GALEX Detector
Flight Operations Guide

GAL-CIT-329v6b

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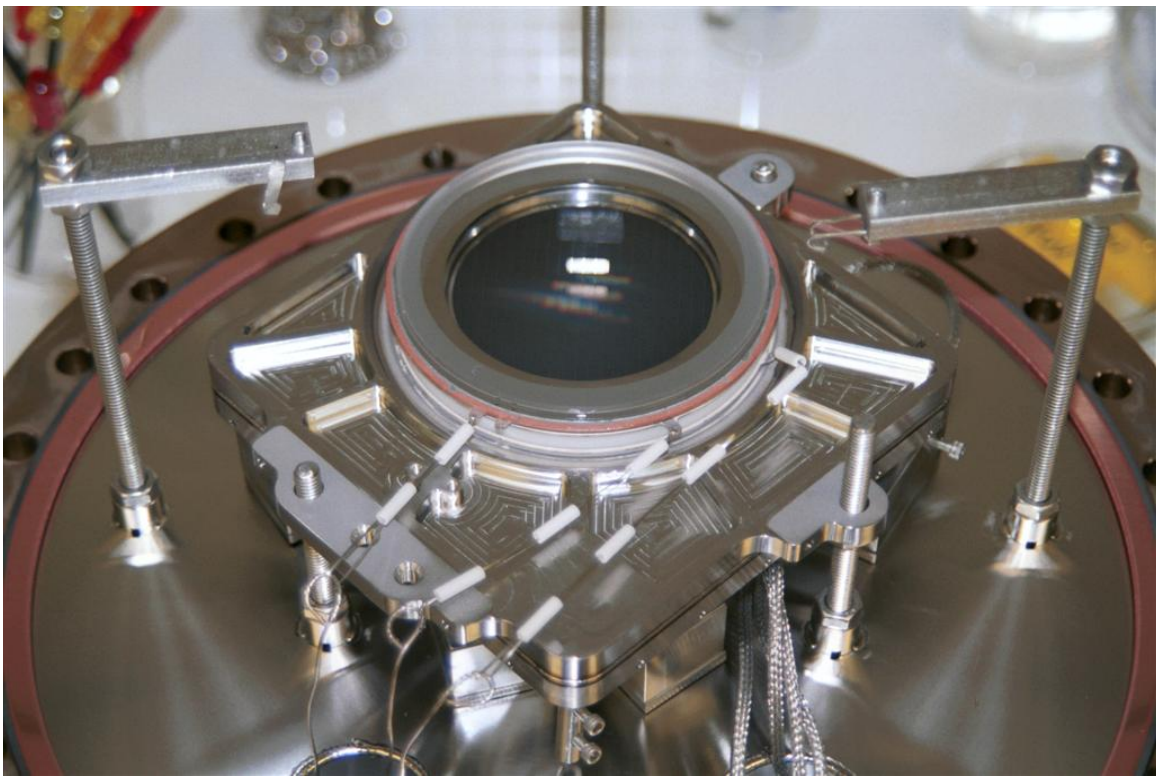

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Contents

1 Introduction

This guide provides a general overview of the GALEX detector subsystem, critical detector parameters, and the procedures required to perform safe operations. The detector system operates at high voltage, is sensitive to very low illumination levels, and may be damaged if proper care is not exercised. The following warnings are an indication of some of the key areas of concern:

- THE NUV DETECTOR IS VERY SENSITIVE TO VISIBLE AND UV LIGHT. CARE MUST BE TAKEN THAT POTENTIALLY BRIGHT SOURCES OF VISIBLE LIGHT ARE REMOVED BEFORE RAMPING THE DETECTOR TO NOMINAL GAIN. SOURCES OF CONCERN INCLUDE: BRIGHT STARS, THE MOON, THE LIMB OF THE EARTH, ETC.
- THE INTERNAL DETECTOR VOLTAGES ARE A FUNCTION OF THE DETECTOR HEAD TEMPERATURE, WHICH MUST BE TRENDED TO VERIFY SAFE OPERATING CONDITIONS.
- THERE ARE FOUR HIGH VOLTAGE STATES FOR THE DETECTOR SYSTEM:

HVOFF:	HVPS output is 0 V.
HVIDLE:	HVPS output is -2550 V.
HVLOW:	HVPS output is $\sim$ -2571 V (NUV), $\sim$ -3670 V (FUV).
HVNOM:	HVPS output is $\sim$ -5200 V (NUV), $\sim$ -6300 V (FUV).

  ANY VOLTAGE LEVEL ABOVE HVOFF IS POTENTIALLY HAZARDOUS WITH REGARD TO LIGHT LEVELS.

