984 (notebook p 27)
No other spontaneous resets in MMDA, VAP or A&V testing.

Blue side microprocessor reset day 90.186, July 4 1990 coincident with HV turn-on (HSTAR 743). Tests on July 16 caused a microprocessor reset pulse and autosafe on first blue
HV relay command. Microprocessor did not reset properly (HSTAR 826).

Red side microprocessor reset; required patch to open up trim coil current limit (YTRMFCUR) from 167440 to 177400 octal (HSTAR 1557?), day 90.325. Ref letter Barnett to Randall Nov 24, 1990.

C. High Voltage Ramp-Up:

Practice in testing was a maximum of 2000 V over 10 sec. We safed the FOS deliberately during initial HV turn-on due to a concern over a 6000 Volt jump in 10 sec.

D. FOS - Related HSTARs

Included below is a list of HSTARS through 4/23/91 which may indicate further items which might be added to the list of FOS anomalies and operational problems.

#	Title	Status	Occurrence
0323	Switch FGWA Motor temp Monitor A/B	Closed	
0464	ESS Extractor Jumps Backward in Time	Closed	
0565	SMS Text Statement Error	Closed	
0572	FOS High Voltage Turn-On Rates (Ramp-Up)	Closed	
xxxx	Sci tape recorder Data Loss (Cut Off End)	Closed	
0743	FOS Autonomous Safing 185/17:50	Closed	185 1990
0826	Microprocessor Reset when HV Relay Closed	Closed	185 1990
0856	Derived Param. YDATACTL Shows Incorrect Error	Closed	
0994	FOS Begac Started 1.5 sec Late	Open	
0995	FOS Red Side Diode Array Movement	Open	
xxxx	DM-03D Incorrectly Describes FOS T.A. Failure	Closed	10/07/90
1330	Anomalous FOS Aperture Offset (day 281)	Closed	10/08/90
1331	DF/PIT Dwell Scan Request rejected (day 281)	Closed	10/08/90
1386	FOS Science Data Ready Signal	Open	
1554	FOS Data Contains Inversions	Open	
1557	FOS Safed During Initialization on Red Side	Open	Fitch?
1579	FOS Improper Centering Slews for FOS Dwell Scans	Open	Kinney?
1639	Missing FOS Observation on Sci Tape Recorder	Closed	
1642	Star Not in FOS 4.3" Aper 12/10/90 (344)	Open	12/10/90
1674	FOS Mode II TA (Couldn't Find Target Star)	Open	Kinney?
1794	FOS Binary Search Fail 12/17/90 in 1428	Reopen	12/17/90
1795	FOS Onboard Acquisition Fails	Open	
1796	FOS Slew request Failure	Open	
1801	FOS Overlight protection Tripped 1/10/91	Open	01/10/91 Fitch
1810	Target not in FOS Aperture SV 1318	Open	
1811	Target not in Vicinity of FOS Aper SV 1317	Open	
1824	FOS Mode 2 TA Failure 22/14:45 field crowded?	Open	01/22/91
1852	FOS Data Missing from STR Dump at 27/15:51	Closed to 1601	
1853	Loss of RT decision image 3123 2/9/91 Y0G60D01A	Closed	02/09/91
1886	Kidney or S shaped images in TA, 3123 1/28/91	Closed	01/28/91
2202	Pointing error >2" 3137 Blue [date?]	Open	
2203	Pointing error >2" 3137 Red [date?]	Open	