The Hopkins Ultraviolet Telescope

Engineering Report
for the
Astro-2 Mission

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1. Introduction

The Hopkins Ultraviolet Telescope (HUT) was flown for the second time as part of the Astro-2 mission aboard the space shuttle Endeavour (STS-67). The mission began at liftoff from Kennedy Space Center (KSC) at 1:38 AM EST on March 2, 1995, and ended at 4:48 PM EST on March 18 with the landing at Edwards Air Force Base. The total mission elapsed time (MET) was 16 days, 15 hours, and 10 minutes. Activation of HUT began at MET 0/03:44 with the activation of the heater bus, and ended with its deactivation at MET 15/03:48. Once again there were no significant anomalies, and the instrument was able to gather significantly more data than during the Astro-1 mission. This improvement was due to the increased efficiency of the instrument, longer duration of the mission, and the nearly trouble-free operation of the Instrument Pointing System (IPS) and other Spacelab and orbiter systems. Observing efficiency exceeded 60% with 385 observations of 265 different objects, yielding 205 hours of on-target integration time. In addition, the stable pointing of the IPS enabled full resolution spectra to be obtained by HUT before any post-flight data processing is done to reduce the effects of pointing jitter.

HUT was designed and built during the early 1980's and delivered to KSC in March, 1985. The Astro-1 instruments were integrated in 1985 and early 1986, but due to the Challenger accident were put into a hold condition for three and a half years. During this period the HUT spectrograph was replaced with an upgraded model containing a newer detector and improved grating cell, and the acquisition TV camera was replaced with a flight spare due to a problem caused by the long storage period without regular run time. HUT was finally flown in December, 1990, as part of the Astro-1 mission aboard the shuttle Columbia. Problems with the IPS and other Spacelab systems were overcome, and HUT and the other instruments were able to collect a great deal of important new data. Scientific aspects of the design and performance of HUT for the Astro-1 mission are detailed in Davidsen et al. (1992, ApJ, pp 392, 264).

HUT remained in storage at KSC after Astro-1, with the exception of the spectrograph and the TV camera. These two items were removed from the telescope and returned to the Johns Hopkins University (JHU) for post-flight calibration and maintenance. Prior to Astro-2, several upgrades were made to the hardware and software to improve the instrument performance. The iridium-coated primary mirror was replaced with its flight spare, which was coated with a more reflective silicon carbide layer. The spectrograph was again replaced with an upgraded model, containing a silicon carbide-coated grating and a new detector. These changes increased the effective area of the instrument by more than a factor of two for wavelengths shorter than 1600 Å (see the plot in §3.3). Numerous software changes were also implemented to consider the hardware changes, to add functionality, and to correct problems from Astro-1.

This report concentrates on the engineering performance of HUT during the Astro-2 mission, with references to Astro-1 as appropriate. It also discusses the mission operations relative to both the instrument and its ground support equipment. In addition, the current status of HUT is discussed with a view toward reflight should a third Astro mission be planned. A preliminary assessment of the in-flight scientific performance and calibration of HUT during the Astro-2 mission is given by Kruk et al. 1995, ApJ, 454, L1, and is attached as Appendix B to this report.

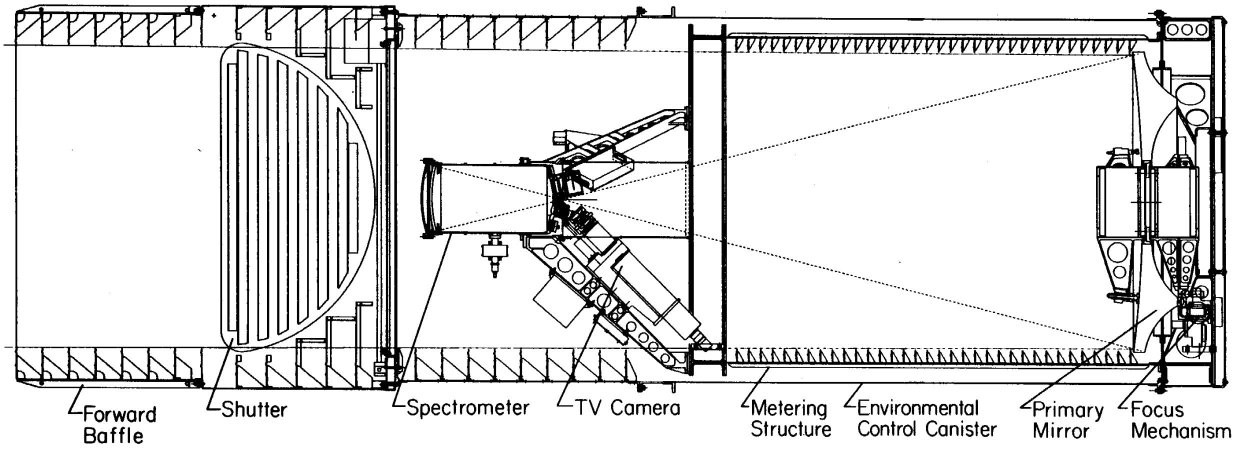
2. HUT Systems Description

HUT produces first order spectra in the wavelength range of 820 Å-1840 Å. Light is collected by a 0.92 meter, f/2 primary mirror coated with 1400 Å of silicon carbide over an original iridium layer. The light from the target under study is focused onto an aperture wheel containing several slits and holes of different sizes. Light passing through the selected aperture is diffracted off a concave grating, also coated with silicon carbide, and is dispersed in wavelength. The grating refocuses the dispersed light onto the face of a microchannel plate detector with a UV-sensitive photocathode, where it is converted to electrical signals and recorded.

The instrument is physically divided into two parts, the telescope module and the electronics module. The telescope module is composed of all the light gathering components and supporting equipment. The electronics module, which is mounted on the Integral Radiating System (IRS) of the IPS, contains all of the power converters and computer processors needed for the instrument.

As with the Astro-1 mission, all the instrument hardware and software performed exceptionally well. The few anomalies that did occur were minor and easily worked around. No failures occurred during the mission, despite the fact that all the hardware except the spectrograph is now more than ten years old. Without question, the instrument maintained and extended the excellent track record begun during Astro-1.

Unlike Astro-1, the orbiter and Spacelab experienced few problems which had any impact on the science observations. The IPS performed very well, providing the instruments with stable pointing and rapid acquisitions.



System Diagram of HUT

3. Upgrades for Astro-2

3.1 Spectrograph

The original Spectrograph A that was scheduled to fly in 1985 was removed from HUT in 1987 and replaced by the improved Spectrograph B in 1989. The mechanical improvements in this spectrograph were then implemented on Spectrograph A, which was renamed Spectrograph C. After Astro-1, Spectrograph B was removed from the telescope and used as a backup. Spectrograph C was installed in September 1993.

The only improvements made to Spectrograph C were to replace the slit wheel apertures and the grating. The slit wheel apertures were replaced with more useful sizes based on Astro-1 experience. The osmium-coated grating was replaced with a silicon-carbide-coated one. This coating was done by the Optics Branch at Goddard Space Flight Center (GSFC) in August, 1992. It is more reflective in the far ultraviolet spectrum and was not available prior to Astro-1.

Published data show a much improved quantum efficiency for a potassium bromide photocathode (compared to the Cesium Iodide coating used on Astro-1), for wavelengths shorter than 1200 Å. The efficiency falls off rapidly for wavelengths longer than 1600 Å. For this reason, there were several attempts to produce a combined cesium iodide/potassium bromide coating for the Astro-2 detector microchannel plate stack. Although the .030" region of overlap between the two coatings behaved as expected, the quantum efficiency of the potassium bromide was never as high as predicted. Since none of the coating attempts yielded a significant improvement, the Astro-2 detector used the same cesium iodide photocathode as on Astro-1.

3.2 Primary Mirror

The backup mirror for Astro-1 was flown on an Aries rocket experiment in 1979. This mirror is made of Cer-Vit (the Astro-1 flight mirror was made of Zerodur). The improved reflectivity of a silicon carbide coating piqued interest in replacing the Astro-1 flight mirror with the backup mirror, if a silicon carbide coating could be applied to its surface. Since the backup mirror had previously been coated with iridium, there was a concern about coating the silicon carbide directly on top of the iridium. Tests at GSFC during early 1993 performed on small witness mirrors indicated that this was not a problem. The backup mirror was sent to GSFC for coating in July, 1993. The 92 cm HUT mirror was more than a factor of two larger in diameter than the largest mirror previously coated at this facility (40.6 cm). The 1408 Å coating thickness was optimized for visible light reflectivity (any thickness over 350 Å is opaque for ultraviolet light), in order to help maintain the faint target acquisition capability of the TV camera. The coating produced 55% reflectivity in the visible, a slight drop from the 67% reflectivity of the original iridium coating. Calibration of the coating UV reflectivity in a JHU test chamber showed a significant improvement compared to the iridium coating of the Astro-1 mirror, so the decision was made to install the more reflective backup mirror for the Astro-2 flight.

This operation was performed in June-August, 1993. After removal of the Aft Environmental Control Canister (ECC) and the Metering Cylinder, knife-edge tests were performed on the primary mirror to see if it was the source of the astigmatism noted during Astro-1. The poor repeatability of the results made this test inconclusive, so the source of the Astro-1 astigmatism remains unknown.

The net effect of the new coatings on the grating and primary mirror can be seen in figure 3-1 at the end of this section. The effective area was increased by more than a factor of two for all wavelengths shorter than 1600 Å.

3.3 Software

Twenty-seven HUT Dedicated Experiment Processor (DEP) Software Requirements Requests for Change (RFC's) were submitted in preparation for the Astro-2 mission, of which 17 were implemented and 10 were withdrawn or not implemented. All RFC's, including the seventeen implemented RFC's, are described fully in APL Memoranda TSS-94-042, "HUT Flight Software Requirements Request for Changes, Set 12", and S1I-94-207, "HUT Flight Software Requirements Request for Changes, Set 13". These changes brought the HUT flight software from version 3.4 flown on Astro-1 to version 3.6 flown on Astro-2.

The 17 software changes fall into three categories:

- Correction of problems from Astro-1
- Changes required by the spectrograph and primary mirror refurbishment performed prior to Astro-2
- New features for Astro-2

The changes made in each of these categories are discussed below.

3.3.1 Correction of Software Problems from Astro-1

All of the problems from Astro-1 were minor inconveniences that did not affect science data collection, but were not corrected before Astro-1 because of the lack of test time available when they were discovered. The change notices associated with these changes are as follows:

DEP-252	Change the sequencing of code to prevent the HRM downlink from dropping out at the issuing of a BEGIN (Item 25), SETUP (Item 20), or QUIT (Item 28)
DEP-254	Delay testing slit wheel position during a slit wheel move to avoid catching the telltale at the original position
DEP-269	Fix guide star fiducial evaporation problem

DEP-275 Correct errors in status mode table

3.3.2 Software Changes Required by Refurbishment

The changes required by the spectrograph and mirror refurbishment consisted of updates to calibration data and other tables to reflect the slightly different mechanical configuration of HUT after the work was completed. The associated change notices are as follows:

DEP-255 Update the following tables to reflect hardware changes:
1) slit wheel positions
2) SP thresholds
3) HVPS voltage settings and readbacks
4) TV magnitude tables
5) nominal mirror focus position
6) video RAM pixel size
7) TV Camera roll angle

DEP-267 Update the following:
1) Spectrograph heater H11-14 conversions
2) Proton Induced Soft Error
3) Spectrometer coverage
4) Cal Lamp pixel bins
5) Slit scribe marks

DEP-274 Update mirror backlash table

3.3.3 New Software Features for Astro-2

Most of the new features for Astro-2 were minor enhancements to make the telescope more convenient to operate in normal observations; however two of them (DEP-259 and DEP-261) added significant new capability to the telescope.

DEP-259 changed the source locate mode so it automatically transitions to track the guide stars when the source disappears into the slit; previously the DEP stopped generating pointing errors when the source disappeared, often causing an offset at guide star lock-on at the ‟BEGIN” command. The enhancement increased the speed and quality of target acquisitions, contributing to more efficient science data collection.

DEP-261 added the ability to command the main doors to positions between the fully closed and fully open positions. This change filled the gap in available telescope apertures between the 50 cm^2 position of the small aperture door and the 2600 cm^2 of the half aperture position, allowing better dynamic range control for some brighter targets.

The change notices associated with the new Astro-2 features are as follows:

DEP-249	Change default locate slit from blank to observe slit.
DEP-250	Report photon count rates in counts/2 sec instead of counts/10 sec.
DEP-251	Insert JOTF-ID's into HRM stream in response to the SETUP command, instead of at receipt of the joint PREVIEW observation load.
DEP-253	Execute the INVERTER OFF command whether or not motors are running.
DEP-258	Change the QUIT timeout value from 0 sec to -1000 sec.
DEP-259	In source locate mode, generate guide star based pointing errors when the source disappears.
DEP-261	Implement partial main door openings with a single item entry based on seconds of opening time from the fully closed position.
DEP-270	Speed up mirror position averaging.
DEP-272	Allow ECOS commands with any source identifier F0XX hex, where X is any hex digit, instead of only F00X. This accommodates timeline commands, with source id F010 hex.
DEP-273	Change ITEM 99 (shutdown) so it closes but does not latch the main doors.

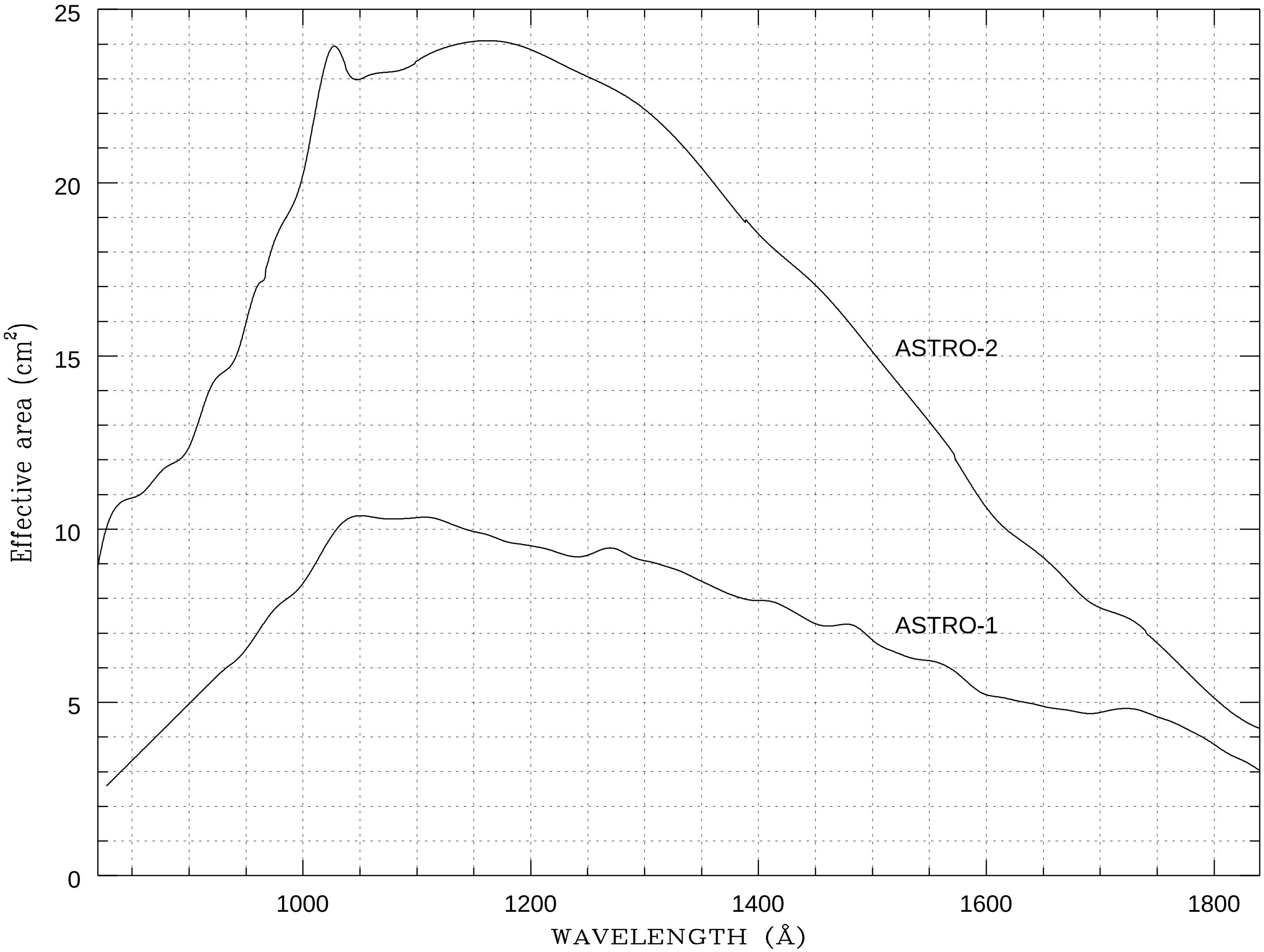

25
20
15
10
5
0
Effective area (cm^2)
1000
1200
1400
1600
1800
WAVELENGTH (Å)
ASTRO-2
ASTRO-1

Figure 3-1

4. Instrument Processing for Astro-2

After the telescope was removed from the cruciform following the Astro-1 mission, it was moved into the ATM Cleanroom within the O&C Building at KSC in November, 1991. Disassembly of the telescope back to the Aft ECC section was performed to remove the TV camera, spectrograph, and the various electronics located on the spectrograph mounting arms. The Electronics Module (EM) was left attached to the Integrated Radiating System (IRS). While the removed items were transferred to JHU, the EM and the rest of the instrument were left at KSC. The state of the instrument remained unchanged until further disassembly was required to change the primary mirror in June, 1993. The removed items, or their replacements, were returned in September 1993.

The TV camera was maintained and monitored for degradation until its return to KSC. One week prior to shipment back to KSC, the readout beam control voltage was adjusted in the Camera Control Unit (CCU), to compensate for aging of the camera tube. The longest period of time that the camera went without being operated was 136 days immediately following the flight. Although the ion spot was quite visible after this period, a longer-than-normal maintenance run appeared to reduce it to its former level. Detailed ray-tracing analysis of the camera optics and transfer lens assembly seemed to indicate little astigmatism was present in this camera. Since there was no good reason to replace this camera with the backup camera, it was decided to fly the same camera again.

After Spectrograph B was returned to JHU, a post-flight calibration was performed. The cesium iodide photocathode used on the HUT detector degrades with time, so the decision was made to fly the backup Spectrograph C with a more recently coated detector. The new detector was coated as late as possible (May 1993), to reduce the time degradation. The electron repeller grid in front of the detector was replaced with two parallel wires strung parallel to the dispersion direction. This eliminated the shadows cast by the original grid when observing through reduced aperture door positions. In addition to the new detector and repeller grid, the grating was coated with silicon carbide, a more reflective coating than the osmium coating used in Astro-1. Silicon carbide was not available prior to Astro-1.

The only changes made to the internal power supplies was to adjust the operating range of the Phosphor high voltage supply to accommodate the new detector, and to replace the Reticon Control Electronics with a spare matched to the new detector. In addition, the CCU was readjusted to boost the beam control voltage of the camera, as described above.

One final change was made prior to the reassembly of HUT. The primary mirror was replaced with the backup after the backup's improved reflectivity was confirmed (due to the silicon carbide coating as described in §3.2). This operation was performed in June-August, 1993. Although the telescope was already partially disassembled from the removal of the spectrograph and TV camera, a near total disassembly was required to remove the primary mirror. The lengthy alignment process was completed in November, and final assembly finished in December. A baseline test of all telescope systems was successfully completed in January, 1994. The instrument was then turned over to KSC.

Reintegration onto the cruciform and the Spacelab pallet also proceeded nominally until the final instrument test (Level III/II Mission Sequence Test), in August, 1994. During this test a communications problem between the DEP and Spectrometer Processor (SP) appeared, resulting in a complete loss of data from the SP. The cruciform was removed from the Spacelab pallet and returned to Level IV the following week. The IRS was swung open to expose the HUT Electronics Module (EM). The faulty board in the DEP and the connecting board in the SP were subsequently removed, with the EM left in place.

The source of the problem was determined to be the construction of one of the DEP circuit boards. A Stitch-Weld design was used, which has the potential to leave sharp edges protruding through the circuit board. The conformal coating used on the surface of the board can, as a result of thermal cycling, put pressure on wires running along this surface, resulting in the penetration of the wire insulation and leading to a short-circuit. This is what is believed to have happened, with the result that one of the bits on the communications bus between the DEP and SP was locked high. The short-circuit was repaired at the Applied Physics Lab (APL) in August and September of 1994, in addition to replacing parts on the SP board which may have been stressed by the failure. The boards were requalified at APL and reinstalled in September. Offline testing showed that the DEP and SP were functioning normally.