The two detector channels are completely independent systems. Either may be initialized and ramped to full voltage independently of the other, with the caveat that the DPU DOFFEN fault protection does not distinguish between the two detector channels. This places a requirement that both FEE channels be powered before enabling DOFFEN protection. In this document, it is assumed for convenience that both systems are being initialized together. In practice, the FEE low voltage is powered together, but high voltage operations (HVOFF to HVNOM) are performed one detector at a time.

2 Hardware Overview

2.1 Detector Heads and Readout Electronics

Each detector subsystem consists of a vacuum sealed, microchannel plate intensified, cross delay line readout detector head (shown schematically in Figure 3) and associated power and readout electronics. The detector heads are actually sealed tubes very similar to night vision image intensifiers. They are manufactured in a high vacuum environment ($< 1 \times 10^{-9}$ Torr) and utilize a small passive “getter” pump that maintains the vacuum environment for the life of the tube. The sealing process has the advantage of reduced vacuum maintenance requirements, however the vacuum of space will not improve the vacuum inside the tubes, which is actually defined by the getter pumps and other internal tube materials.

The microchannel plates multiply each photoelectron (one per photon) by a factor of approximately 10 million. A dual-output high voltage power supply (HVPS) with one programmable (HV_{window}) and one fixed (-900 V) output provides power to each detector head. The resultant charge cloud lands on a delay line anode inside the tube head where it is split and travels to the

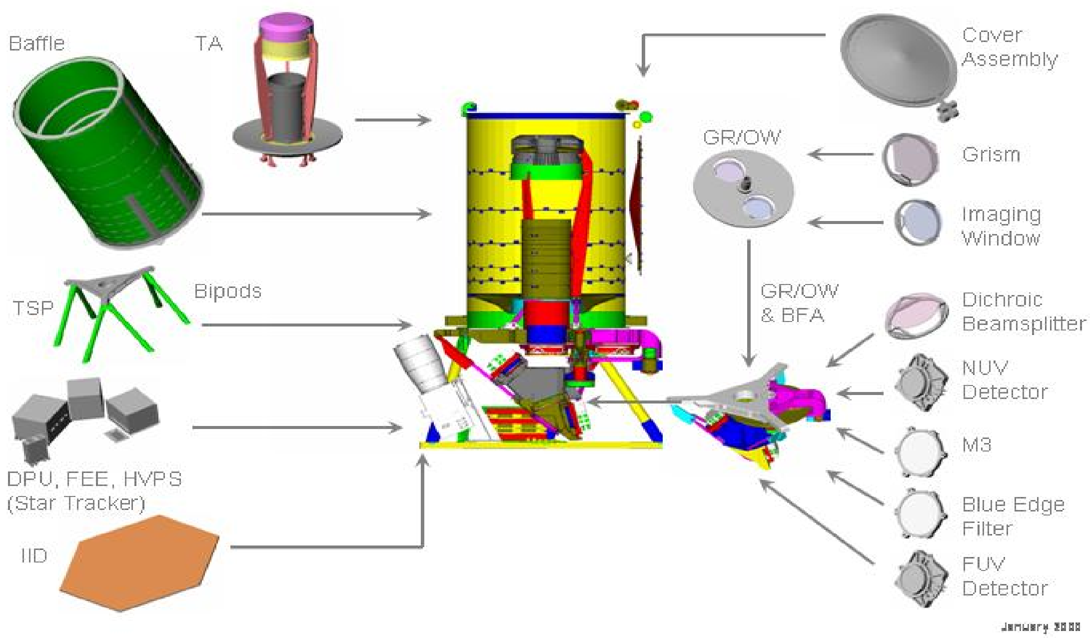

Figure 1: The GALEX Instrument.

Figure 2: The GALEX detector front end electronics, or FEE. The unit is comprised of two identical and parallel readout channels, each containing a low voltage power supply (LVPS), data interface box (DIB), digitizer and digitizer controller.

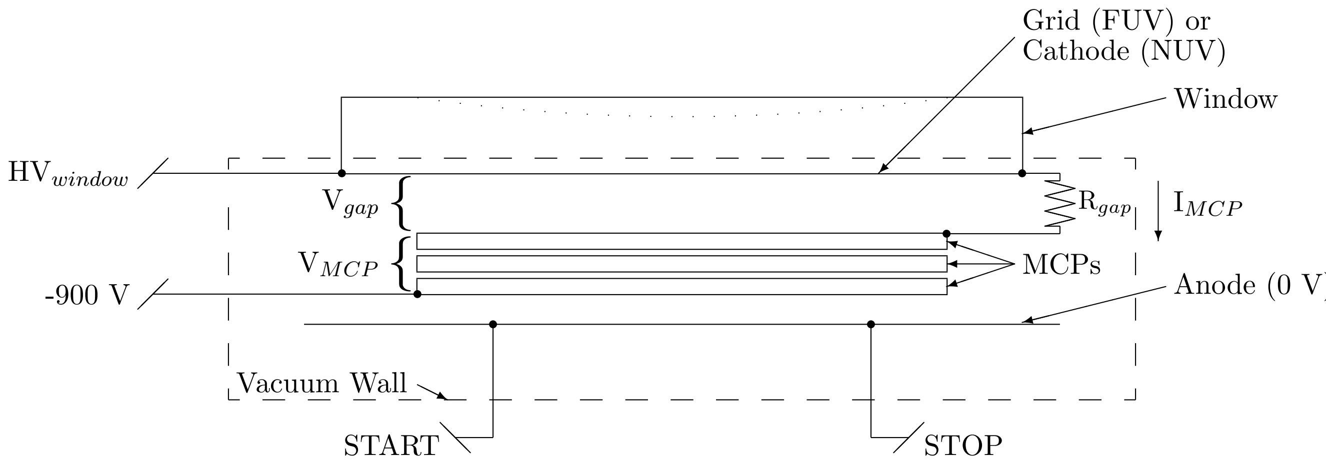

Figure 3: GALEX sealed tube detector head electro-mechanical block diagram. The NUV and FUV tube heads are nearly identical with the principal differences being in the choice of photocathode material (CsI for FUV and Cs_2Te for NUV) and window material (MgF_2 for FUV, SiO_2 for NUV). Also, the cathode material is deposited on the detector window in the NUV channel but directly on the MCP in the FUV channel. Instead of a cathode, the FUV window has a charged grid of wires that enhances the sensitivity of the detector. The other practical difference between the two channels is that the NUV cathode is proximity focused on the front MCP, thus the window-MCP gap in the NUV channel is much smaller (and the electric field at a given voltage much higher) than in the FUV. This difference coupled with the inherently higher sensitivity of the NUV detector to visible light makes operations with the NUV channel significantly more delicate than with the FUV channel.

four detector outputs (2 axes with one output at each end denoted “START” and “STOP.”). By measuring the timing difference at the ends of each axis, the position of the cloud can be determined. At the $\sim 50\ \mu$m resolution of GALEX, the timing requirement on this system amounts to approximately 50 ps! This precision coupled with the 65 mm diameter format of the detectors resulted in an unusual readout design combining a traditional current source-capacitor timing measurement (time-to-amplitude converter, or TAC) with a running coarse clock so that the TAC scale is effectively applied to a relatively small fraction of the anode for each measurement. This approach has led to some unique requirements on the detector data as will be discussed later in this section.

The readout electronics are referred to collectively as the front end electronics, or FEE. These include a low voltage power supply (LVPS), data interface box (DIB), a digitizer and digitizer controller. Preamplifiers for the four delay line anode outputs are mounted directly on the detector head and provide high speed timing signals to the FEE.

The FEE provides a position measurement for each photon in the form of a 40 bit word that contains the following information:

Detector Photon Content

ID	Bits	Description
X_{AmC}	12	X-axis fine position
Y_{AmC}	12	Y-axis fine position
X_B	3	X-axis coarse clock
Y_B	3	Y-axis coarse clock
X_A	5	Wiggle
Q	5	Pulse height

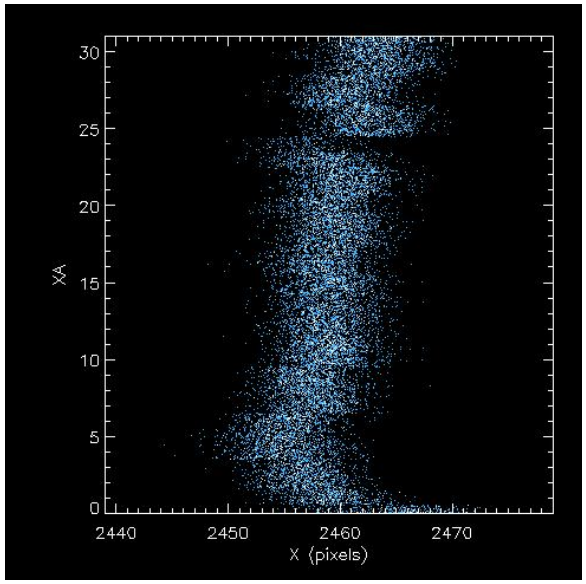

Figure 4: A "wigglegram" for a point source before fine position corrections illustrating errors of order an image-width.