Reintegration and testing proceeded nominally after this point. The external vacuum pump was removed for the final time on November 29, 1994. The limited-life internal vacuum pumps were used exclusively after this point. The payload was installed into the space shuttle Endeavour on December 14. The shuttle was placed on the Mobile Launch Platform on February 3, 1995, and rolled out to the pad on February 8. There were no launch delays and the shuttle lifted off 13 seconds after the scheduled launch time.

5. In-Flight Problems

Anomalies for the Astro2 mission are detailed in the sections shown in Table 5-1. Of these, only four could have had an impact on the collection of data. Only two of these were instrument problems. The +Y Door TT Mismatch error delayed the opening of the main doors although this was at the end of an observation and did not affect data collection. The Verification Error 8 (Slit Wheel) remains an unexplained problem but did not seriously hamper any observation since the longest delay this caused was only about two minutes. The other two problems were procedural errors. The Photon Count ↑ could have caused severe damage to the detector but this was prevented by a safety-monitor shutdown ordered by the DEP. The Ram Violation could have caused a loss of sensitivity by degradation of the coating on the primary mirror but later calibrations do not show any sign of this.

Table 5-1 is a direct comparison of Astro-1 problems versus Astro-2. Column one shows the error, columns two and three the number of occurrences, and column four lists the fix instituted after Astro-1 or the section of this report that describes the Astro-2 events.

ANAMOLY	ASTRO-1	ASTRO-2	SECTION or FIX
-Y DOOR TT MISMATCH	3	0	Adjusted Telltale
+Y DOOR TT MISMATCH	0	5	§ 5.4
PHOTON COUNT ↑	12	1	§ 5.9
VERIF ERROR 8 (SLIT WHEEL)	5	21	§ 5.3
VERIF ERROR 9 (FILTER WHEEL)	2	0	Software Change
INVERTER I ↑	2	1	§ 5.11
SCAN COUNT ↓	0	2	§ 5.1
+Y+Z MIRROR MOTOR POT	0	1	§ 5.2
PHOSPHOR V ↓	0	1	§ 5.5
INVERTED HUT VIDEO	0	3	§ 5.6
HEATER ALARM	0	21	§ 5.7
DOUBLED SCAN AND PHOTON COUNTS	0	MANY	§ 5.8
RAM VIOLATION	0	1	§ 5.10
BRIGHT FLASHES ON VIDEO	0	~25	§ 5.12
DEP PARITY ERRORS	1	3	§ 5.13

Table 5-1

5.1 Scan Count Low Errors

During a Ku-band loss-of signal (LOS) period at MET 0/09:00, the "HSP>SCAN COUNT ↓" error message (ECOS error 5F) was received in the S-band data still being downlinked. This error is generated when fewer than 1900 reticon scans are processed by the SP in a two-second data collection period (the nominal count is 1953 scans per two-second interval). At the time, the detector was off and the SP was in high time resolution mode. The same error was recorded again at MET 2/23:21, with the detector and SP in the same configuration as before.

This error results from the way the software builds periodic histogram frames when the SP is in high time resolution mode. This is a known condition from Astro-1, and is documented in §10.8 of the Astro-1 HUT Engineering Report, in reference to a different effect caused by the same software process. Also see the discussion of this problem in §11.2.1 of this document.

5.2 +Y+Z Mirror Motor Potentiometer Dropouts

At MET 0/17:20 during the joint focus and alignment procedure (FO-J3), the +Y+Z mirror motor generated a "HUT>VERIF ERROR 12", which indicated that the mechanism, upon completing a motion, was more than 4 µm from the commanded position. The mirror had just been commanded from a position of –150 µm to –200 µm (relative to the pre-flight, nominal focus position), and at –200 µm the +Y+Z position feedback potentiometer should produce a scaled reading of ~5100 (on a scale from 0 to 10,000). However, the pot for this motor actually indicated a value of 24, corresponding to a position of +430 µm from nominal focus, while the –Z and –Y+Z motor pots indicated the expected values for a position of –200 µm. For the +Y+Z value to be real, the motor would have to have run in the wrong direction for 24 minutes, as opposed to the nominal 50 µm focus step of ~2 minutes. In addition, the focus target would have moved off of the TV camera field with a tilt of this magnitude in the primary mirror. Therefore, it was immediately suspected that the +Y+Z motor had indeed moved to the commanded –200 µm position, but that the position feedback pot was exhibiting a dropout, or dead spot, at this position.

A check of the +Y+Z pot voltage during the mirror motion from –150 µm to –200 µm did show several downward spikes to zero with durations of only one sampling interval (~2 seconds). Once the motion completed, the pot voltage averaged 1.27 V with a noise level of 1.03 V rms (over 50 samples), with the voltage ranging from 0.00 to 3.74 V. At a position –200 µm, the pot should have been reading about 6.06 V. The large downward spikes and the very high noise on the pot voltage are both indicative of dead spots on the pot, presumably narrow regions of poor wiper contact or high contact resistance resulting in an open or near-open circuit. There was no indication in the data of any problems associated with the mirror reference voltage, which is the stable reference applied across each of the mirror motor pots.

As a temporary workaround, an ITEM 83 was issued in order to run the +Y+Z mirror motor. Since the DEP thought the mechanism was at +430 µm and the commanded position was still –200 µm, the ITEM 83 caused the DEP to calculate a new run time for the +Y+Z motor and to turn that motor on. An ITEM 84 was then issued immediately to abort the motion. The net effect was to run the motor for approximately 4 seconds, long enough to move away from the bad area of the pot, and the resulting pot voltage was 6.06 V as expected. This gave a scaled position of 5099, very close to the original commanded position of 5101.

After the focus sequence was completed, the mirror was returned to nominal focus. A plot of the mirror motor pot voltages during this motion provided a map of the dead spots between nominal focus (0 µm) and –200 µm. The +Y+Z pot exhibited the most severe dropouts. One region near –180 µm, about 10 µm wide, had several dropouts down to 0 V, including one dip about 6 µm wide (as opposed to the single sample wide spikes discussed earlier, which are <1 µm in width). There were many smaller dropouts throughout the region from about –110 µm to –200 µm, some of which were fairly broad. The –Y+Z pot had several narrow (single sample wide) dropouts, the largest being a 0.6 V spike down from 5.8 V, over the range from –130 µm to –200 µm. The –Z pot only had two narrow dropouts of about 0.8 V down from 4.6 V, but located very close to nominal focus at –25 µm.

After the initial error, there were no further problems due to the mirror motor pots. The mirror focus was changed many times throughout the mission, mostly between 0 and –100 µm, but it was also moved to –50, –150, and –200 µm with no errors. In addition, many observations included offset pointings, all of which completed successfully.

Although the impact of this problem was minimal, serious consideration should be given to replacing the pots in the event these mechanisms are ever used again for flight. As a minimum, the dropouts should be thoroughly mapped over the full range of motion and tracked over time for further degradation.

5.3 Slit Wheel Verification Errors

Twenty-one times during the flight, the slit wheel generated a "HUT>VERIF ERROR 8" error message indicating that the slit wheel failed to reach the commanded position. This was about the same frequency of occurrence as during Astro-1, when five errors were generated in one third the number of slit wheel movements. Because the slit wheel is a critical single point failure for HUT, these errors were investigated in great detail. No evidence of a mechanical or electrical malfunction was found during troubleshooting, and a software change prior to Astro-2 dealt with the software/hardware interaction suspected during Astro-1. The most likely explanation at this point is that the logic in the slit wheel telltale circuitry is picking up edge effects or other transients in the signal from the telltale sensor switch, sometimes causing spurious telltale trips which interrupt the normal slit wheel motion. It should be noted that all errors occurred with the slit wheel at a nominal slit position; the mechanism never ended a motion between slit positions.

Since the slit wheel also provides a vacuum seal for the spectrograph, which must remain under vacuum at all times once the detector has been installed, the mechanism cannot be tested as part of the telescope unless the entire instrument is under vacuum. The mechanism was tested extensively at atmosphere during assembly of the spectrograph, and it was also tested informally under vacuum during the spectrograph focus and calibration activities on the ground. However, all ground testing was done using a GSE controller which, due to its design and operating characteristics, would have prevented the detection of the type of error seen during flight.

The slit wheel mechanism flown on Astro-2 is from the original Spectrograph A which was replaced by the upgraded Spectrograph B in 1987. Although the mechanism was refurbished and reassembled onto Spectrograph C, the telltale sensor switch was untouched from the original mechanism. This means that this particular sensor switch was tested with the telescope during the instrument-level thermal vacuum (T-V) test in January, 1985 (where no errors occurred). If the explanation proposed above is correct, the same conditions were likely present during the 1985 test, and it is reasonable to expect that the same error should have occurred at some point during the test. However, the frequency of occurrence during the flight was roughly 2% of mechanism steps, and the total number of steps during the T-V test was probably ~50. So it is very possible that the T-V test would not have produced the verification error.

The slit wheel mechanism uses a Hall-effect sensor switch to activate the slit wheel telltale. The sensor is located on the Geneva mechanism used to rotate the slit wheel, so the same switch is used for every slit position (i.e. the Geneva mechanism completes one full rotation to move the slit wheel one eighth of a turn). The DEP reads a feedback potentiometer to distinguish between the different slit wheel positions.

During a slit motion the DEP samples the slit wheel telltale every two seconds, but the slit wheel motor is actually turned off in hardware as soon as the telltale becomes active. The Hall-effect sensor's active state is fairly broad, spanning about 2-4 seconds of the Geneva wheel's 26 second rotation cycle. It is not known how the output of the sensor behaves as the magnet on the Geneva wheel is swept past the sensor mounted next to the wheel. The control circuit which stops the motor uses edge-triggered logic to determine the telltale state, so if the telltale output is not clean at the level transitions or across the active portion, the motor control circuitry could pick up false transitions of the telltale switch. This would cause the motor to shut off before the mechanism had even moved from the previous position, and the verification error would result.

Of the twenty-one errors generated, three were the second half of what were termed "double hit" events. The three double hits followed the same pattern:

1. Multiple step slit wheel command issued.
2. Slit wheel moves 1 position in same direction as last motion (fwd-fwd or rev-rev).
3. Second step fails, error generated.
4. Slit wheel re-commanded to desired position, no motion occurs, second error generated.
5. Slit wheel re-commanded again, motion is successful.

Not counting the errors which occurred as the second error of a double hit pair, the remaining eighteen errors can be characterized according to the commanded motion and the achieved motion of the slit wheel before the error was generated:

1. Commanded in same direction as previous motion (fwd-fwd or rev-rev):
   9 errors: 6 fwd-fwd 3 rev-rev
2. Commanded in opposite direction as previous motion (fwd-rev or rev-fwd):
   9 errors: 6 rev-fwd 3 fwd-rev
3. Mechanism moved one or more steps before error generated:
   8 errors: 8 same direction 0 opposite direction
4. Mechanism moved zero steps before error generated:
   10 errors: 1 same direction 9 opposite direction

The following is a record of the slit positions where errors occurred, although this is most likely a function of how often the given slit position was used, thus the high number of hits on slits 0 and 7.

Slit 0.....6 times
Slit 1.....1 time
Slit 6.....3 times
Slit 7.....11 times

The two second resolution of the data is inadequate to properly diagnose the cause of these errors. This is primarily due to the fact that hardware is controlling the motion independently of the DEP sampling of the telltale states. Other mechanisms, such as the doors, are fully controlled by the DEP based on the telltale states it samples every two seconds, the same data that is available through the HRM channel. A full understanding of the slit wheel problem will require observing the output of the Hall-effect switch with an oscilloscope or similar instrument which can provide the needed time resolution.

Although any error generated by the slit wheel should be viewed as potentially fatal to the instrument's science return, several factors mitigate the seriousness of these errors. First, the slit wheel always reached the commanded position after at most two retries. Second, there were no other symptoms, such as high inverter current, to indicate a problem with the mechanism. Third, the frequency of error events did not increase over the course of the mission, which would have raised serious concern about a worsening condition which might lead to ultimate failure. Finally, the frequency of occurrence was low enough so as not to impact the crew's activities or the instrument's data return. All these factors indicate that the slit wheel mechanism could be re-flown as is, without any loss of confidence in its performance or reliability.

5.4 +Y Door Closed Telltale #2

At MET 1/07:24, after quitting from a 200 cm^2 partial door state observation, an "HDC>+Y DOOR TT MISMATCH" error was received. Examination of the data showed that four seconds after the +Y door clutch was released, the #1 "closed" telltale became active while the #2 "closed" telltale remained inactive. Both of the "open" telltales were inactive at this point, and the combination of telltale states indicated that the door had indeed closed, but that the #2 "closed" telltale was not operating properly. Four seconds later, the telltales were still in disagreement and the error was generated. Six seconds after the error, the #2 "closed" telltale became active, and the doors then opened as expected for the slew configuration. No action was taken at this point, as it was thought that the cause of the problem was a very slight misalignment in the #2 "closed" telltale microswitch. When closing from a 200 cm^2 door state, the force from the closing spring might not be sufficient to drive the door all the way against its stops, and a slight misadjustment in the position of one of the telltale microswitches could cause the mismatch error.

The balky telltale could have been masked in software to prevent the DEP from using it in determining the door state, since the doors have two redundant telltale microswitches for both the "opened" and "closed" positions. However, if one of the "closed" telltales is masked and the other one fails, the logic used by the DEP in a door closing operation causes the door motor to power drive the door closed, and this will damage the drive mechanism if the door is already against its stops. Therefore, masking the telltale would not be used unless the error occurred on a regular basis.

Another +Y door telltale mismatch error occurred at MET 3/15:47, again after a quit from a 200 cm^2 door state observation. This time, however, both of the "closed" telltales were active for a single sample when the door first closed, then the #2 telltale became inactive on the very next sample two seconds later. Four seconds later, the mismatch error was generated. Because both "closed" telltales did activate, however, the DEP was satisfied that the door had indeed closed, and did not generate a Verification Error 20 (+Y Door Fails To Close). (Note: This error is only generated when both door "closed" telltales do not activate within 12 seconds of a close command). The doors then began opening to configure for the slew configuration. Again, no action was taken to mask the telltale in software.

The same error occurred twice more throughout the remainder of the mission, both times after quitting from a partial door state observation. Unlike the first two occurrences, these errors were accompanied by Verification Error 20's (+Y Door Fails to Close), which indicated that the #2 closed telltale did not activate within the 12 second verification timeout on door closings. While in this error state, the DEP does not accept commands to open the door. Either the telltale must become active on its own, or it must be masked in software.

The first of the double error events happened at MET 5/05:51. An initialize mechanism command for the +Y door (ITEM 65_-1) resulted in another Verification Error 20. Approximately 14 minutes after the initial error, the #2 closed telltale became active on its own and it was then possible to command the door open without a software fix. The second double error occurred at MET 14/10:51, more than nine days after the previous error. This time, the #2 "closed" telltale was still not active fifteen minutes after the initial error, and an ITEM 90 command was uplinked to mask the telltale in software. The door was then successfully commanded open, and another ITEM 90 was uplinked to unmask the telltale for future operations. No further errors concerning the +Y door were received.

A similar problem occurred during Astro-1 with the #1 "closed" telltale on the -Y door. After occurring on three consecutive door closings, the software mask fix was installed for the remainder of the mission. Although a permanent software fix was not required on Astro-2, the cause of the problem was almost certainly the same -- a slight misalignment in the telltale microswitch caused by launch vibrations, 1-g release, or the cold temperatures at the door deck on orbit. The recommendations from the Astro-1 Engineering Report are equally applicable after Astro-2, and the reader is referred to §4.1 of that report.

5.5 Phosphor HVPS Voltage Low

At MET 1/19:11, the "HSP>PHOSPHOR V ↓" performance monitor error was received, indicating that the phosphor high-voltage power supply (HVPS) output was more than 75 V below the expected voltage for the setting of the supply. The data revealed a downward spike in the voltage at this time, 5 V below the low monitor limit and lasting for only a single two second sample interval. There were many other smaller spikes as well, most of them downward and most lasting for one to two sample intervals. The data also revealed that the supply was nominally producing 6847 V at program setting 3, about 10 V below the midpoint of the DEP's monitor limits for this setting. The monitor limits were derived from test data obtained at room temperature, but the operating environment on orbit was 10°C. The output of this supply is known to decrease with decreasing temperature, and the effect for a 10°C change would be about 5 V, or half the offset that was seen from the midpoint of the monitor limits.

The same error occurred at least two more times within about seven hours. Each time the spike lasted for a single sample, and each time the spike voltage was identical at 6777 V. The resolution of the A/D converter for this channel is 2.44 V. Because the data indicated the error was most likely due to noise in the A/D conversion circuitry, and because the supply was running 10 V below the midpoint of the monitor limits, the decision was made to lower the low monitor limit for setting 3 of the phosphor HVPS by 10 V. This was implemented at MET 2/06:17 with an ITEM 93 to patch the phosphor HVPS monitor limits table, uplinked by the POCC. No more errors were generated for the phosphor HVPS output voltage after the patch was installed.

5.6 Inverted Spectrum on Video

At MET 2/00:35, the detector spectrum which is overlaid on the HUT TV camera video suddenly inverted, so that the baseline was at the top of the image with the spectrum building downward toward the bottom of the image. The TV camera video did not invert, and the spectrum continued to build normally (although downward) as data accumulated in the histogram. An ITEM 29, which zeros out the histogram in the DEP, was found to restore the video spectrum to its proper orientation.

This problem was believed to have occurred once before it was documented in the problem log, and it recurred again at MET 3/00:59. The DEP software engineers discovered an error in the code which generates the video spectrum, causing the spectrum to invert when the total number of counts in a histogram bin exceeds 65535. This problem only affects the video spectrum, not the actual histogram (science) data accumulated in the DEP memory.

Because this problem only appeared during long observations of bright targets and did not affect the science data, its impact was very minimal. In fact, these types of observations were not performed later in the mission, in order to preserve the sensitivity of the detector at certain wavelengths associated with very strong emission lines. This is a software problem only, and is discussed in §11.2.2 of this report.

5.7 Heater Alarms

At MET 2/02:02:11, and for several hours following this, the "HMH>HEATER ALARM" performance monitor error was received. This monitor checks the temperature of heaters 1-14 and compares them to the range of acceptable values as derived from the set point and alarm limit for each heater. The error indicates that one or more of the temperatures is outside of the allowable range.

All performance monitor errors indicate a change in condition, not the continuation of an out-of-limit condition. This alarm was generated earlier during the initial activation of the DEP when the temperature of the instrument was 18-20ºC, well above the upper limit of 12ºC. This is a normal condition which was noted during all ground testing. The error flag will not repeat until the heater temperatures fall within their nominal range and then go out again.

At the time when this error recurred, the instrument had fallen to within its normal operating temperatures for the first time. Until this point was reached, only the original error flag noted above would have been generated. The heater causing the error (going in and then out of its acceptable limits) was Heater 11. This heater is on the grating end of the spectrograph and faces out toward space. The heater here is slightly too powerful and tends to overshoot its limits due to the slow sampling rate of the Heater Control Electronics. This forces the heater to remain on for a minimum time of one minute.

The temperature sampling rate cannot be changed during the flight, so the temperature swings of Heater 11 could not be reduced. At MET 2/09:40, the set point was dropped to 9.5ºC from 10ºC, and the alarm limit was raised to 2ºC from 0.5ºC. The effect of these two changes was to turn the heater on after the temperature fell below 9.5ºC (which would keep the temperature closer to the desired value of 10ºC), and to give an alarm after a temperature of 11.5ºC was measured. No heater alarms were received after these changes were instituted.

A possible side effect of this condition is a loss of resolution due to the non-uniform temperature of the spectrograph. This could cause distortion of the spectrograph by differing thermal expansions. Since the temperature sensor for Heater 11 is mounted in the center of the grating end of the spectrograph, it represents little thermal mass and is a poor indication of the overall temperature of that end of the spectrograph. The same amount of fluctuation was present during Astro-1. Thermal expansion from a 2ºC delta would change the length of the spectrograph by 8µm. For the F/2 grating mirror, this would move the spectrum by 4µm (less than half of the pixel size of 12.5µm). Since the actual temperature change was less than this heater would indicate, it can be assumed that the resolution of the spectrograph is not measurably affected by a 2ºC change in the temperature at this heater location.

5.8 Doubled Scan and Photon Counts

During the first observation of the quasar 1700+64, an intermittent doubling of the scan and photon counts was noted on the DEP's HSP page. Since this was one of the top priority HUT targets for the mission, there was considerable concern as to the cause of this response and the validity of the data collected.

The problem was caused by the high exposure time required by the TV camera for faint targets (magnitude 19). If the video exposure time takes longer than the two second data collection cycle, no data is sent to the DEP from the SP. In this case, a Status Only frame is sent which contains no science data but does have all instrument monitoring. When the next cycle is ready, the two previous cycles are read so no data is lost.

This is a software problem only and is detailed in §11.2.3.

5.9 Detector Shut Down due to High Count Rate

At MET 5/19:46, the "HSP>DET OFF, COUNT ↑" safety monitor error was received due to an excessive count rate on the detector. This safety monitor immediately shuts off the detector when the count rate exceeds ~12000 counts per second. In addition to this error, related performance errors of "PHOTON COUNT ↑", "SCAN COUNT ↓",and "WIDE COUNT ↑" were received. The count rate peaked at 13000 counts per second before the safety monitor in the DEP shut off the detector.

The cause of this problem was a procedural error in which the crew failed to turn off the detector prior to the QUIT. Since this was a 200 cm^2 partial door observation, the QUIT command opened the doors fully to the 5200 cm^2 opening. The safety monitor shut down the detector after about 75 seconds of door opening, which is approximately 2200 cm^2 of aperture area. This factor of eleven increase in area could have caused severe damage to the HUT detector. However, data collected after this incident revealed no damage to the detector. After this error, partial door observations were flagged for special attention by the POCC, and the few instances that the detector was not turned off by the crew were handled in a timely manner from the ground.

5.10 Ram Constraint Violation

At MET 6/11:15, the 20º minimum ram constraint of HUT was violated during a setup. The doors were mistakenly opened seven minutes early and were fully open at a ram angle of 8.6º. This angle increased linearly with time until a safe angle of 22º was reached five minutes later. Approximately 40% of the +Z portion of the mirror was exposed during the violation, with a peak value of 16% as shown in figure 5-1.

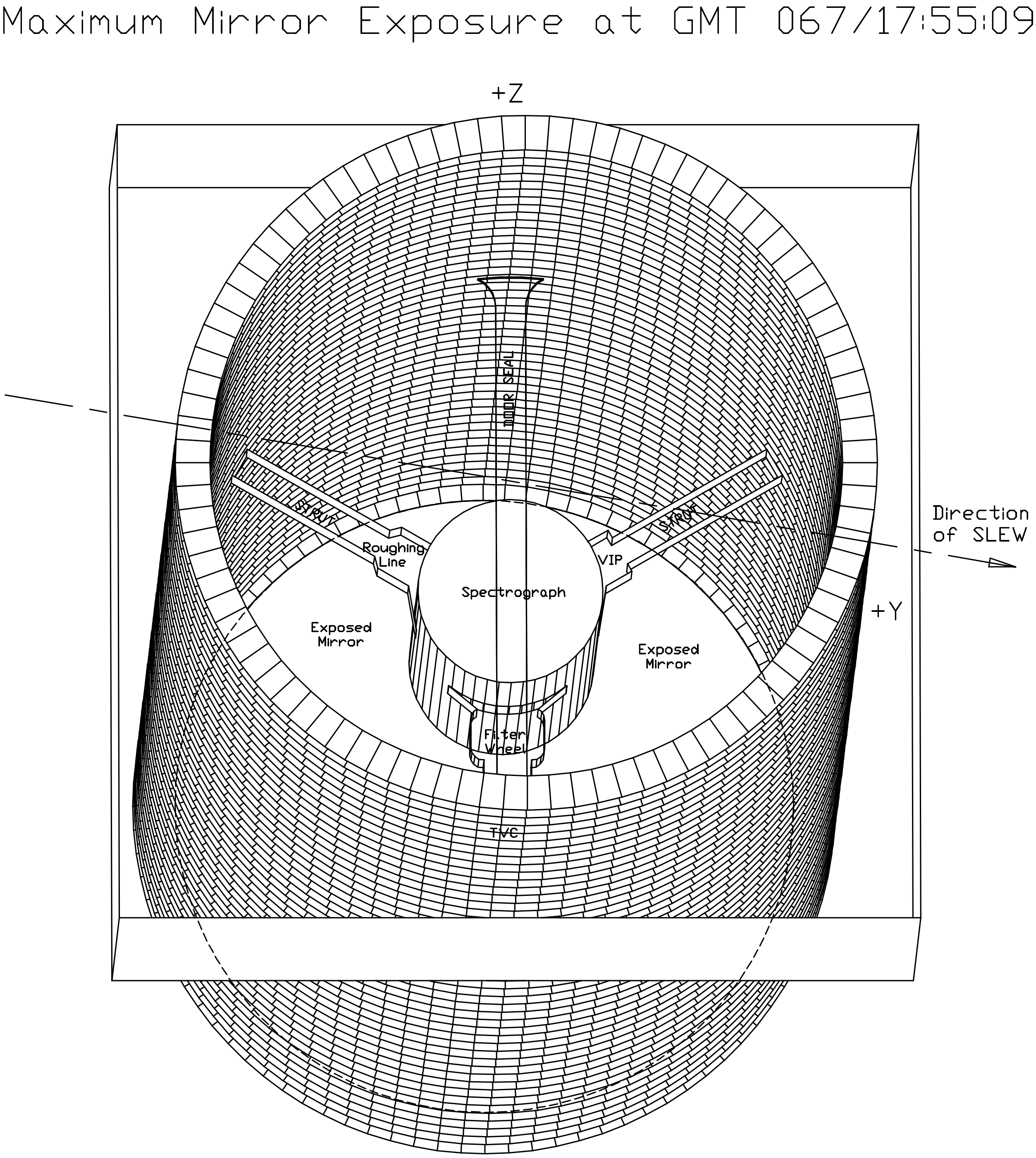


Figure 5-1

This constraint violation occurred due to an error in the sequence load. The doors were closed prior to the QUIT on the previous target as required. The sequence load for the next target, (M49), should have included a closed door state but had a door state of '5' (both open) instead. This opened the doors when the SETUP command was given. For future observations, all RAM test procedures were flagged to check for the proper door state.

The ram constraint is derived from the 16° angle (plus margin), before the edge of the HUT primary mirror is exposed. Silicon carbide is degraded by direct exposure to atomic oxygen. Analysis up to this point does not indicate any noticeable degradation. The plot on the following page shows the point of maximum mirror exposure and the direction of SLEW. This indicates that approximately the top 40% of the mirror was directly exposed to the ram during the SLEW. The total duration of the exposure lasted six minutes, although the maximum exposure to any part of the mirror did not exceed two minutes.

Since the direction of SLEW only exposed the +Z portion of the mirror, it would be difficult to determine if a small degradation of the silicon carbide coating took place. Only a full aperturecalibration before and after the incident would be able to show the degradation. There has been no noticeable drop in efficiency noted to this point.

5.11 Inverter Current High

At MET 7/05:06, the "HDC>INVERTER I ↑" performance monitor error was received, indicating the inverter current exceeded 0.75 amperes. This error was received at the end of a mirror motion requiring all three mirror motors. Dynamic braking is used to halt all motor motions by reversing the motor direction for 100 milliseconds. This prevents the motor inertia from causing the motor mechanism to coast past the desired position. It also nearly doubles the current draw of the inverter.

Since the current draw of three mirror motors is 680 mA, dynamic braking of the three motors will certainly exceed the 750 mA performance monitor limit. The peak current reading in this case was 1.12 amperes. Although the current will exceed the monitor each time, the two second sampling rate will miss the 100 millisecond dynamic braking in most cases.

This is a nominal condition that could be addressed by a software change. One way to eliminate this error is to check for motor stoppage so the error will not be issued in the same cycle as dynamic breaking. A second way to eliminate this error would be to require the current limit to be exceeded for two consecutive cycles, as is required of certain other monitoring.

5.12 Bright Flashes on Video

During many observations, the POCC noticed the HUT video suddenly became very bright, as if the camera sensitivity had been increased by two magnitude settings. It was also noticed by the crew on a few occasions. In the POCC, this condition was usually only present in one-eighth of the image at a time, indicating that the condition only lasted for the duration of a single image. Since the crew sees live video, the condition was only visible for a few seconds. The video the POCC sees is only refreshed about once per minute so the condition would be visible for much longer. A review of the camera magnitude settings reveals no change during the times in question.

There are several possible explanations for this anomaly. The first possibility is scattered light from the bright earth limb. A related possibility is a reflection from some part of the shuttle or of HUT itself reflecting sunlight into the camera. Another possibility is a camera flash. It is also possible that there could be a latched bit in the video A/D converter. The final possibility is a change in camera exposure time, which effectively boosts the magnitude.

A record was kept of the anomaly after MET 10/09:30, and all occurrences were during the day at camera magnitude 13 through 16. Since all cases appear to have been day targets, scattered or reflected light seems an obvious possibility. The bright band also fades towards the edges forming a "bulls-eye" pattern which is typical of the images while observing a bright field (such as the earth). The main reason to dismiss this possibility is the short period of time that the bright condition persists. Because it generally only lasts for a single two second interval, the change in pointing of HUT would need to be fairly rapid. Since the bright image was only noted during observations, the pointing would be stable, tending to discount any momentary reflection of light due to attitude change. (Note that even if this condition occurred between targets, the camera settings used would not have revealed the presence of a bright image). Another problem with this explanation is the method the camera uses to gather its video. As described in §7.1, the camera gathers two separate images to create an interlaced image. Because the bright image occurs in both halves of the interlaced image (although it does not affect the interlaced and non-interlaced images equally), but in neither half of the image immediately preceding or following it, a momentary flash of light seems unlikely.

The next possibility is a camera flash caused by breakdown in the camera tube. This would probably saturate the entire image then being collected. It would not affect the other half of the interlaced image. Not only do both halves of the interlaced image brighten during this anomaly (albeit to differing degrees), the field does not usually saturate. This possibility can be thrown out.

In order to check for a latched bit, a comparison of the bright field to the normal field was made. This check indicated the increase in the light levels of the interlaced and non-interlaced rows of the image was not uniform, and thus could not be explained by a single bit flip. In addition, the "bulls-eye" pattern cannot be explained by a uniform increase as should be seen with a single bit flip.

Examination of two video images where this condition was present showed a doubling of the total counts of the stars in the field. This doubling is in addition to the higher background. This seems to indicate a higher magnitude setting on the TV camera. The possibilities for a higher magnitude setting could be a transient change in any of the following: lower white level setting, higher gain setting, and higher exposure setting. Of these possibilities, two can be discounted by the magnitude settings of the camera when the anomaly arose. Since most of the occurrences were at camera magnitudes of 15 and higher, the camera gain was already at 7, its highest level. So an increase here was not possible. In order to increase the light level in the camera using the white level setting, a decrease in this setting would be required. White level settings of 4 and 1 were in place when the brightening occurred. A change in setting from 1 to 0 would cause a doubling in the light level. Examination of two cases where this setting was used showed a factor of three increase in light level, making this explanation unlikely.

The only remaining explanation for this problem being caused by a change in magnitude is an increase in exposure setting. This is the power-of-two integration of an image before a new one is started (e.g. an exposure of 5 has 32 integrations for each image). It is clear that an increase of this value would double the light levels of the image. This setting (and the other camera levels) is made in hardware and only altered by the DEP when a new magnitude setting is commanded. It is unlikely that this value would increase from 5 to 6 for a single video frame, and then change back without the DEP ordering the changes. It is also unlikely that this could be a bit flip from 5 to 6 (a bit change from 101 to 110) since this requires a change in two bits.

Since all known explanations have been exhausted, the cause of this condition remains unknown. It is possible that other possibilities are responsible, but there is no way to prove them without detailed analysis on the ground. If time permits, attempts should be made to recreate this problem on the ground prior to another flight to determine its cause.

5.13 DEP Parity Errors

At MET 7/23:39 it was noted that three DEP parity errors had occurred, reflecting the number of times a parity mismatch was noted between the primary and redundant DEP memories. Some research was required to determine that all three errors actually occurred within ten seconds of each other, fourteen hours earlier. These do not generate error messages and thus would only be noticed if the DEP's HDC page is displayed. These errors are bit flips in the DEP memory that could affect operation of the instrument. Since the DEP has redundant memory planes, a single detected parity error can be corrected by copying from the unaffected memory. This process is described in more detail in §11.2.5.

This problem occurred a total of five times, in three separate incidents, during the mission, compared to only one instance in Astro-1. While this is well within the range of predicted errors, only one occurred during transit through the South Atlantic Anomaly (SAA). A higher fraction was expected to occur through SAA, but the small number of errors do not provide enough statistics to draw any firm conclusions. Each of the five errors were corrected by a background DEP process and had no impact on the mission.

Since the SP uses similar memory as the DEP (without redundancy), it was expected that parity errors might occur in the SP memory as well. Since the SP does not have redundant memory, and only performs a parity check during hibernation, there was reason for concern about SP parity errors. Since it was decided to observe through the SAA for this mission, the SP was not placed into hibernate mode at regular intervals. After receipt of the first DEP parity errors, the SP was commanded into hibernate mode several times during the rest of the mission to permit parity checking. Since it does not report any errors found, it is impossible to determine if any occurred. However, it can only fix a single parity error at a time, so it is known that there was no more than one parity error between commanded hibernate cycles.

6. Optical Performance

For discussion of the TV camera and spectrograph performance, see §7.1 and §7.2.

6.1 Bright Object Sensors (BOS)

The bright object detection system on HUT consists of two phototransitors that are intended to produce signals corresponding to the limb of the bright earth and direct sunlight. The earth bright object sensor (EBOS) was designed to trip whenever the line of sight of the telescope is approximately 20° from the bright earth limb. In this event, the DEP will put a safe neutral density filter in place to protect the TV camera. The sun bright object sensor (SBOS) was designed to detect the sun within 40° of the telescope line of sight. On a sun detection, the DEP will close the telescope doors, and if the ND6 filter is not already in place, also turn off the TV camera.

In flight, both sensors worked well. The EBOS was tripped approximately 67 times when the camera filter was not already in a safe configuration. The SBOS only tripped once, during a maneuver prior to the first Venus observation. The doors were already closed and the filter was at ND6, so no action was taken. It is unknown at what angle the SBOS became active. Post-flight analysis of the single detection gave a sun angle of approximately 50°. However, there was no detection nine hours later at a sun angle of 39.7° during the second Venus observation. The 42° cited below is from Astro-1.

During Astro-1, the EBOS had a tendency of tripping in daylight when the earth limb was not in sight. Direct sunlight scatters off the quartz window and inside the EBOS baffle when the sun is within 57°. A special SUN_60 alternate procedure was created for Astro-2 to disable the EBOS for observations within 60° of the sun. Having the EBOS disabled leaves the TV camera vulnerable to damage when the earth comes into view at the end of many observations. Special care was taken to monitor the brightness of the TV camera field during these times.

Technical Data

Approximate Trip Angles:	Earth Limb/EBOS	16°
	Sun/EBOS	57°
	Sun/SBOS (Astro-1)	42°

6.2 Primary Mirror and Focusing

The primary mirror of HUT is 92 cm in diameter, has a focal ratio of f/2, and is coated with silicon carbide. The mirror is mounted on a mirror positioning mechanism that has three independent positioners with a piston range of about 1000 µm. This mechanism was designed to allow the mirror to be focused to the spectrograph or to the TV camera (nominally both would be at the same focus position). The fact that the three positioners are independent allows the mirror to be tilted to offset a given target without requiring movement of the IPS.

The best focus position for the TV camera was found to be at about +180 µm from the ground-measured position. This is only an estimate, (±20 µm), due to the procedural error in FO-5A as discussed in §7.1. The best focus position for the spectrograph was found to be at about -200 µm from the ground-measured position. Ideally, the mirror would be placed at the best focus position for the spectrograph since this would yield the best quality science data. However, the TV camera images were too defocused to allow proper centroiding at this position. The compromise mirror position used after MET 4/14:10 was at -100 µm.

The ground calibration of the instrument's sensitivity differed as much as 45% from the calibration obtained in flight. This is shown in figure 7-1, and discussed in detail in §7.2. A decline of at least 30% was expected due to the aging of the detector's photocathode.

6.3 Baffles

The baffle design of HUT was adequate for our requirements. The amount of scattering in the far ultraviolet was roughly equivalent to the dark counts, an acceptably low number. The scattering for visible light while pointed near the sun was also acceptable as measured with the TV camera. The closest pointing to the sun, Venus, was about 40º away. Since a magnitude 2 camera setting was used, we cannot tell much about the baffle performance from this target. The closest pointing in Astro-1 was at a sun angle of 43º using camera magnitude 15 to observe Comet Levy. No visible scattering was observed in that case, either.

All known cases of visible light scattering occurred near the earth limb, typically when the EBOS was disabled. This would allow the TV camera to see reflected light at less than the EBOS detector angle of 20º without the protection of the neutral density filter. In these cases, the TV camera field brightened considerably. This was typically near the end of observations and only lasted for a short duration of time with no impact on the TV camera.

7. Telescope Module Component Performance

7.1 Television Camera

HUT has a television camera that is used in directing the object under study into the slit of the spectrograph. This camera is a black and white Silicon Intensified Target (SIT) type tube, and it is sensitive to visible light. While the camera itself was not intended to produce science data, it was of great importance to make sure the correct target was being observed. The video from the camera could be adjusted for gain and contrast from a software table based on stellar magnitudes. Additional dynamic range was obtained by using a filter wheel that had four levels of neutral density filters mounted on it. This filter wheel mechanism was mounted between the camera tube and the transfer lens assembly. The camera was able to identify guide stars and targets as faint as magnitude sixteen.

The camera was powered on at MET 0/05:47 and was run continuously until the end of observations at MET 14/22:30 with the exception of an accidental 10 minute shutdown which occurred at MET 8/20:55. It should also be noted that while reviewing engineering plots following the mission, a downward offset of 1% to 5% in the monitoring of several parameters was noticed while the TV camera was operating. These were:

Converter #1 Input Current
Converter #1 +16 Volts
Converter #1 -16 Volts
Converter #2 +5 Volts
Converter #2 +18 Volts
Converter #3 Input Current
Reticon Temperatures
DEP Temperatures
SP Temperatures

The reason for these offsets are not yet understood, but are believed to only be in the monitoring hardware. It caused no problems or error messages during the flight.

The video from the TV camera is sent through the DEP to the monitors on the aft flight deck of the shuttle. This signal can also be downlinked directly by the orbiter television system. The DEP also has the ability to downlink frames of digitized images, as well as to inject target and guide star marks into the video. Since the target star is not seen during an observation, these marks give a visual indication of the pointing accuracy, as well as helping in target acquisition.

Prior to Astro-1, the camera was never used in combination with the telescope to view a real star field during preflight testing. Construction of the magnitude table was based on calibration of the camera with a black body source. There was reason to believe that the table could well require substantial adjustment in order to properly image a star field of a given magnitude. It was found during Astro-1 that brighter settings, about magnitude eight or brighter, simply required an offset of about one magnitude toward a fainter setting. The fainter magnitudes generally required two magnitudes of offset in the same direction. Additional adjustment was required to the table itself at magnitudes dimmer than fifteen.

The same magnitude table was used for Astro-2 but needed adjustment due to a decrease in the camera sensitivity of 30 to 50%. This can be partly attributed to the silicon carbide coating of the primary mirror, which was 20% less reflective for visible light than iridium. The rest can probably be attributed to the less than optimum camera focus used throughout the mission. A global two magnitude offset to increase sensitivity was put into effect at MET 01/23:30. This change had the effect of configuring the TV camera two magnitudes fainter than the requested setting (e.g. a command to set the camera to magnitude 14 would actually configure the camera using the settings in the table for magnitude 16). This same offset probably would have been appropriate during Astro-1, since the camera magnitude was bumped up manually during most target acquisitions. For magnitude 13 and brighter objects, the actual camera settings used were nearly identical for the two flights. On Astro-2, objects fainter than magnitude 13 required the camera settings to be increased an additional one or two magnitudes in order to provide the best video images for the DEP to process.

The background noise level was negligible for camera magnitudes less than 13. At magnitudes dimmer than this, the dark current was a factor of two higher than on Astro-1, even before considering the higher magnitude settings required for the same object brightness. Although this had no apparent impact on acquisitions by the DEP, adjusting the camera white and black thresholds could have significantly reduced the dark current level for improved visibility on the video monitors.

Long periods without running the original camera, which was replaced in 1989, resulted in a bright ion spot at the center of the field. This bright spot, if not corrected, would have interfered with the process of identifying and tracking targets. With the exception of the 4½ months following Astro-1, the flight TV camera was run at least once every three months. The ion spot was not visible during Astro-1, and only appeared during the initial activation of Astro-2 when the field was artificially lit by the illumination lamp. This posed no problem during the mission.

The transfer lens assembly appeared to perform satisfactorily. It was found that focusing the primary mirror produced images that were astigmatic during Astro-1. Prior to Astro-2, a knife-edge test of the primary mirror was performed, but the results from this were inconclusive. The main test which would reveal astigmatism in flight (sequence FO-5A) was performed incorrectly and no useful data were recorded. This was due to an error in the procedure which called for software integration. Software integration has the effect of raising the brightest pixel to saturation level and scaling the others accordingly. When the POCC saw a saturated pixel on the video downlink, the crew was instructed to lower the magnitude setting of the camera, which reduced the light levels to a point where only the brightest pixel could be seen. Analysis of data taken during observations using different mirror positions showed little evidence of astigmatism.