In order to construct a photon position from these data, one would apply the following formulas:

$$X = X_{AmC} + \alpha X_B$$
$$Y = Y_{AmC} + \alpha Y_B,$$

where the constant α is in the range of 2000. In the GALEX design, the coarse clock is free running and the photon positions are measured as they interact asynchronously with the detector. The fine position data represents the fraction of the coarse clock required to complete the timing from the two measurements of a pulse along one detector axis, and the coarse clock is the integer number of cycles during the timing interval. One artifact of this approach is that for a given position on the detector a photon may have any available 12-bit fine position, since the photon can arrive at any time relative to the coarse clock. To further complicate things, the fine and coarse measurements are made independently in each measurement pair, so the values with the "AmC" subscripts are *timing differences* - literally "A minus C" (or "START minus STOP"). This makes it impossible to tell where on each TAC a given measurement was made, and non-linearities in the fine position measurements transform into *blur* rather than spatial distortion. With careful part selection, this "wiggle" in the flight units has been minimized considerably, however one still has the practical problem of reconstructing each photon to its correct location. This could be solved with precise knowledge of scaling for each coarse-bit subset of the data, however we have included 5 bits of X_A, which represents the actual position on the TAC at which each photon measurement was made. This data allows fine corrections to be made to the individual photon positions. A typical wiggle, or X_A, versus position plot is shown in Figure 4. After correction, the variation of X_A with respect to position is minimized.

In addition to wiggle, the pulse height of each photon measurement must be considered. Since the GALEX microchannel plates are large, the gain of the plates varies significantly ($\sim 40\%$) over the field of view. This is due to variations in the MCP chemistry, mechanical variations such as the varying gap between the large plates (which are nominally in direct contact), and statistical fluctuations. The variations in gain affect the position measurement triggering in the FEE and as a result the position becomes a function of pulse height ("Q") in a way entirely analogous to the wigglegram shown in Figure 4. It is worth noting that the offset and scale for each of the four TACs in the digitizer are programmable, as are the thresholds for the timing signals and pulse heights.

After the primary corrections, there remains significant spatial distortion (a product of both high voltage field effects in the tube head and position measurement residuals) and flat field variations. These have proved to be calibratable quantities and are corrected for using look-up tables in the analysis pipeline. Further details of the detector hardware are provided in the Detector to Instrument Interface Control Document (GAL-JPL-303).

3 Software Overview

There are two pieces of instrument software that control the detector system. The primary software runs on the 8051 processor in the DIB and was provided by UC Berkeley. This software is initially loaded from PROM at power-on (version 17217), however a modified version is required for high voltage operations (17257). Its primary functions are to provide a command interface for the DPU, housekeeping (on changes at 1 s intervals), and fault protection. The second piece of software is the DPU code, which boots from EEPROM to version 7.1 but is currently patched to version 7.7.

FEE Code Versions

Version	Description
17217	PROM
17257	Fixes 3 s HK, Improves overcurrent fault response adds #DHVIPER and #DHVIRAT commands

DPU Code Versions

Version	Description
7.1	EEPROM
7.3	Adds HVOFF to PSAFE
7.5	Adds EEPROM checksum monitor
7.6	Turns FEE OFF if $FEC > 0$, $TEC = 0$
7.7	Restores HV to HVLOW after overcurrent Monitors FEC instead of TEC for count rate Adds 5 second delay before power off in the case of high count rate.

3.1 Fault Protection

GALEX has been designed from the beginning to respond autonomously to problems encountered on orbit. This is a requirement for a spacecraft operating in complex conditions with only a few short ground contacts per day. To date, the fault protection has performed very well on orbit in response to a variety of unpredictable circumstances.

The fault response strategy chosen for the detector system was to have the detector respond to every fault it could, and in cases where it couldn't it would request shutdown. Cases that the detector can handle itself essentially include all of the high voltage related scenarios, such as count rate or current exceptions (since the detector can control the state of the high voltage). On the other hand, if the detector senses a temperature out of limit, it has no ability to change the thermal condition and is forced to request power-off. In this latter case, the request is made to the DPU, which in turn interfaces with the spacecraft.

In this section, the detailed fault limits and responses of both the detector subsystem and the DPU will be outlined.