There were several minor problems with the camera, none of which had any significant impact during the flight. The hot pixel in the lower right part of the field present during Astro-1 was still there. Since this presented no operational problems and would be difficult to repair, it was decided to fly again in this condition.

The interlacing of the video image showed a definite odd/even pattern in both light and dark conditions. This was more prevalent during faint observations where the settings for the white and black levels are nearly equal, thus "stretching" the video signal. The problem was first noted during the thermal vacuum test prior to Astro-1 and was alleviated by reading the images of two consecutive video frames. This allowed each image to get equal exposure without the read of one affecting the other. The amount of blanking (17 frames) between the two exposures was sufficient to remove any residual exposure. This is the only known cure for this problem, so further research would be required to address this condition. Since this condition was not noted until after the Astro-2 mission, it is unlikely that it played any part in target acquisition.

The focused image size could not be accurately determined during the mission due to the procedural error in sequence FO-5A. The best focus position of the TV camera was determined to be at approximately +180 µm from nominal focus, whereas the best spectrograph focus was at -200 µm. Spectrograph focus being more important, the focus was left at -100 µm for most observations after MET 4/14:10. At this mirror position, an image "donut" with a bright section could be seen on saturated images. The bright section did not increase dramatically in size despite the formation of the donut. Since the bright section of the donut was the proper position of the star and the DEP centroids on the 5 pixel box surrounding the brightest pixel, acquisitions should have proceeded nominally. The main effect of the donut was to distribute the light over more pixels, reducing camera sensitivity. The adjusted camera magnitude settings is shown in table 7-1.

The camera and DEP interacted well in finding guide stars. In many cases, the guide stars were located despite their not being visible on the video downlink by eye. This sometimes caused problems during source locates when the DEP picked up noise after the image disappeared in the slit. This was corrected by using the blank slit on all source locates dimmer than magnitude thirteen. For its intended purpose, the camera worked as well as was expected.

Technical Data

Approximate faintest star detected:	16th magnitude
Star image size (@nom focus)	3.1 x 2.3 pixels 3.4 x 3.3 arcsec
Star image size (@-100 µm)	4.3 x 2.8 pixels 5.0 x 4.0 arcsec
Camera head temperature (average):	16ºC
Total camera runtime prior to flight	1033 hours
Total camera runtime during flight	352 hours, 42 minutes

Magnitude	Exposure	High Voltage	White	Black	Soft Int	Filter
-5	0	5	7	0	0	0
-4	0	5	7	0	0	3
-3	0	5	7	0	0	3
-2	0	5	7	0	0	3
-1	1	5	7	0	0	3
0	1	1	7	0	0	2
1	0	2	7	0	0	2
2	0	3	7	0	0	2
3	0	5	7	0	0	2
4	1	5	7	0	0	2
5	1	1	7	0	0	1
6	0	2	7	0	0	1
7	0	3	7	0	0	1
8	0	5	7	0	0	1
9	1	5	7	0	0	1
10	2	5	7	0	0	1
11	3	5	7	0	0	1
12	4	5	7	0	0	1
13	5	5	7	0	0	1
14	5	6	4	0	0	1
15	5	7	4	0	0	1
16	5	7	1	0	0	1
17	6	7	6	1	0	1
18	6	7	4	1	0	1
19	6	7	4	1	0	1
20	6	7	4	1	0	1

Table 7-1

This table takes the two magnitude shift into consideration, such that the commanded magnitude will give the above settings for full aperture.

Error flags: None

7.2 Spectrograph and Detector

The HUT spectrograph takes light passing through the slit wheel, diffracts it from a reflection grating, and reimages it onto an ultraviolet detector. This process separates the light by wavelength, and the detector is used to convert this ultraviolet spectrum into electrical signals.

The spectrograph is a stainless steel cylinder that is vacuum-sealed. On one end is the slit wheel mechanism, which controls the light admitted to the spectrograph and acts as a vacuum door. The slit wheel mechanism is described in section §8.2 of this document. The detector is mounted next to the slit wheel. The HUT detector is an open-faced microchannel plate (MCP) intensifier. The intensifier is coupled to a linear photodiode array. Two vacuum ion pumps are mounted on the side of the spectrograph, and are discussed in section §7.6 of this document. On the far end of the spectrograph is a stainless steel, silicon-carbide-coated, holographically ruled, concave diffraction grating.

The spectrograph worked well during the flight with some notable exceptions. Degradation of the detector sensitivity was noted during ground testing. This was demonstrated by a 50% drop in count rates of the UV calibration lamp and the gain of the detector as monitored during these tests. This was attributed to "scrubbing" of the MCP by the long time under vacuum. During an early observation, the operating voltage of the MCP was raised three levels to reach the pre-flight calibration gain. Since the "scrubbing" is greatly accelerated by exposure to ultraviolet light, the detector setting was changed again at MET 06/14. In this case, the phosphor voltage was raised one level where it remained for the rest of the flight. Calibration data was taken regularly to monitor this change in detector performance for post-flight calibration.

The discrepancy between the initial in-flight calibration and the predicted efficiency was small. From the short wavelength end of the detector to 1055 Å, the effective area was greater than the preflight calibration, up to a peak difference of 14% at 1028 Å. Above 1055 Å however, the effective area was smaller than the initial calibration with peak differences as follows: 33% lower at 1176 Å, 39% lower at 1413 Å, and 50% at 1700 Å. A plot of the preflight calibration versus the in-flight calibration is shown in figure 7-1. Since roughly a 30% decline in efficiency was expected (from degradation of the detector's photocathode over time), the in-flight calibration was very close to the predicted values.

Due to alignment differences between the spectrograph and television camera, it was not possible to focus both simultaneously. Ideally, the best spectrograph focus position would be used during the flight but the 380 μm difference in focus between the two was large enough to force the use of a compromise mirror position about 100 μm from the optimum spectrograph focus. The worst focus was at 1250 Å, where the spectral resolution was limited to 4.5 Å. The points of best focus were at 900 Å and 1600 Å, where the resolution was 2 Å. These positions are shifted slightly from the desired locations of 1050 Å and 1350 Å. This shift can probably be attributed to the compromise mirror position used. A plot of the spectral resolution versus wavelength appears in figure 7-2.

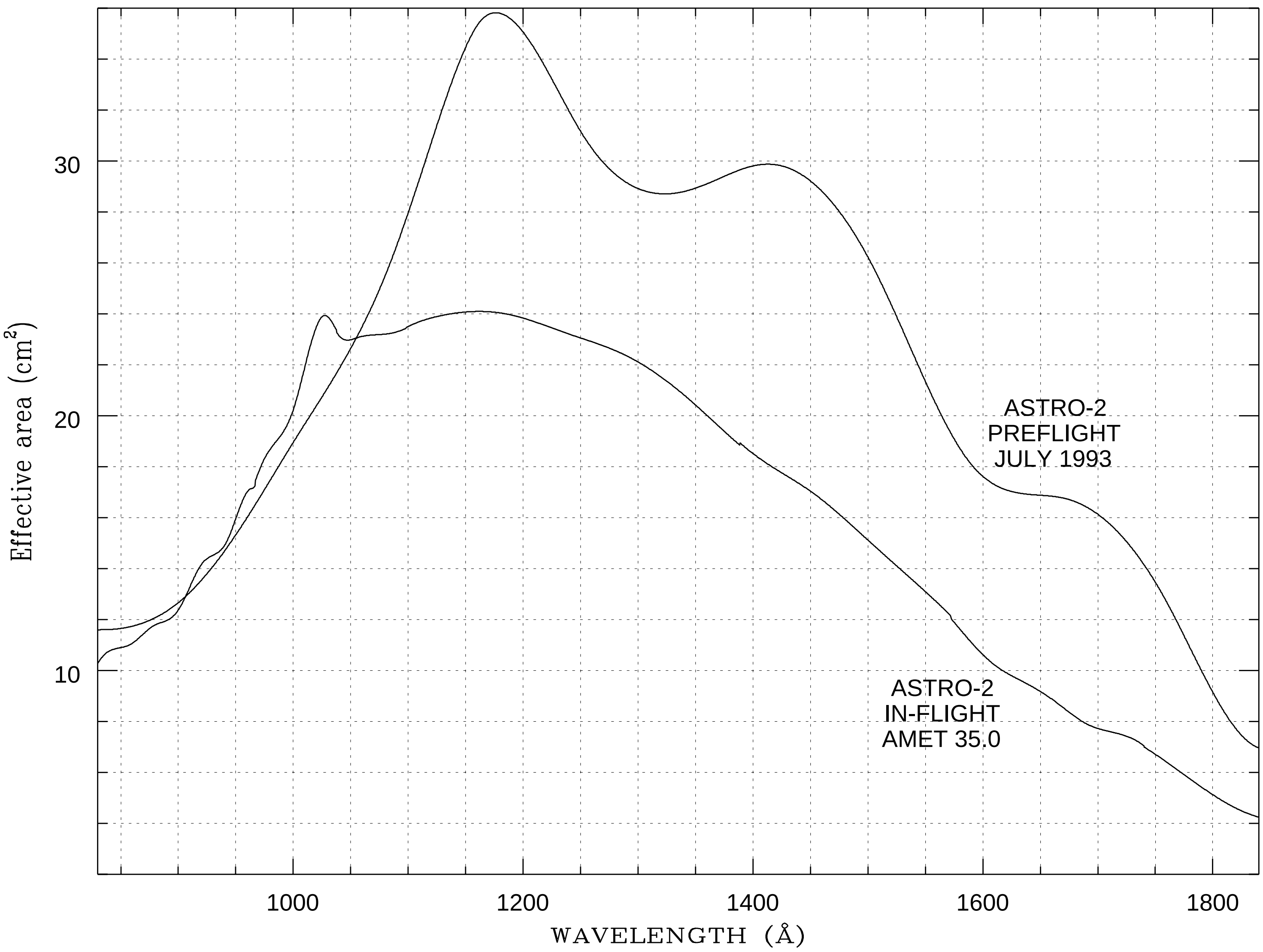

Effective area (cm^2)
30
20
10
1000
1200
1400
1600
1800
WAVELENGTH (Å)
ASTRO-2
PREFLIGHT
JULY 1993
ASTRO-2
IN-FLIGHT
AMET 35.0

Figure 7-1

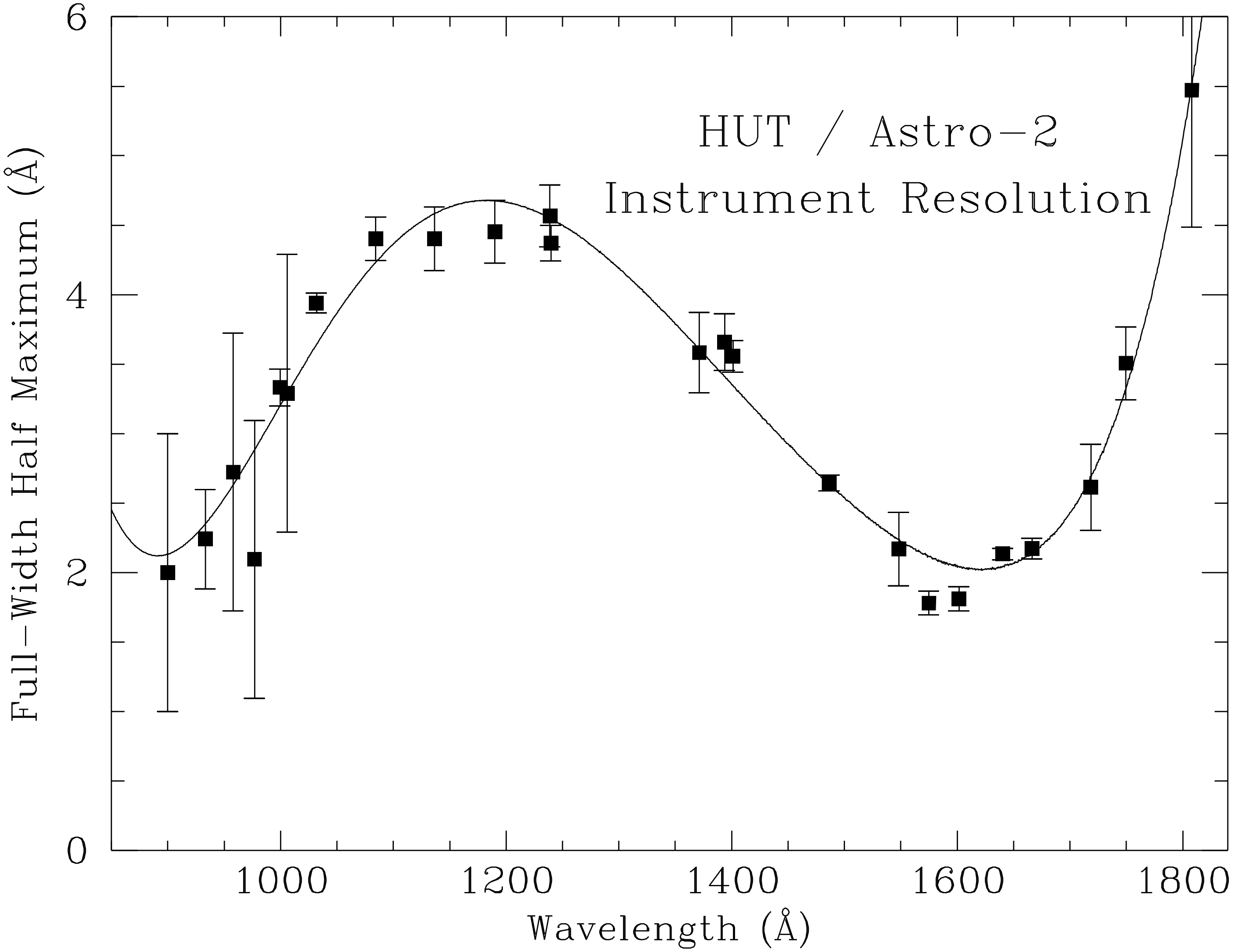

HUT / Astro-2
Instrument Resolution
Full-Width Half Maximum (Å)
Wavelength (Å)
0
2
4
6
1000
1200
1400
1600
1800

Figure 7-2

The dark count of the detector varied during the mission from about 3.8×10^{-4} counts/Å-sec for the first 160 hours, to an average value for the remainder of the mission of 4.6×10^{-4} counts/Å-sec. The jump at 160 hours is due to the increase of the detector high voltage setting.

7.3 UV Calibration Lamp

A mercury UV calibration lamp is part of the HUT spectrograph. It is able to illuminate the spectrograph with two wavelengths that result in spectral lines on the detector. The calibration lamp was intended to monitor the condition of the detector during ground preparations, and to check for movement of the optics in the spectrograph after launch.

As planned, the calibration lamp was only used once during the flight. During the initial activation of the spectrograph, the lamp was run for 11 minutes (MET 0/11:14-0/11:25) while a spectrum was acquired. The count rate was reasonable, indicating that the detector's efficiency had not dropped any large amount. This can only be used as an approximation, as the count rate changes significantly depending on whether the spectrograph is in a vacuum environment or in air. This is due to the absorption of ultraviolet light in the short air path that the light must traverse before reaching the spectrograph vacuum. The position of the spectral lines on the detector will indicate if the optics internal to the spectrograph moved during the vibration of launch. The data taken in flight showed no measurable movement.

The calibration lamp is powered by a DC to DC converter, operating as high as 2300 volts. No problems were encountered with this converter during flight.

Technical Data

Count rate in flight with lamp (before raising detector voltage)	75 cts/sec
Primary current draw by lamp:	44 mA

Error flags: None

7.4 Reticon Control Electronics and Spectrometer Processor

Data from the reticon diode array is digitized in the Reticon Control Electronics (RCE) package, then passed along for processing to the Spectrometer Processor (SP). The processor in its normal mode takes the data and produces a histogram showing the number of events centroided in each bin. Another common mode gives the individual photon event locations and the times of occurrence. A single scan mode is also occasionally used to provide data on pulse width and height (to monitor detector gain), but this mode allows processing of only a small number of photon events per HRM downlink frame (2 seconds).

Pattern noise due to a change in RCE tuning was a concern prior to the flight. The data from alternating diodes on the array is read through separate differential amplifiers before being digitized. Thermal-vacuum testing has shown that the tuning of the amplifiers to match the outputs can vary for a number of reasons. This could cause some compromise of the science data if it happened during flight. Single scan data taken during the flight showed a low level of odd-even pattern noise on the order of 1%.

The RCE and the SP were turned on at MET 0/05:36 and left on until after the last observation at 14/23:31. The processor never crashed. None of the spectral masks were used during the flight. These were provided for use if the processor was being swamped with data from one part of the spectrum at the expense of a more scientifically interesting part.

The processor was run through nearly all of the South Atlantic Anomaly (SAA) passes without problems. If not in its protective hibernate mode, a single bit flip caused by energetic particles could cause a processor crash. Five parity errors in the DEP memory were received during the flight. As the SP is similar to the DEP, there is a small but real chance of having the SP crash during a given SAA passage if not hibernating, but this did not occur. Discussion of the SP software is in §11 of this document.

Technical Data:

Average ratio wide counts/counts:	0.13% at low count rates	(< 250/sec)
Average ratio wide counts/counts:	0.49% at medium count rates	(500-1500/sec)
Average ratio wide counts/counts:	0.93% at high count rates	(> 2500/sec)
Average ratio narrow counts/counts:	1.54% at low count rates	(< 250/sec)
Average ratio narrow counts/counts:	0.80% at medium count rates	(500-1500/sec)
Average ratio narrow counts/counts:	0.75% at high count rates	(> 2500/sec)
Average ratio high counts/counts:	approaching zero at all rates	
FIFO overflows	502 during length of mission (338 from detector shutdown §5.9)	

Error flags: None

7.5 Vacuum Ion Pumps

The open-faced detector on HUT has a photocathode coating of cesium iodide that degrades quickly from exposure to air; therefore it must be maintained in a high vacuum state. For this reason, the spectrograph on HUT is actively pumped at all times, either by an external pump or by one of a pair of redundant internal ion pumps.

Through most of the ground processing, an external pumping system is used to keep the spectrograph at high vacuum. This is done because internal pumps have a limited lifetime which is dictated by the time they are run, and the pressure they pump against. Prior to flight, pump #1 had used up 26.1% of its manufacturer's rated lifetime, and pump #2 used 2.8%. We have found that the actual lifetime can be as short as 40% of the rated lifetime. As the failure mode of these pumps is sometimes damaging to the devices they are mounted on, there could be considerable concern if a pump were to fail.

For the last month and a half of ground processing, as well as throughout the flight, pump #1 was used. The pump was powered through the T-0 umbilical until the end of the 9 minute hold before launch. It was then turned off until MET 0/01:04, when the cabin payload power switch on the mid flight deck was activated. When the 28V bus of HUT was powered at MET 0/03:48, the umbilical power routing was automatically removed and primary power was activated.

During observations the pump must be turned off, as it produces a large dark count on the detector. The pump turned on instantly at the end of each of these periods, and worked flawlessly. During ground testing at room temperature, the pump could only be left off about 25 minutes before the pressure in the spectrograph would rise above a safe level for the detector. The rate of pressure build-up varies greatly with temperature. It was found that during the mission, with the spectrograph at 10ºC, the maximum time to operate the detector could be extended to hundreds of minutes if desired. There is also limited pumping through the observation aperture in the slit wheel, which also helps to keep the pressure in the spectrograph low. As the very longest observations were scheduled for about 65 minutes, the extension of the time limit was quite beneficial.

At the end of the mission, the umbilical routing was again used to power the pump for several hours before it was turned off for landing. As there was no way to power the pump during transport of the orbiter from California to Florida, it was decided in advance not to power it on the ground in California. The actual pump off time following the flight was approximately 25 days. After Astro-1, the pump was left off for 84 days following the flight. The pressure in the spectrograph rose to about 30 millitorr during this period, compared to 70 millitorr following Astro-1. Since no degradation was noted in the detector following Astro-1, it is suspected that the same is true for Astro-2.

Technical Data

Average pump #1 pressure:	4.6×10^{-7} torr
Average pump #1 primary current:	94 mA
Rate of pressure build at 10ºC:	$< 5 \times 10^{-8}$ torr/min

Error flags: None (other than nominal time warnings)

7.6 Detector High Voltage Power Supplies

The detector on the HUT spectrograph requires three high voltage inputs. The lower two voltages are applied to the microchannel plates and are roughly 250 and 2900 volts. A single DC to DC converter supplies these two voltages. A separate DC to DC converter supplies the 7000 volts required by the phosphor screen anode of the detector. Both of these power supplies are mounted on the spectrograph spider arms of the telescope, and are designed and constructed to operate in a vacuum environment.

The power converters were turned on for the first time on orbit at MET 0/11:06. They were turned on anytime the detector was required, and turned off at all other times. There were two errors with the phosphor supply during the flight. These are documented in §5.5. Neither problem caused any constraints to observations.

Technical Data

MCP HVPS nominal current: 24.5 mA
MCP HVPS nominal voltage: 2.90 kV
MCP nominal program setting: 7

Initial Setting:
Phosphor HVPS nominal current: 36.4 mA
Phosphor HVPS nominal voltage: 6.85 kV
Phosphor nominal program setting: 3

Setting after MET 6/14:35:
Phosphor HVPS nominal current: 37.3 mA
Phosphor HVPS nominal voltage: 6.99 kV
Phosphor nominal program setting: 4

Approximate flight run time: 205 hours

Error flags: (2) Phosphor Voltage Low

8. Mechanism Performance

8.1 Shutter Door and Small Aperture Door Mechanisms

The HUT door system consists of two independent half-shutter doors, and a Small Aperture Door (SAD). During flight, only one problem developed on these mechanisms. This error, involving the +Y door, is detailed in §5.4 of this report. The error occurred four times during the mission and was caused by a misaligned "closed" telltale. In three of the four cases, there was a delay in the telltale becoming active. In the last case it was necessary to mask the telltale in order to reopen the doors.

There were six door configurations available for HUT. These were referred to by the area of primary mirror exposure (1, 50, 200, or 750 cm^2), or as half (2560 cm^2) or full aperture (5120 cm^2). The smallest openings were achieved by using the SAD mounted in the +Y door. The 200 cm^2 and 750 cm^2 positions were reached by closing the -Y door, and partially opening the +Y door for 37 or 60 seconds. For detector safety during 1 cm^2 observations, the -Y door would be partially opened for ten seconds (not enough to permit light to enter), to keep the telescope pressure from rising to an unacceptable level due to outgassing.

All door configurations except the 1 cm^2 were used during the flight. The reasons the 1 cm^2 configuration was not used were that few targets this bright were planned (none were HUT prime targets), and these were not observed by HUT due to operational concerns. All other door configurations worked nominally. There was concern prior to Astro-1 that the pumping speed through the 50 cm^2 opening would not be sufficient to keep the telescope to a pressure low enough for safe detector operation. Tests during both flights seemed to indicate that this precaution was unnecessary, and it was not used on Astro-2. However, if the 1 cm^2 opening had been used, the -Y door would have been partially opened.

Another potential problem with the doors was the lack of heaters and temperature monitors. This is discussed in §10.2 of this report.

Technical Data

Opening of SAD for outgassing:	0/07:38
Opening of shutter doors for outgassing:	0/08:31
Measured +Y opening time:	121 sec
Measured -Y opening time:	120 sec
Measured +Y closing time:	6 sec
Measured -Y closing time:	6 sec
Measured +Y latching time:	60 sec
Measured -Y latching time:	60 sec
Measured +Y unlatching time:	8 sec
Measured -Y unlatching time:	10 sec

Measured 1 cm^2 opening time: 26 sec
Measured 1 cm^2 closing time: 24 sec
Measured 1 cm^2 to 50 cm^2 time: 90 sec
Measured 50 cm^2 to 1 cm^2 time: 89 sec
Total flight cycles +Y door: 104
Total flight cycles -Y door: 114
Total flight cycles +Y door (200 cm^2): 13
Total flight cycles +Y door (750 cm^2): 25
Total flight cycles to 1 cm^2: 0
Total flight cycles to 50 cm^2: 26

Error flags: (2) +Y closed verification errors
(4) +Y telltale mismatch errors

8.2 Slit Wheel Mechanism

The slit wheel mechanism on HUT has two functions: to provide a vacuum door for the spectrograph, and to position different size slits to control the light admitted to the spectrograph. The slit wheel is powered by a synchronous motor driving a Geneva mechanism. Vacuum sealing is provided by a viton o-ring that the wheel is compressed against. There are eight slit positions including the blank position used to seal the spectrograph.

The slit wheel mechanism completed all commanded motions nominally, with the exception of twenty-one that were aborted before the wheel moved. All of these problems were addressed by reissuing the commanded movement, sometimes twice. A discussion of this software/hardware interaction problem is in §5.3 of this document. It should be noted that early ground testing showed minor mechanism wear after 200 motions. Since there were over 1000 motions during the flight, an inspection is suggested before another flight. This not only requires disassembly of the mechanism, but also requires bringing the spectrograph up to atmospheric pressure.

Technical Data:

Approximate observational uses:	position 0	127
	position 1	48
	position 2	16
	position 3	0
	position 4	0
	position 5	9
	position 6	77
	position 7	238

Approximate number of single steps: 1052

Average time per step: 22.1 seconds

Error flags: (21) Verification errors

8.3 Filter Wheel Mechanism

The filter wheel assembly is used to control the amount of light received by the TV camera on HUT. It is powered by a synchronous motor driving an eight position Geneva mechanism. The eight positions consist of four neutral density filters and four color filters.

The filter wheel assembly worked perfectly. Although the mechanism is similar to the slit wheel, there were no errors by the filter wheel during the flight. The color filters on the filter wheel were not used. These were originally intended for use during observations of Comet Halley. Depending on the amount of work to be done before another flight, it might be worth considering changing these out in favor of additional neutral density filters. After the flight, fourteen cases were found where the filter wheel either moved in the wrong direction or moved an extra rotation. Most of these motions moved from position 1 to position 0 by the long way (eg. 2,3,4...0), or after returning to 0, moving an additional rotation (8 steps) before resting at position 0. These are not yet understood.

Technical Data:

Approximate observational uses:		
	position 0	0
	position 1	388
	position 2	17
	position 3	6
	position 4	0
	position 5	0
	position 6	0
	position 7	0

Approximate number of single steps: 1244

Average time per step: 5.8 seconds

Error flags: none

8.4 Mirror Positioning Mechanisms

The mirror positioning mechanisms worked nominally throughout most of the flight. Backlash test data agreed well with that measured on the ground. The pots responsible for giving position data had bad spots that resulted in voltage dropouts, causing occasional invalid position indications. This was especially evident in the +Y+Z pot in the region from -150 µm to -200 µm.

The amount of mirror motion necessary to reach a commanded position is calculated in terms of motor run time. An erroneous pot reading at the end of a motion could force a large erroneous mirror motion for the next movement. In this case, a motion would need to be started and aborted to reach a "good" region of the pot. This was necessary once during the mission, at MET 0/17:24. This was also the only error resulting from this problem and is detailed in §5.2 of this report.

Due to the focus difference between the TV camera and the spectrograph, the mirror was moved much more than anticipated. When a loss in TV camera resolution could be tolerated, the mirror was moved from the nominal position to -100 µm. Other than follow-up efforts to determine the TV camera focus, the mirror was generally left in the nominal focus position until MET 4/14:06. After this point, the mirror was generally positioned at -100 µm.

Technical Data

Focus Position	-Z position	+Y+Z position	-Y+Z position	
nominal	3742	3559	3496	counts
-100 µm	4550	4367	4304	counts

Backlash times (seconds):	Mirror Motor	Ground	Orbit
	-Z	10.81	12.81
	+Y+Z	3.06	4.19
	-Y+Z	3.75	4.31

Mirror reference voltage:		
	(min)	11.87 volts
	(max)	11.92 volts

Error flags: One mirror position error

9. Power Supplies and Other Electronics

HUT has three separate low voltage DC to DC converters. It also has an AC inverter to power the eight synchronous motors used for various mechanisms. All of these converters performed nominally throughout the flight. The only error message received was for a high inverter current. This problem, detailed in §5.11 of this report, was actually a nominal condition that was not accounted for in the monitoring logic.

The electronics bus input voltage was not directly monitored, but can be inferred from the current drawn by converter #3. Based on its average current of 146 mA (see below), the inferred average electronics input voltage was 27.7 V. Therefore, the average electronics power for the Astro-2 mission, exclusive of heater power, was 177 watts.

Technical Data:

	minimum	maximum	average	
Total current draw (excluding heaters):	3.3	7.9	6.4	A

Error flags: One

9.1 Converter #1

Converter #1 powers the Spectrometer Processor and the Reticon Control Electronics package. Current draw and voltages produced were steady throughout the mission and corresponded well to the values obtained during ground testing. There were no real problems with any of the devices that used the power produced by this unit. Converter #1 was powered up at MET 0/05:37 and left on until 14/23:31.

Technical Data:

	minimum	maximum	average	
Current draw:	1.55	1.70	1.59	A
+5 volts SP:	4.89	5.01	4.955	V
+5 volts RCE:	4.83	4.88	4.857	V
+16 volts:	16.97	17.43	17.35	V
-16 volts:	-16.10	-15.64	-15.90	V

Error flags: None

9.2 Converter #2

Converter #2 powers the DEP, reference voltages, television camera, and the illumination lamp. Current draw and output voltages were unchanged throughout the mission, except when the load was changed. The levels measured were close to those logged during preflight testing. All electronics using the outputs of Converter #2 behaved well during the flight. This power supply was turned on at MET 0/04:42 and run continuously until 14/23:32. The DEP was not operational until MET 0/05:09, so no HRM is available prior to this time.

Technical Data:

	minimum	maximum	average	
Current draw:	2.88	4.17	4.07	A
+5 volts:	5.216	5.282	5.259	V
+12 volts:	12.02	12.18	12.14	V
-12 volts:	-12.59	-12.46	-12.54	V
+18 volts:	18.70	18.90	18.80	V

Error flags: None

9.3 Converter #3

Converter #3 powers the Heater Control Electronics and the current monitor circuitry. Current draw and the single monitored output voltage changed little during the flight, with a slight general increase in current towards the end. This is indicative of a slight decrease in input voltage to the instrument, which was expected. All values measured were very close to the preflight testing levels. No problems were detected on any of the devices which were supplied by Converter #3. The converter was turned on at MET 0/03:44 and turned off at the end of the mission at MET 15/03:48.

Technical Data:

	minimum	maximum	average	
Current draw:	143	151	146	mA
+12 volts:	12.05	12.13	12.08	V

Error flags: None

9.4 Inverter

There are eight synchronous motors which drive the mechanisms on HUT. They are powered by a 400 Hz inverter, which is able to supply up to four motors at the same time. The inverter phasing is controlled by the DEP to choose the direction of motor movement. Whenever a mechanism motion is stopped, the inverter reverses its direction for a brief time in order to control the stopping position of the motor. This reverse motion causes a doubling of current draw for the brief 100 ms duration. The one error message indicating high inverter current was explained by this action. This is detailed in §5.11 of this document. There were no problems with the inverter during the flight.

Technical Data:

	nominal	braking	
Current draw (1 motor):	.255	.490	A

Current draw (2 motors):	.480	.905	A
Current draw (3 motors):	.710	1.360	A

Approximate total on/off cycles: 2633

Error flags: (1) Inverter current high

9.5 Other Electronics

Other electronics that are used on HUT include power switching, heater control electronics, filtering, fusing, telltales and pressure switches. All of these functioned nominally throughout the mission. Current and voltage monitoring had occasional problems with the fifth or sixth bit of the analog to digital converter, latching low in cases that it should have been high. This problem was known from preflight testing. This seems to occur in about 1 of 100 conversions for which these bits should be high. This results in an error of less than 1.5% of the full scale reading.

Technical Data:

Error flags: None

10. HUT Thermal Control System Performance

10.1 System Description

The HUT thermal control system consists of 19 groups of foil type heaters, 24 temperature sensors, 4 thermostats, multi-layer insulation (MLI), thermal control coatings, and a smart controller called the Heater Control Electronics (HCE). The purpose of the system is to control the absolute temperature of the structure and the electronics as well as the thermal gradients of the metering cylinder and the spectrograph housing.

The 19 heaters are located as follows: 3 are on the telescope mounting feet, 7 are on the aft section of the Environmental Control Canister (ECC), 4 are on the spectrograph, 1 is on the baseplate of the Electronics Module, and 4 are on the electronics mounted on the exterior of the Telescope Module (i.e., the Camera Control Unit, the Bright Object Sensor Electronics, and the Sun and Earth Bright Object Sensors). The 14 Telescope Module (TM) heaters (feet, ECC, and spectrograph) as well as the Electronics Module (EM) heater are individually controlled by their associated temperature sensors. The 4 electronics heaters are thermostatically controlled.

The seven heaters on the ECC were used to control the absolute temperatures and the thermal gradients of the metering cylinder. The ECC is an aluminum cylinder mounted concentric to and outside of the Invar metering cylinder. The metering cylinder is used to control and maintain the alignment between the primary mirror and the spectrograph. The seven heaters are located on the ECC and their respective temperature monitors are located on the metering cylinder itself. The metering cylinder had a 7ºC longitudinal and 4ºC circumferential maximum thermal gradient specification.

The four spectrograph heaters had a similar function for the spectrograph. Three heaters are located on the spectrograph mounting ring, and the fourth is on the grating end of the spectrograph itself. The corresponding temperature sensors are all located on the spectrograph vacuum housing. In that case, the longitudinal and circumferential gradient specifications for the spectrograph were 1.0ºC and 0.7ºC maximum, respectively.

In addition to the 15 control temperature sensors, there are 9 temperature monitor sensors all located on electronics packages in the EM (6) and the TM (3).

The HUT thermal control system has two modes of operation: survive and slave. The survive mode was intended for use whenever the DEP was not activated. In this mode all of the heaters are always enabled and the on and off thresholds are fixed in hardware. This mode of operation was used for the period of time from HUT heater bus activation to DEP activation at the beginning of the mission and for the period of time after DEP deactivation until heater bus deactivation at the end of the mission. The total time that the instrument was in survive mode was 5 hours 45 minutes. These on and off temperature thresholds for survive mode are given in table 10-1.

HEATER LOCATION	ON THRESHOLD	OFF THRESHOLD
Telescope Heaters (14)	0 ºC	5 ºC
Electronics Module	-8 ºC	-2 ºC
EBOS and SBOS	-35 ºC	-25 ºC
BOS Electronics	-18 ºC	-10 ºC
Camera Control Unit	-10 ºC	-2 ºC

Table 10-1

The thermal control system operated in the slave mode whenever the DEP was active. This is the primary mode of the system. In this mode, the 14 TM heaters have commandable on/off and alarm thresholds. The HCE samples each temperature every 32 seconds and controls the heaters every 64 seconds. There is no temperature hysteresis in the control algorithm. The system provides hysteresis and prevents oscillation by ensuring that the heaters are either on or off for a minimum of 64 seconds each. The system also has the capability of either enabling, disabling, or powering on any subset of the 14 TM heaters by command. The Electronics Module heater can be disabled in the slave mode; otherwise, it operates the same as in the survive mode. The thermostatically controlled electronics heaters operate the same independent of mode.

10.2 Summary of Operation

The HUT thermal control system worked extremely well. The maximum temperature recorded during the mission was 43ºC at the DEP shortly after turn-on. The minimum temperature was -2.6ºC at the inverter. The telescope temperatures were approximately 18.6ºC at turn-on and gradually fell to the heater set points of 10ºC (telescope and spectrograph) over a period of 6 to 25 hours. Once the heaters turned on, the temperatures were controlled to within a maximum of 1.7ºC of the set points for the remainder of the mission.

The EM baseplate temperature gradually dropped to ~2ºC and then drifted from -1ºC to +8ºC. The low power electronics in the EM fluctuated from -3ºC to +14ºC while the high power DEP and SP varied from 27ºC to 36ºC.

The metering cylinder gradient specification was 7ºC longitudinal and 4ºC circum-ferential. Once the heaters began controlling the system, the maximum gradients were 0.5ºC and 0.3ºC respectively.

The spectrograph gradient specification was 1.0ºC longitudinal and 0.7ºC circumferential. The number of thermocouples is insufficient to directly measure these gradients. An indirect, worst case measurement resulted in a maximum 1.5ºC longitudinal and 0.3ºC circumferential. This did not affect the operations of the instrument.

The TV camera temperature fluctuated from 15.1ºC to 17.5ºC, generally about 1ºC warmer than Astro-1. As noted in §7.1, the dark current was noticeably higher than Astro-1, but with no known impact on observations. The spectrograph temperature was controlled at 10ºC and calculations for the allowed vacuum ion pump off time were in the hundreds of minutes range.

Prior to Astro-1, there was a concern that the front end of the telescope would run too cold, (that the actual cold case would be colder than the cold case to which the telescope was designed). This could result in damage to the Bright Object Sensors, the doors, or the Small Aperture. There are no thermal sensors in this area of the telescope and therefore no means of determining how cold things actually got. The post-flight condition of the hardware and the flawless operation during both flights of each of the subsystems involved have alleviated this concern.

The heater bus dissipated a rough average of 80 watts while the HUT doors were open and 63 watts while they were closed over the length of the mission. The maximum current drawn was 9.36 amperes.

10.3 Times of Operation/Survive Mode Performance

The HUT heater bus was activated at MET 00/03:44. The system came on in the survive mode and remained in that mode until the DEP was activated at MET 00/05:09. During that period the system temperatures were approximately 18ºC and the heaters did not activate. Upon powering and loading of the DEP, the heater control system was automatically switched to the slave mode. The system remained in slave mode until the DEP was powered off at MET 14/23:32. At that time the system went back to the survive mode until the heater bus was powered off at MET 15/03:48. The shuttle was positioned bay to earth for the remainder of the flight, so heaters were no longer required.

10.4 On/Off and Alarm Thresholds

The default on/off threshold was set to 10ºC for the ten (10) TM heaters and for the four (4) spectrograph heaters. The default alarm thresholds were 2ºC for the TM heaters and 0.5ºC for the spectrograph heaters. The set point and alarm limits for H11 were changed at MET 02/09:40 to 9.5ºC and 2ºC, respectively, due to the excess power dissipated by this heater. The temperature for H11 frequently exceeded the original alarm limit of 10.5ºC during the 64 second control cycles of the HCE. A lower power heater for H11 would alleviate this condition. No heater alarms were received after the new alarm limit was set.

10.5 Temperature Trends - Telescope Module

The temperatures in the TM were between 17.5ºC and 20ºC when the DEP was first loaded and telemetry initiated. As can be seen from the plots on the following two pages, the temperatures in the telescope tended to drop in groups with the forward section of the aft ECC [H8, H9, H10, and H3 (foot)] dropping the fastest, followed by the spectrograph (H11 through H14), the aft section of the aft ECC (H5, H6, and H7), and finally the rear of the telescope (H1, H2, and H4).

On Astro-1, the temperatures at the forward section of the aft ECC [H8, H9, H10, and H3 (foot)] dropped linearly at about 1ºC/hour. The first heater to turn on was H9 at MET 00/11:15. The other three heaters in this group turned on within 1.5 hours of this time. On Astro-2, the rate of temperature decline was nearly the same as on Astro-1 until 13ºC was reached at MET 0/10:30. At this point, the temperature remained nearly constant until MET 0/23:30. Then the temperatures fell to the heater set points of 10ºC. The first heater to turn on was H10 at MET 01/01:02.

The spectrograph temperatures (H11 through H14) dropped linearly at 0.4 - 0.5ºC/hour and heaters 11-13 first turned on between MET 01/02:53 and 01/03:59. H14 dropped at a slower rate and did not turn on until MET 1/14:31. This heater also was on less often and for shorter periods of time than the other heaters.

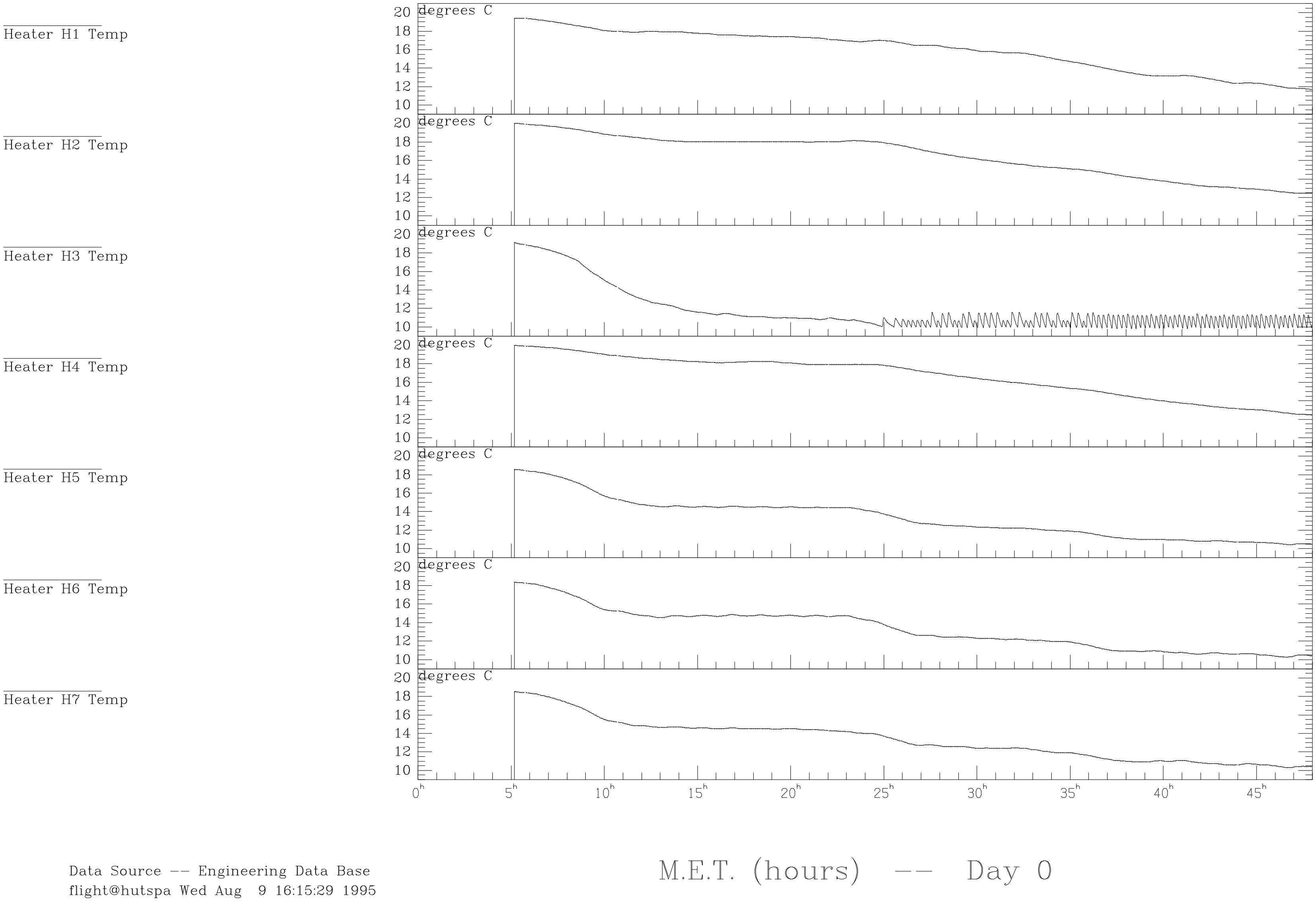
The third set of heaters to turn on were those at the aft end of the aft section of the ECC (H5 through H7). These three sensors dropped linearly until they reached ~16ºC at MET 0/10:30. They then fell at a slower rate until MET 0/13:30 when they reached 14ºC. They remained stable here for ten hours before continuing to fall to their setpoints. These heaters came on in the period from MET 02/01:32 to 02:03:58.

The final set of heaters to turn on were at the aft end of the telescope (i.e. the two aft feet, H1 and H2, and the rear cover, H4). These heaters came on between MET 2/13:44 and 6/08:09. On Astro-1, these turned on between 01/14:17 and 01/21 :20. It is not understood why H2 came on nearly 4 days later than H1. Since this is near the WUPPE Electronics, perhaps the delay was due to radiative heating from there.

Only one of the four thermostatically controlled heaters has a temperature sensor output associated with it. The Camera Control Unit is mounted on the outside of the forward section of the ECC. Its temperature fluctuated between a high of 29ºC shortly after turn-on to a low of 11ºC. At 14/22:30 the TV camera was turned off and the CCU temperature dropped exponentially from 20ºC to 2.2ºC, which was the last available reading. The heater did not come on in survive mode. The small current drawn by the other three thermostatically controlled heaters is difficult to read when compared to the other much larger heaters, but can be measured when run alone. It was derived from this method that these heaters were used during the mission.

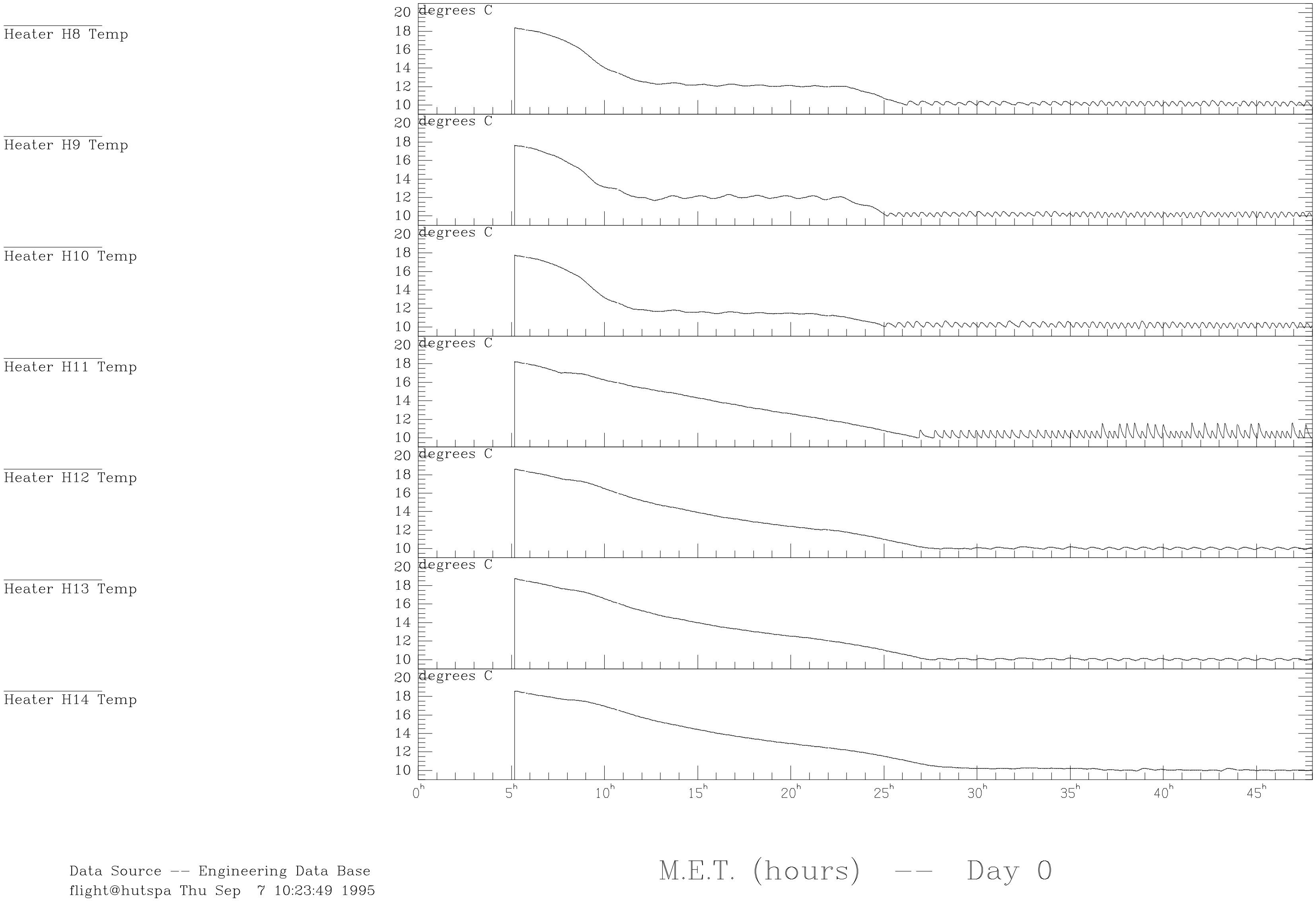
The camera head temperature was at 19.5ºC at turn-on and rose exponentially to 25ºC over a period of 2 hours. It then fell to ~16ºC over a period of 36 hours and fluctuated between 15.1ºC and 17.5ºC for the remainder of the mission. In the hour following the turn-off of the camera, the camera head temperature fell 3.8ºC.

The Reticon Control Electronics was at 16.2ºC when the system was powered on and increased to 29.2ºC over the first two hours. It then drifted down to 22ºC over the next 30 hours. The temperature remained in the range from 21.0ºC to 22.9ºC for the remainder of the mission.



Data Source -- Engineering Data Base
flight@hutspa Wed Aug 9 16:15:29 1995
hutstar.flight 061:06:38:13

Temperatures of Heaters 1-7 for First 48 Hours



Data Source -- Engineering Data Base
flight@hutspa Thu Sep 7 10:23:49 1995
hutstar.flight 061:06:38:13

Temperatures of Heaters 8-14 for First 48 Hours

10.6 Temperature Trends - Electronics Module

The EM was bolted to the Integrated Radiator System (IRS). The EM heater, H15, which was mounted on the baseplate of the EM, had fixed setpoints of -8ºC (on) and -2ºC (off). H15 did not activate during the mission. The baseplate temperature started at 20ºC and fell gradually to 2ºC by MET 01/00:00. It fluctuated between -1ºC and 8ºC for the remainder of the mission. The EM baseplate temperature was the only temperature that appeared to have variations with the orbital period. Variations of 3ºC to 4ºC peak-to-valley with 90 minute periods occurred throughout the mission.

The EM circuit board temperatures tended to follow the baseplate temperature. The Command Relay Module, Converter #1, and Converter #2 all remained within about 3ºC of each other and 2ºC to 4ºC above the baseplate. The inverter generally was about 1ºC lower than the baseplate, and generally was the coldest temperature measured on the instrument.

The DEP and SP temperatures were nearly identical and remained about 28ºC to 29ºC above the baseplate. These temperatures, which were the hottest measured on the instrument, peaked at 43ºC one hour after turn-on.

10.7 Temperature Gradients

The maximum temperature gradient specification for the metering cylinder was 7ºC longitudinal and 4ºC circumferential. The maximum longitudinal gradient was 4ºC prior to the metering cylinder temperatures reaching the set point and 0.5ºC after all of the temperatures reached the set points. The maximum circumferential gradients were 1ºC and 0.3ºC, respectively, before and after the temperatures reached the 10ºC set points.

The requirements for the spectrograph longitudinal and circumferential thermal gradients are 1.0ºC and 0.7ºC, respectively. The location of the H11 through H14 temperature sensors did not provide true spectrograph longitudinal thermal gradient information since they are located on the spectrograph cylinder (H12-H14) and the rear face (H11). An indirect measurement resulted in a maximum 1.5ºC longitudinal and 0.3ºC circumferential. Exceeding the gradient specifications could result in a degradation of the focus and/or a shift in the wavelength location in the detector as detailed at the end of §5.7. Neither of these temperature-induced conditions were evident in the data.

10.8 Heater Bus Power

The maximum current drawn on the heater bus during the mission was 9.36 amperes. The average current is difficult to judge from the plotted data but a good estimate is approximately 2.9 amperes while the doors were open. For five small aperture observations where the main doors were closed, the average heater bus current was 2.3 amperes.

11. Software Performance

11.1 DEP and SP Performance

The Dedicated Experiment Processor (DEP) and Spectrometer Processor (SP) performed virtually flawlessly during the Astro-2 mission, as the few anomalies which occurred were either corrected by system redundancy or had no operational impact. Both the DEP and the SP were powered up and loaded at the beginning of the mission, and ran continuously throughout the mission until powered off at the end of the mission. There were no crashes, resets or MMU reloads. Section 11.2 below describes the software anomalies that occurred and their resolution.

11.2 Anomalies

11.2.1 Scan Count Low Errors

On two occasions during the flight, the "HSP>SCAN COUNT ↓" error message was received while the Spectrometer Processor was in high time resolution mode with the detector off. This is caused by a software error that allows these messages to be generated erroneously in some cases; there are no other adverse effects besides the incorrect error messages.

The problem occurs in the performance monitoring software that checks for reticon scan counts too low (< 1900 scans per 2 seconds). In high time resolution mode, the SP sends periodic histogram messages to the DEP once per minute in addition to the regular high time resolution messages every 2 seconds. The DEP software was designed to check the scan counts in the regular high time resolution messages but not in the periodic histograms, which may not cover exactly one 2 second period. However, the checking code does not lock the SP data buffers, with the result that the data can be updated during the checking process. Specifically, the DEP software can read the SP message type as "high time resolution", but a periodic histogram can then be received before the software checks the scan count. As a result it tests the scan count value from the periodic histogram, producing the error message.

This error condition is caused by the software's failure to lock the SP data buffers while checking the scan count value. It is very infrequent due to the small time window during which an incoming periodic histogram message must arrive to create the symptom. The problem had no adverse effects other than operator inconvenience, and did not affect the science data.

11.2.2 Inverted Spectrum on Video

Several times during the flight, while observing bright targets using video mode "spectrum" or "down spectrum", the science histogram on the video display suddenly became inverted. The normal display has the baseline at the bottom of the display, with spectral lines extending upward to a maximum of 1/4 of the display height. When the problem occurred, the histogram display had its baseline at the top of the display, and the spectral lines extended downward. Clearing the histogram through the Payload Specialist or ground command corrected the histogram orientation.

The source of this problem was the software that generates the histogram display on the video image. The routine that rescales the histogram values to fit within 1/4 of the screen produced a division by zero if any histogram display bin not in a pre-defined airglow line saturated with a value of 65,535. The resulting division operation produced negative length values for the vertical segments making up the histogram display, which wrapped around the bottom of the display and appeared on the upper 1/4 of the display.

Since this was a problem with the display software only, it did not affect the science data in any way. When the cause of the problem was discovered, the question arose as to why the same problem was not observed during Astro-1, since the errant software routine had not been changed between missions. The reason for this is that during Astro-1, HUT was not sensitive enough and the on-target observing times were not long enough to saturate a non-airglow spectral line!

11.2.3 Doubled Scan and Photon Counts

During several observations of faint targets, the photon count and scan count reported with the Spectrometer Processor data would simultaneously double for 2 seconds, then return to their normal ranges. This behavior repeated periodically, sometimes as frequently as every 5-10 seconds. Immediately after the quit for each affected observation, the anomalous behavior ceased.

The cause for this problem was traced to an interaction between the DEP software that reads data from the SP and the software controlling video image acquisition. Both routines use a common database, and the image acquisition routine locks access to the database while it acquires each image. For short TV camera exposures this presents no problem, but for exposures of more than 2 seconds the SP data communications routine is locked out long enough to miss an SP data collection cycle. Two seconds later, the DEP reads the next set of SP data, but it represents two collection cycles and therefore the scan and photon counts are doubled.

The only TV camera magnitudes that use an integration time of more than 2 seconds are magnitudes 19 or 20, which were in use whenever this problem was observed. The problem had little or no impact on science data since the histogram accumulated continuously without loss of data. All recorded occurrences of the anomaly were in histogram mode; in high time resolution there would be a chance of losing some high time event data due to filling the buffer before the end of the double-length data collection period.

11.2.4 Memory Parity Errors

The DEP recorded 5 parity errors during the mission. The first three errors all occurred within a 10 second period as the orbiter approached South America over the Pacific Ocean, but clearly before entry into the South Atlantic Anomaly (SAA). The fourth error occurred squarely in the SAA, while the fifth happened several hundred miles off the east coast of Florida, 10 hours after the previous SAA passage and almost 2 hours before the next. For what it's worth, the parity errors occurring outside the SAA roughly outline the areas of El Niño and the Bermuda Triangle. The time of the parity errors and the nearest SAA is shown in table 11-1.

GMT	MET	Closest SAA	Time From Closest SAA
068:16:07:05	07/09:28:52	07/09:36 - 9:50	0:07
068:16:07:11	07/09:28:58	"	0:07
068:16:07:15	07/09:29:02	"	0:07
070:12:22:04	09/05:43:51	09/05:36 - 05:56	in SAA
073:00:42:52	11/18:04:39	11/19:54 - 20:03	1:50

Table 11-1

The DEP's redundant memory system detected and corrected these errors, and operation continued unaffected. This observation of 5 soft errors during the 16 day mission is well within the range of predicted errors. It was expected that a higher fraction of the soft errors would occur in the SAA, but the small number of errors do not provide enough statistics to draw any firm conclusions. This is especially true since the three that occurred together could have been caused by the same radiation event.

For example, if the errors occurred virtually simultaneously, but in the backup memory or in cells of the main memory that are not frequently accessed by the main program, they would only be revealed by the memory "scrubber" process. This process uses all otherwise unused CPU time to read and refresh all random access memory, thus forcing a parity check and hardware error correction if necessary. Since the scrubber process runs at the lowest priority in the system, it is easily possible that it would take 10 seconds to cycle through the entire memory space, especially during video processing. This could cause a 10 second delay between reports of errors that actually occurred at the same time.

Due to Astro-1 experience (only 1 DEP parity error during the entire mission), and data from other satellites which provided improved SAA models, the Spectrometer Processor was operated through most SAA passages without hibernating for most Astro-2 observations. Since the SP only detects and corrects errors during hibernation, it was commanded to hibernate several times during the mission to correct possible accumulated errors. The SP does not report any single errors that it is able to correct, so it is impossible to know whether the SP had any single parity errors. However, the fact that it always returned from hibernation indicates that no more that one parity error ever occurred between hibernations.

12. Mechanical Structure

The mechanical structure of the instrument apparently was again adequate for the task. The only noticeable change between the preflight and flight conditions was a slight difference in the focus of the TV camera. However, this could be from any number of factors that are not necessarily related to the mechanical structure of the instrument. None of the flight data indicated any other changes. Post-flight inspection of the instrument also indicated no problems.

Note that a stress analysis prior to Astro-1 showed that the bolts that mount the forward baffle section and the door deck to the Forward ECC were only to be used for a single flight. These bolts were replaced prior to flight with equivalent hardware. They would need to be replaced again for another flight.

13. Mission Operations

13.1 POCC Operations

The HUT area of the POCC was nominally staffed by 11 persons. Of these, six were scientists, four were engineers or programmers, and one was administrative support. This document concentrates on the work done by the engineers and programmers.

For Astro-2, three 8-hour shifts were implemented to support mission operations, as opposed to the two 12-hour shifts utilized during Astro-1. The decision to work three shifts was based on the experience from Astro-1, when personnel became noticeably tired toward the end of the mission. Because Astro-2 was to be a significantly longer mission, the situation would be even worse. However, staffing three shifts was not a simple task, as 33 people are not normally required on the HUT team to support pre-mission activities. To overcome the staffing shortage, more graduate students were trained for POCC duty, four guest investigators joined the POCC team, personnel were cross-trained for different positions, and the duties of two positions were covered by one person on some shifts. Two engineers from KSC and one from MSFC were able to join the HUT engineering team at the POCC; all three had been involved with HUT prior to the mission in some capacity. The pre-mission simulations at MSFC were invaluable in training the HUT team for POCC operations, particularly those with no Astro-1 experience, and for resolving many of the issues related to supporting three shifts during the mission.

The duties of the engineers and the programmers were to monitor, troubleshoot, and fix all of the flight and ground-based hardware and software. One instrument engineer provided support to the air-to-ground lead with current and upcoming operational issues, and kept the engineer's flight operations log. The other instrument engineer monitored and logged the currents, voltages, and temperatures available in the telemetry, kept the engineer's timelines and as-run target book up-to-date, and gathered data needed for troubleshooting activities. The software engineer was responsible for uplinking ground commands, troubleshooting flight software problems, and resolving questions about flight software functioning. A programmer monitored the ground support hardware and software, tracked the real-time and playback downlinked data flow, and was responsible for recording and archiving the data onto disk and tape.

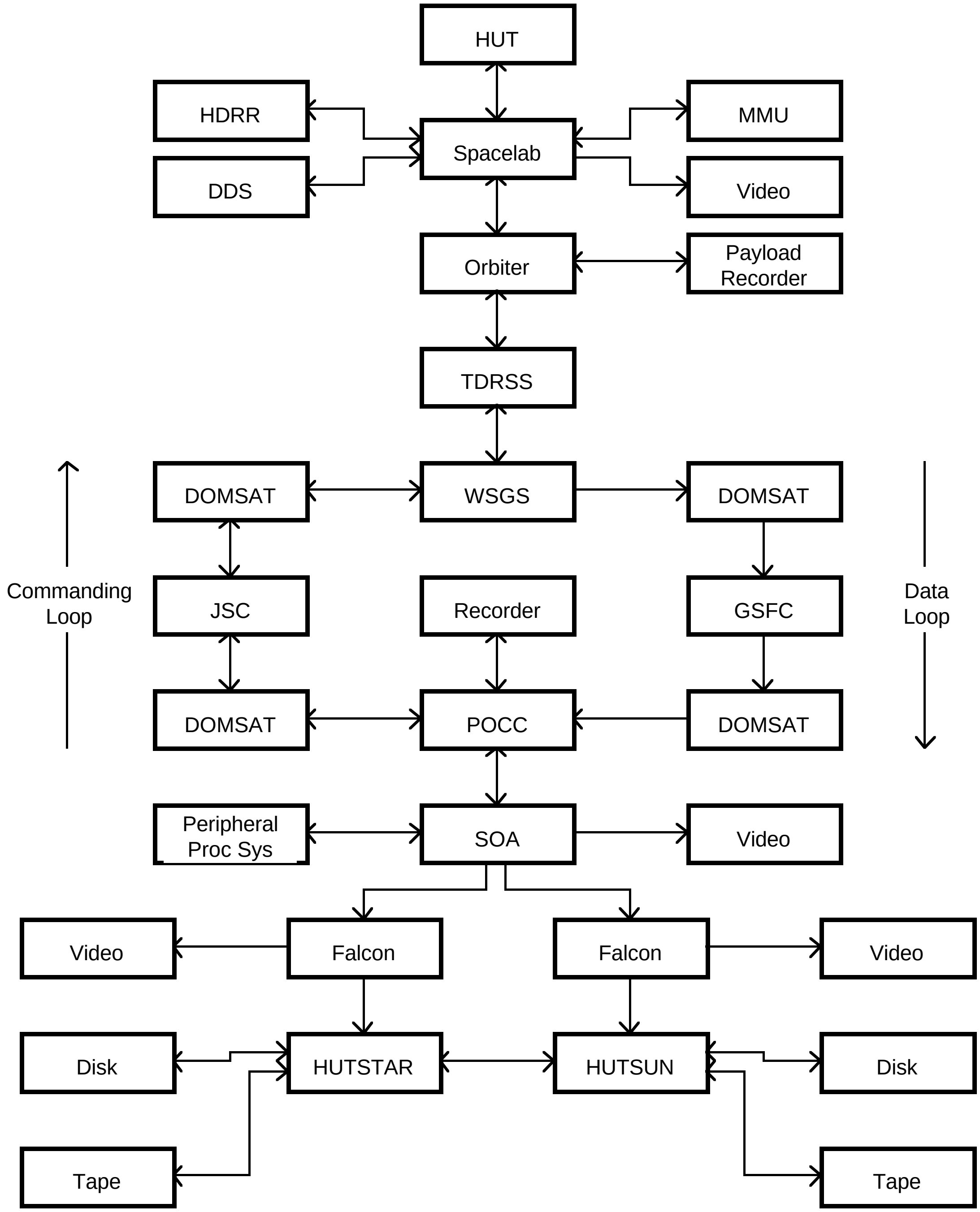
The level of technical staffing for the mission was adequate. Because there were so few real instrument problems, the engineers were not heavily taxed at all times; however, there were periods which required all the available engineering personnel. Three shifts made it more difficult to keep track of issues from shift to shift, but the benefit of more time away from the POCC more than compensated for this difficulty. At least for the engineering team, fatigue was not a problem during Astro-2.

13.2 Ground Support Hardware

The major elements of the Astro command and data loop are shown in figure 13-1. During

HUT Astro-2

Commanding & Data Block Diagram



Astro-1, both orbiter DDU's failed and the ground command loop became the single method available for commanding the instruments and Spacelab subsystems. Originally intended only for occasional use, it proved critical to the success of the mission.

Based on the Astro-1 experience, ground commanding was utilized as an integral part of the instrument operations for Astro-2. In general, the payload crew handled the normal flow of science observations and were responsible for keeping the instrument operations on the planned timeline. This involved configuring the IPS and the instruments for the upcoming observation, performing target acquisitions, and starting and stopping observations according to the timeline. The POCC, through the ground command loop, was responsible for last minute changes to instrument configurations, real time changes during an observation, and many of the special procedures unique to individual observations. The POCC also helped to lighten the command load on the crew during very busy times, in particular during initial instrument activations and while performing troubleshooting procedures.

Sharing the commanding responsibilities in this manner worked very well for Astro-2. Astro is a very command-intensive payload, and the dual command loop capability added both flexibility and redundancy to the instrument operations. The flexibility helped to maximize the observing efficiency of the instruments, which in turn increased the science return from the mission. The commanding scenario used for Astro-2 was probably the most operationally efficient available, taking good advantage of the capabilities of both the payload crew and the POCC.

The command and data system at the POCC consisted of the MSFC-provided peripheral processor system and the JHU-provided telemetry and ground support equipment (TEGSE). The peripheral processor system produced data that was mainly used to mimic the payload specialist displays. It was also used to do all ground commanding of the instrument. Many custom-made displays were produced for this system, but few were used during the flight. Those that were used involved data that was not available in the HUT HRM data stream, such as other instruments' pointing errors and Spacelab subsystem telemetry.

The TEGSE comprised two parallel data paths. Each path consisted of a telemetry processor (FALCON) and a Sun Microsystems computer. The FALCON decommutated the raw telemetry data, transferred it to the Sun over an 8-bit parallel DMA link, and generated RS-170 video output from the digitally downlinked HUT images. There were two Sun computers, HUTSUN and HUTSTAR, both SPARCstation 2's. Each Sun had a console and several terminals, through which different POCC positions could access the data simultaneously.

There were two reasons for having parallel data paths. First, data came from two sources (live and playback) because of the TDRSS coverage during the flight. Coverage was limited at times by the orbit, the shuttle attitude, and other high priority TDRSS customers. During TDRSS Loss Of Signal (LOS) periods, data was stored on the shuttle in the High Data Rate Recorder (HDRR) or the Payload Recorder. These data would then be dumped to the ground during Acquistion Of Signal (AOS) periods while live data were also downlinked. A FALCON/Sun combination could only handle one data stream at a time, so two systems were required. One system, HUTSTAR, was used to collect live data. This was the system the engineers used to monitor the telescope's condition. The second system, HUTSUN, was used to collect playback data. It was also used by the astronomers to monitor the quality of the data that was gathered. The second reason for having two systems was to have a backup. HUTSTAR was the primary real-time system, but if HUTSTAR failed, HUTSUN could be reconfigured to process the live data stream in just a few minutes.

Each data path also had the ability to save and archive the data that came in. Each Sun computer had 600 MB of hard disk space reserved for storing HUT data. Each system also had an 8 mm Exabyte tape drive. When the disk space became full, it was archived to 8 mm tape for future use. This was important because it provided the scientists with data immediately after the flight. The SpaceLab Data Processing Facility at MSFC provided a complete archive of the HUT data. This was delivered on CD within three weeks of the flight but the data was in a binary format that needed to be processed into a format usable by the scientists. This data was not available in a readable form until several months after the flight. The initial scientific results were derived from the data archived by the TEGSE.

The software for the TEGSE was written by many different people at JHU. This software processed the data stream, saved the data to disk, and archived the data to tape. The rate at which the data were saved to disk was controlled by the software. The Suns were able to save data to disk at the real-time rate of one data frame every two seconds with no loss of data. At the 2 second save rate, disks would fill up and require archiving every 24 hours.

The TEGSE software also created displays with which the engineers could monitor the instrument. It created log files of the engineering parameters and the commands, so that the engineers had access to a full history of the flight at all times. It also provided the capability of plotting engineering parameters over time. Overall, this software proved to be very valuable for real-time instrument health monitoring, and for troubleshooting the few problems that did arise.

13.3 Mission Documentation

The HUT engineers made use of many of the documents that were produced by JHU and MSFC. These included several volumes of the Payload Flight Data File (PFDF), the HUT Engineering Manual, the DEP Software Requirements Document, various available timelines, and the HUT Engineering Logbook.

The PFDF documents used by the engineers included the HUT Payload Operating Procedure, the Joint Operations (JOPS) Payload Operating Procedure, the Payload Systems Handbook (PSH), the Joint Operations Target Procedure Book (JOTP), the Target Book, and the Payload Crew Activity Plan (PCAP). The HUT and JOPS Payload Operating Procedures were used during activation and troubleshooting activities to follow what the payload crew was doing. The malfunction procedures were not heavily utilized due to the lack of problems encountered, but the few that were executed worked as intended. The PSH was referred to several times during experiment safing and recovery procedures associated with water dumps and a leaking RCS jet. The JOTP Book and Target Book were essential in preparing for upcoming observations and in keeping track of the current observation. The Target Book pages were produced by JHU, for the most part prior to launch. The JOTP pages were updated and reissued by the MSFC File Manager throughout the mission, in synchronization with the twelve hour replan cycle. This was necessary due to constant revision of existing target procedures that occurred as targets were replanned and as the instrument operation was better characterized. The PCAP is discussed later.

All of the PFDF documents mentioned above were extensively revised for Astro-2, updating and expanding the information contained in the Astro-1 versions, and bringing formats into conformity with JSC standards. For the most part, these revisions aided the engineers in supporting the mission. MSFC did an excellent job in producing these documents, and there are no suggested improvements from the HUT engineering team.

The HUT Engineering Manual was produced by the JHU engineering team prior to Astro-1, and revised for Astro-2. It is basically a hardware manual for the instrument to aid in troubleshooting and understanding systems issues. It was not utilized heavily during the mission, as there were very few HUT problems to diagnose. It did prove to be a useful reference for the non-JHU engineers who supported the HUT team in the POCC.

The DEP Software Requirements Document was produced by the JHU/APL software team early in the history of the HUT program, and was updated to revision F for Astro-2. This revision incorporates the changes made to the DEP software since Astro-1, as described in §3.3 of this document. The engineers made extensive use of this document in preparing for the mission, and during the flight it was used to validate uplinked commands and to gain insight into software/hardware interactions not observed during ground testing.

The various timelines, such as the PCAP and the JHU-produced LIMBRAM, were useful in preparing for upcoming observations. The engineering group referred to both the PCAP and the LIMBRAM constantly. The biggest problem with the timeline documentation was the lack of accurate TDRSS coverage information. Although this could not be helped, it was a hinderance to the POCC's ability to support mission operations.

The HUT Engineering Logbook was used to record nominal operations, problems, and test results in a structured form. It was valuable in helping the transfer of information during shift changes, which was very important due to the use of three shifts for Astro-2. In addition, it provides a useful record of on-orbit operations from the HUT engineering team's perspective, as well as documentation of all HUT instrument problems encountered and their resolutions through the end of mission.

13.4 Mission Timeline

The official timeline (the PCAP) prior to launch covered only activation (MET 0/00:00 -

1/00:00), IPS stow checks (13/06:00 - 13/12:00), and deactivation (14/18:00 - 15/18:00). All other periods were blank, due to the extensive amount of replanning anticipated for any shift containing science observations. PCAP's for the blank periods were uplinked on a shift-by-shift basis during the mission in synch with the replan cycle.

Activation was hampered early on by problems getting the DDS's activated. Because both the instruments and the IPS require heavy commanding during the activation period, this caused the mission to fall behind the timeline. To make up time, some functional objectives (FO's) were completed by ground command, a few non-critical FO's were deleted, and others were postponed to later shifts. By the end of the first day, the mission was about three hours behind the nominal timeline.

Science observations began on the second day of the mission. Problems were encountered with the initial target acquisitions, however, and much of the early science data was missed. The problems were mostly the result of the steep learning curve of the IPS on-orbit, and a great deal of effort was applied to understanding and optimizing the IPS acquisition procedures. By the end of the second day, the problems had mostly been ironed out and observations were proceeding in a routine manner on the timeline.

The engineering team was not involved in replanning activities, except to check upcoming target procedures for instrument safety issues and to alert the replanners of any instrument conditions which could have an impact on future observations. A complete set of target procedures for the upcoming (12-hour) shift was distributed every replan cycle, and this made it much easier for the engineers to keep track of the replan information. One engineer was responsible for reviewing the updated procedures, and highlighted all steps involving HUT in each procedure. The reviewed and highlighted pages were then incorporated into the as-run target book, which the air/ground lead and engineers relied on for up-to-date information about the current and upcoming observations. The only shortcoming was that there was usually not enough time for a thorough review of the updated procedures before the final target pages were generated, but this was due to time constraints the file manager was under in order to generate the updated pages in time to uplink to the crew for the next shift. There was always time to review the procedures before the next shift, however, and any changes could be easily implemented in real time using Target Update Forms. From the engineers' perspective, the replan system worked very well.

14. Status of HUT for Reflight

If HUT is to be reflown as part of an Astro-3 mission, a moderate amount of rework and testing will be required. This amount would generally increase the longer the interval between flights. The single unknown involved is the effect of time on the spectrograph detector.

14.1 Optical System

The efficiency of the primary mirror coating appears not to have degraded significantly. This is based upon the predicted effective area of the instrument versus the in-flight measured effective area, as well as post-flight testing of the witness mirrors. The reflectivity of these mirrors has fallen 20% at 1608 Å and 10% at 920 Å since they were coated in July, 1993. Most of this decline was in the months immediately following the coating. Although there was little change in the witness mirror present in the mirror cell during the flight, the other witness mirror saw a 20% decline. The placement of these mirrors reflect different environments, however. The witness mirror in the mirror cell is essentially sealed from any direct path to the outside of the telescope. The witness mirror in the Forward ECC is positioned between the front of the Metering Cylinder and the back of the spectrograph. Although this position is somewhat protected from the outside environment by the baffles in the Forward ECC, it is only one rebound from the entrance aperture of the telescope. In attitudes near the RAM constraint, atomic oxygen can reach the surface of this witness mirror by a single bounce from either the baffle behind it or a spectrograph mounting arm. This is not true for the primary mirror, so the degradation noted in the Forward ECC witness mirror may not accurately reflect the condition of the primary mirror.

The television camera could easily be flown as is, provided that it is not left unoperated for any long periods of time. If it can be run the nominal 24 hours every 75 days until the next flight, it should work well. It is currently being maintained using GSE. If the time between flights is years, the camera might also require some tuning adjustment prior to flight. The large star images seen with the instrument, while not desirable, had little effect on the operations during the flight. An adjustment of the TV camera focus would be desirable, although this would require a partial disassembly of the instrument. However, this would not force a telescope realignment and could be accomplished in less than one week.

The condition of the spectrograph is the biggest unknown for a reflight. The degradation in the detector noted prior to and during the flight suggest a steady decline that could require replacement of the detector. This would be a lengthy procedure since it would not only require a complete realignment of the instrument, but also development work on new microchannel plates (MCP). The MCP's flown for Astro-2 were purchased in 1988 from Varian, a company that no longer makes them. Several sets of new MCP's were purchased from two other manufacturers in 1992 for installation in Spectrograph C, but these had poor quantum efficiencies. It is not known where acceptable flight quality plates could be purchased.

Unlike the delay-plagued Astro-1, the internal vacuum ion pumps did not get used excessively for Astro-2. While the first internal vacuum ion pump (VIP #1) has used up 28% of its maximum rated life, VIP #2 is virtually unused. Since previous experience has shown pump failure as early as 40% of manufacturer's rated life, VIP #1 should not be used for extended periods of time. It would be useful as a backup since it showed no signs of aging in operation during the flight.

14.2 Electrical System

There were no failures of any of the electronics on HUT during either mission. The electronics would be ready for reflight immediately. The concern here is if the length of time between reflights is very long. Some of the electronic parts are already 12 years old. Eventually, some will fail due to old age. The best way to check this is to perform a thorough test of the entire instrument while access is still available in case of a problem. The failure of the DEP during the August, 1994, ground test was a cause for concern. However, this was not a part failure due to age, but rather a board failure related to the fabrication method and repeated thermal cycling. In effect, it was an "infant mortality" failure which took years to appear. Replacing the flight DEP with the spare DEP would actually increase the risk since it has not been thermal cycled as often. In addition, the spare DEP was made from components manufactured at the same time as the flight DEP, so the age concern of the components would still be an issue.

14.3 Mechanical System

All indications from the flight show that the mechanical system is sound. The bolts that mount the forward baffle section and the door deck would need to be replaced. This is due to mechanical considerations known before Astro-1, and is described in §12 of this document. When the forward baffle section is removed, the door "closed" telltale that was misaligned on orbit will be checked and adjusted as required. Other than this minor change and what is needed to support any optical or electronic system repairs, no other mechanical rework is anticipated.

14.4 Changes for Astro-3

In the event of another mission, the following changes and enhancements would be considered for HUT:

- Look into reducing the power of the heater at the rear of the spectrograph (H11). This heater appeared to be oversized, which caused the temperature to overshoot.
- Consider putting additional temperature sensors in the front end of the telescope and around the grating end of the spectrograph.
- Consider adding heater and main bus voltage monitors.
- Modify the software to have different lower and upper heater alarm thresholds, and for each temperature sensor to be treated as an individual performance monitor instead of monitoring the

outputs of all 14 sensors as a group.

- Modify the software to clear the histogram when more than 65535 events occur in a single bin so that the displayed histogram will not invert during long exposures.
- Modify the software monitoring of the inverter current to only signal an alarm if the limit is exceeded for two consecutive readings.
- Add a motor to the TV camera focus mechanism to allow independent focusing of the TV camera and spectrograph in flight.
- Modify the software to keep track of the number of detected SP parity errors.
- Consider adding a feature that would report if guide stars are saturated. This would alert the POCC that an increase in camera settings is not desired.
- Consider replacing the mirror positioning pots that showed "dead spots."
- Modify the software so that a BEGIN command would not redefine the guide stars. Redefinition of guide stars should be made a separate command.
- Modify the software to close the slit wheel prior to moving other mechanisms when a QUIT is issued. The detector is the most important component to protect, it should be safed first.
- Modify the software so that a software integration value of 1 does not rescale the maximum pixel value to 15. A value of 1 is only used to automatically save video data.

The amount of time and effort available to perform these changes would be the deciding factor in their implementation. Most of the software changes could be incorporated without impact provided that ground testing is possible for debugging. Most of the hardware changes would require disassembly and subsequent realignment.

It should be emphasized that with the possible exception of the spectrograph detector, the instrument requires no alteration to be ready for another flight. The replacement of the bolts on the Forward Baffle Assembly can be accomplished in a single day, and would require no realignment of the instrument. While the different focus positions of the TV camera and spectrograph were undesirable, they had little impact on the mission.

15. Conclusion

After 2 1/2 years of refurbishment and upgrading, an improved HUT instrument was flown aboard the space shuttle Endeavour as part of the Astro-2 mission. The greatly improved pointing stability of the IPS made possible an observing efficiency exceeding 60%. This, in combination with the extended duration mission, yielded 205 hours of on-target integration time, a factor of five improvement over Astro-1. The improved efficiency of the instrument (more than a factor of two) enabled observations of fainter targets, including the successful observation of the quasar 1700+64.

The engineering performance of HUT was expected to be very good, based upon its performance during the Astro-1 mission. It was known that the design, construction, and testing of HUT were first-rate; however, there was still the potential for many problems, especially in light of the new detector and the near complete disassembly of the telescope during the mirror changeout. Once again, HUT performed exceptionally well. The problems that arose were few in number, minor in nature, and had no impact on the observations made with the instrument.

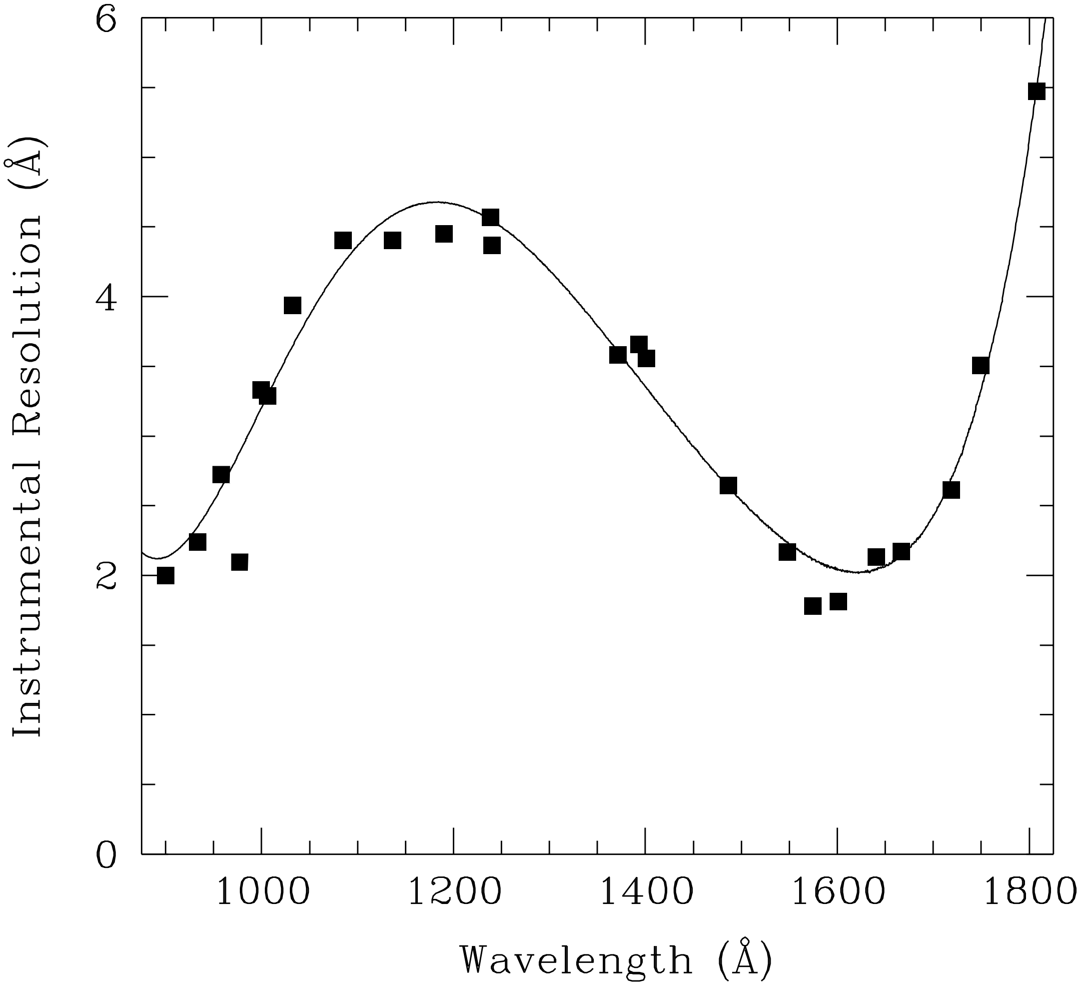
HUT was designed for multiple flights, and the reflight on Astro-2 proved the robustness of its design. HUT has demonstrated its ability to gather valuable scientific data, and it is believed that the instrument could be made ready for reflight in short order.

Appendix A: List of Acronyms

ALT	Alternate (Procedure)
AOS	Acquisition of Signal
APL	Applied Physics Lab
BOS	Bright Object Sensor
CCU	Camera Control Unit
CH	Camera Head
DC	Direct Current
DDU	Dedicated Display Unit
DEP	Dedicated Experiment Processor
EBOS	Earth Bright Object Sensor
ECAS	Experiment Computer Application Software
ECC	Environmental Control Canister
ECOS	Experiment Computer Operating System
EM	Electronics Module
EST	Eastern Standard Time
EXP	Exposure
FO	Functional Objective
GMT	Greenwich Mean Time
GSE	Ground Support Equipment
GSFC	Goddard Space Flight Center
HCE	Heater Control Electronics
HDRR	High Data Rate Recorder
HRM	High Rate Multiplexer
HUT	Hopkins Ultraviolet Telescope
HV	High Voltage
HVPS	High Voltage Power Supply
IPS	Instrument Pointing Structure
IRS	Integrated Radiating System
JHU	Johns Hopkins University
JOPS	Joint Operations
JOTP	Joint Operations Target Procedures Book
JSC	Johnson Space Center
KSC	Kennedy Space Center
LIMBRAM	JHU Generated Time Line Plot
LOS	Loss of Signal
MCP	Microchannel Plate
MET	Mission Elapsed Time
MLI	Multilayer Insulation
MMU	Mass Memory Unit
MSFC	Marshall Space Flight Center
NDF	Neutral Density Filter (Mechanism)

O&C	Operations and Checkout
PCAP	Payload Crew Activity Plan
POCC	Payload Operations Control Center
PFDF	Payload Flight Data File
PSH	Payload System Handbook
RCE	Reticon Control Electronics
RCS	Reaction Control System
RFC	Request for Change
SAA	South Atlantic Anomaly
SAD	Small Aperture Door
SBOS	Sun Bright Object Sensor
SIM	Simulation
SIT	Silicon Intensified Target
SVI	Software Video Integration
SP	Spectrometer Processor
STS	Space Transportation System
TDRSS	Tracking and Data Relay Satellite System
TEGSE	Telemetry Experiment Ground Support Equipment
TT	Telltale
TVC	Television Camera
UV	Ultraviolet
VIP	Vacuum Ion Pump

Figure 1



Instrumental Resolution (Å)
Wavelength (Å)
0
2
4
6
1000
1200
1400
1600
1800

Figure 2

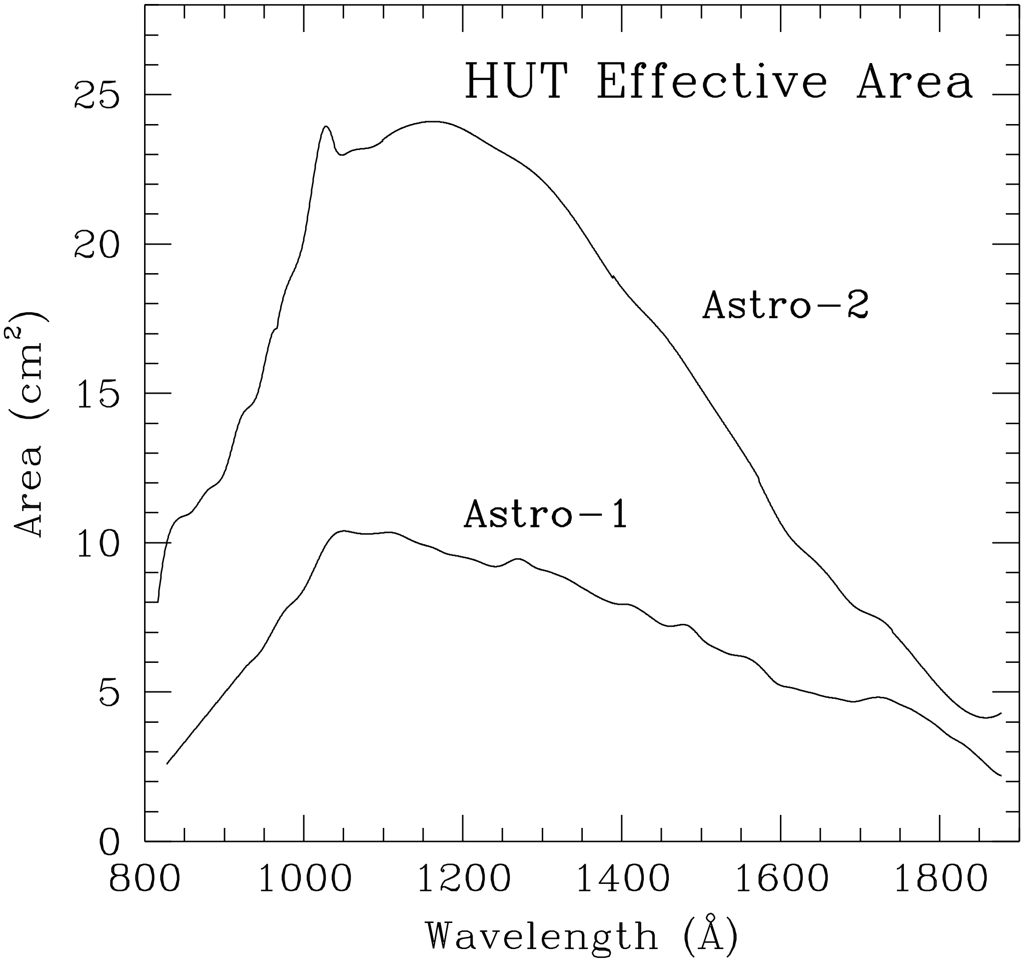
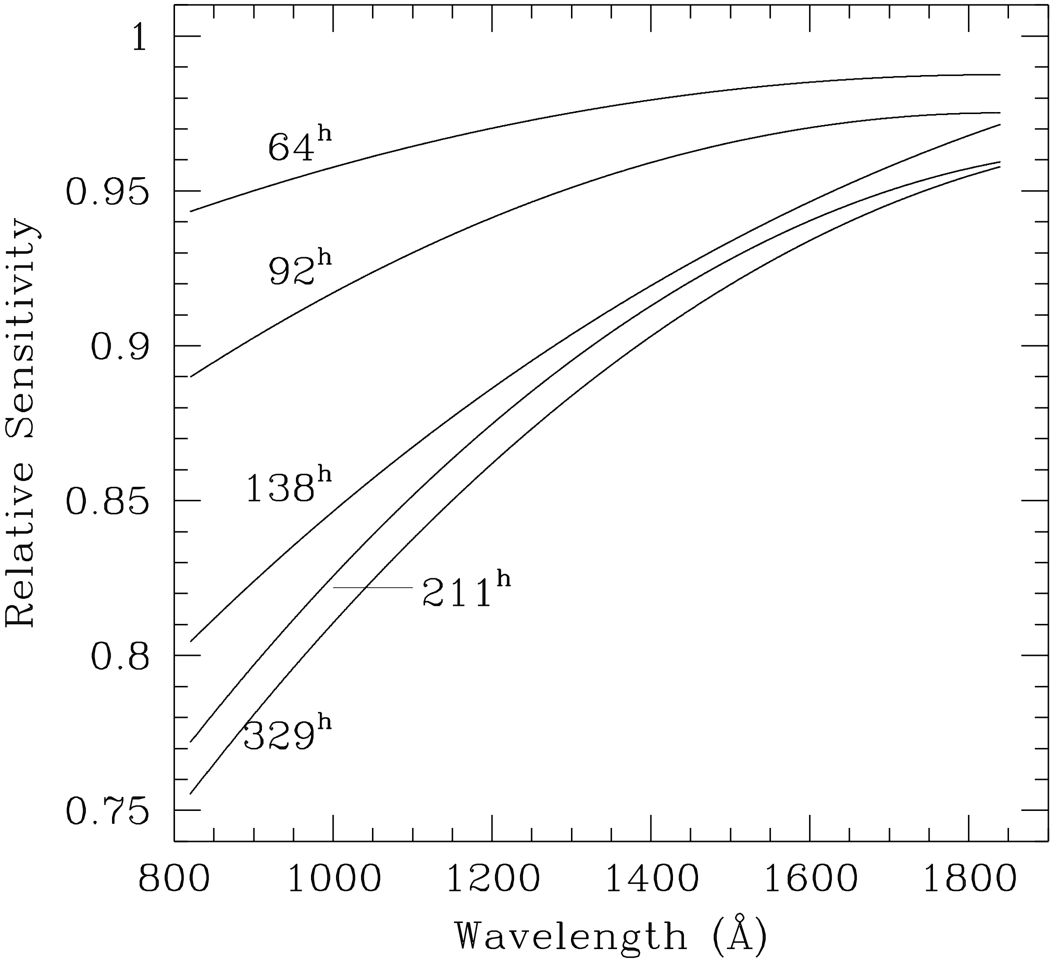

HUT Effective Area
Astro-2
Astro-1
Area (cm^2)
0
5
10
15
20
25
800
1000
1200
1400
1600
1800
Wavelength (Å)

Figure 3



Relative Sensitivity
Wavelength (Å)
1
0.95
0.9
0.85
0.8
0.75
800
1000
1200
1400
1600
1800
64^h
92^h
138^h
211^h
329^h

Figure 4

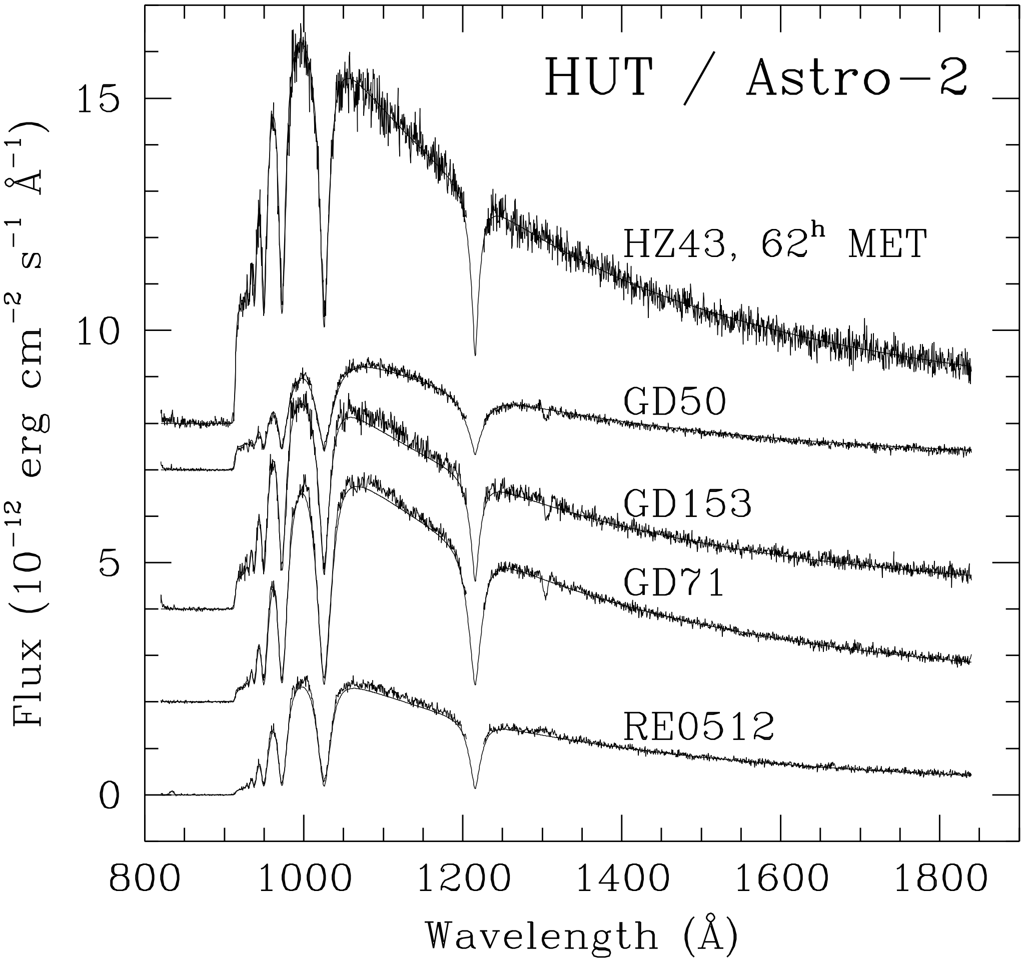

HUT / Astro-2
HZ43, 62^h MET
GD50
GD153
GD71
RE0512
Flux (10^{-12} erg cm^{-2} s^{-1} Å^{-1})
0
5
10
15
800
1000
1200
1400
1600
1800
Wavelength (Å)

Figure 5

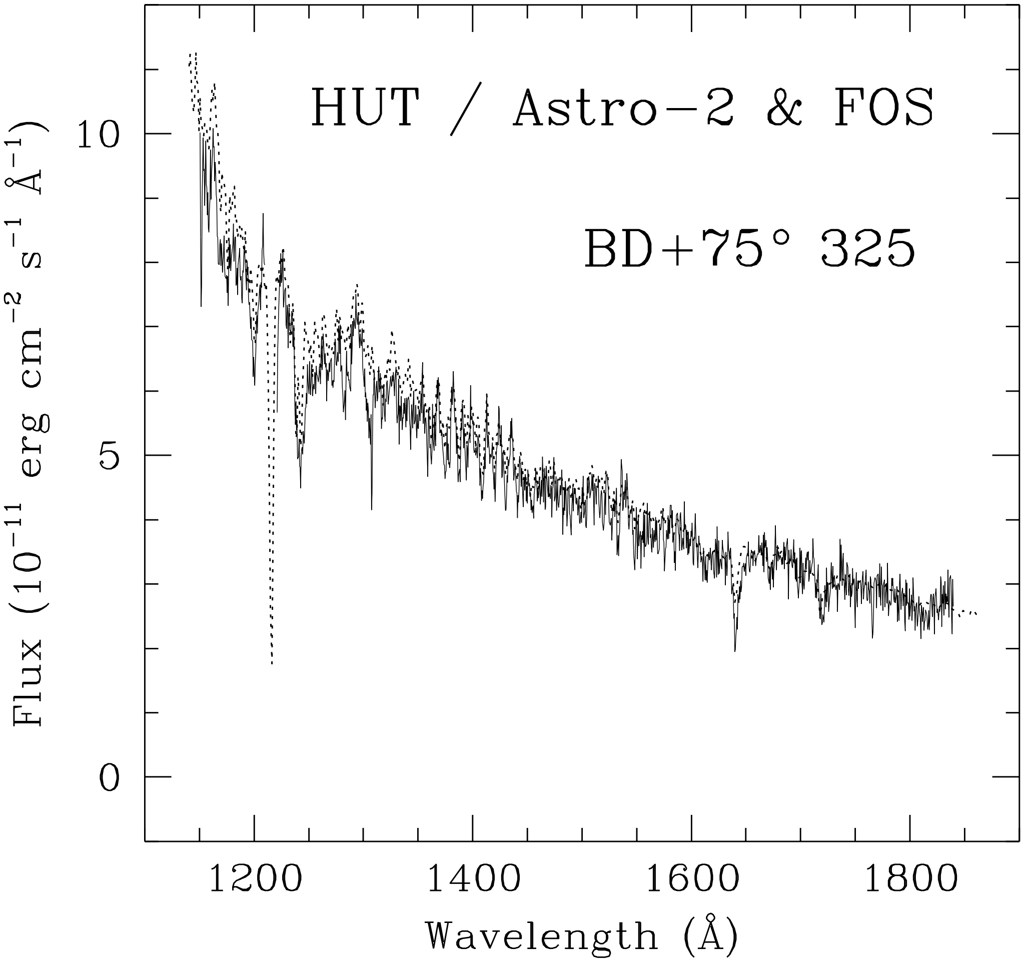
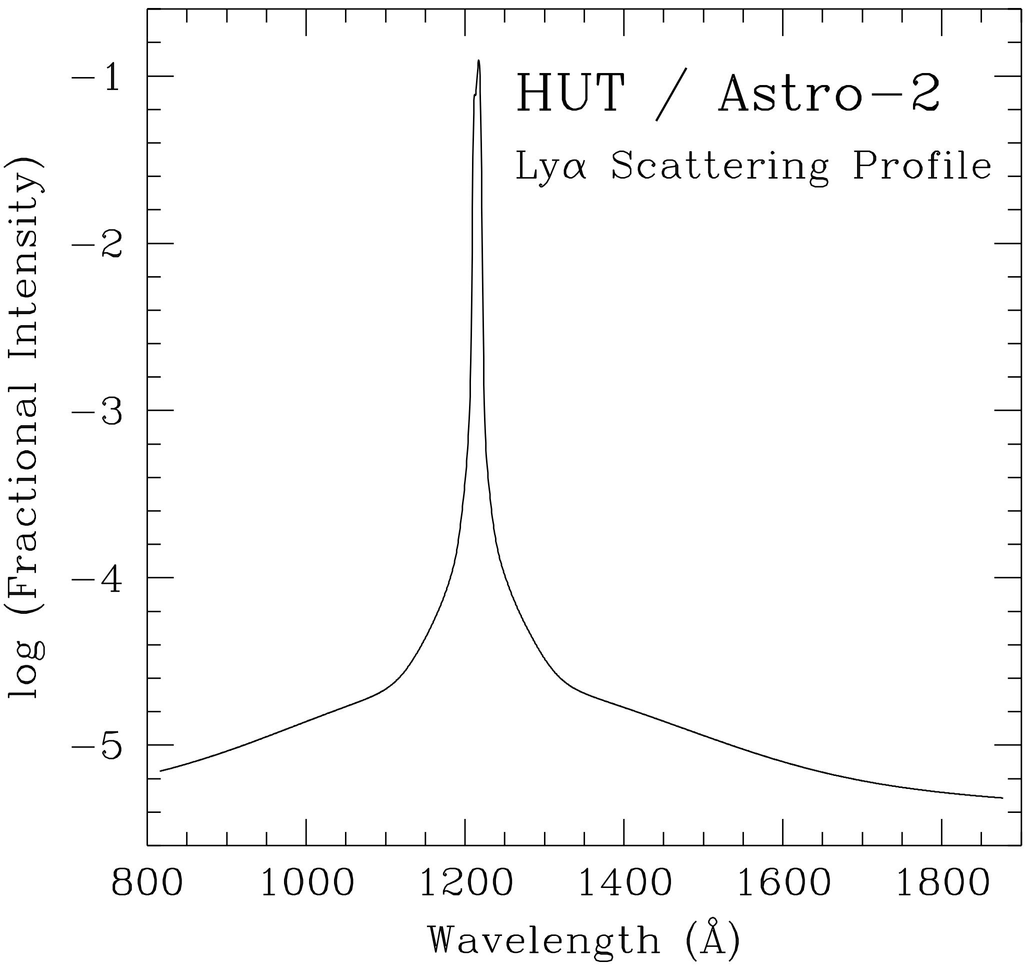

HUT / Astro-2 & FOS
BD+75° 325
Flux (10^{-11} erg cm^{-2} s^{-1} Å^{-1})
10
5
0
1200
1400
1600
1800
Wavelength (Å)

Figure 6


HUT / Astro−2
Lyα Scattering Profile
log (Fractional Intensity)
−1
−2
−3
−4
−5
800
1000
1200
1400
1600
1800
Wavelength (Å)