3.1.1 Temperature

The temperature limits for each detector subsystem are set by jpl_detector_setup.scr, included in Section **??**. Only the composite FEE operational limits are defined (0 → 40 °C), but the internal components require a somewhat larger operational range to account for the placement of temperature sensors nearby warm components on some of the boards (particularly inside the digitizer). Note that the warm temperature limit of the detector amplifiers has been set lower than what is actually allowed by design to provide extra protection for the adjacent detector heads. Similarly, the internal FEE temperature limits (DIB, LVPS, Digitizer Controller) are conservative in order to provide double protection for the normally-hot FEE Digitizer board. If a temperature sensor measurement falls outside the specified range, the detector will request a turnoff by the spacecraft (with a non-zero DIB exception). The limits currently uploaded to the detector subsystem by script are:

Detector Temperature
Limit Settings (°C)

	NUV		FUV	
	Low	High	Low	High
Controller	*	45	0	45
Detector Head	0	30	0	30
Detector Amp (A)	0	35	0	35
Detector Amp (B)	0	35	0	35
DIB	0	40	0	40
Digitizer	0	50	0	50
HVPS	0	40	0	40
LVPS	0	40	0	40

The NUV controller limit is disabled to avoid an inadvertent turn-off request from the DIB since the sensor has failed (it usually reads 0xFF, which corresponds to an impossibly low temperature).

3.1.2 Voltage, Current and Count Rate Limits

The DIB software protects the detectors from high count rate, high current, excessive FEE power consumption, spurious high voltage commands and out-of-range DC voltages in addition to the out-of-range temperature protection described in Section 3.1.1. The DC voltages monitored are the TDC -7 V, +15 V and +6 V supplies, the DIB +5 V and +15 V supplies, and the HVPS +21 V supply. If any of these are more than 0.5 V out-of-range, the FEE will request spacecraft turnoff through the DIB exception. The maximum allowable high voltages and currents are uploaded to the DIB as shown in Section 4.1, Item 5. The safing response of the flight software is as follows:

DIB v17257 SAFING RESPONSE

High FEC count rate	DIB issues HVLOW
High FEC count rate at DPU	DPU requests FEE turnoff after 5 seconds
High HV current	FEE turns HVPS OFF after 10 ms
	(DPU restores HVLOW after 45 minutes)
Excessive LVPS Power	Request spacecraft turnoff
Over/Under Temperature	Request spacecraft turnoff
Over/Under Voltage	Request spacecraft turnoff
Command HV>HVMAX	Voltage ramps to HVMAX

The HV current measurement rate (#DHVIRATE) is programmed to 200 samples-s^{-1}, and two consecutive overcurrent samples (#DHVIPERS) are required for a turn-off to occur. Also, the DPU software version 7.7 monitors detector count rates and will request spacecraft turnoff of the FEE if it measures a *fast event* count rate (FEC) above the programmed value. The DPU response of turning off the FEE is not desirable unless there is a serious commanding failure, so the rate should be high enough to avoid a nuisance response (the DPU count rate protection also has a 5 second delay to reduce this possibility). While a global count rate limit of 100,000 cps is perfectly acceptable for these detectors, the operator must be cognizant of the distribution of light on the detector. Isolated hot patches can be bad for the detector. In general, most operations should be performed at or below 10 c-s^{-1}-pore^{-1} (or about 100 c-s^{-1}-spot^{-1}, about M_{AB} 15). The following chart may be useful for determining acceptable exposure times:

HIGH COUNT RATE PREDICTIONS

	NOMINAL	HIGH	
Rate (c-s^{-1}-pore^{-1})	10	1000	10000
Rate (c-s^{-1}-30μm spot^{-1})	50	5000	50000
Gain (estimated)	1×10^7	1×10^6	$< 1 \times 10^6$
Coulombs-cm^{-2} after 1 hour	0.041	0.41	<4.1
Fraction of 0.15 C-cm^{-2} scrub	0.27	2.73	<27.3

In general, if the scrub fraction is of order 1 or greater, we may expect to see permanent gain depression in the detector flat fields. The detectors were life tested at full gain to approximately 2×10^{-3} C-cm^{-2} (1.4% of scrub), and we observed no modal gain depression as a result. For reference, the FUSE program observed approximately 5% gain sag after their calibration, which comprised a 21 day integration at a rate of about 10 c-s^{-1}-pore^{-1} with no dithering. Since the GALEX detectors have been scrubbed approximately 10 times more than the FUSE detectors, we do not expect significant gain sag if we take care to dither the instrument when possible and to keep the count rates generally below 10 c-s^{-1}-pore^{-1}. Based on measurements of the global detector dead time, the DIB count rate protection should always react to high rates before the DPU with the current settings. The DPU also protects against a stuck FEE timer (crashed DIB) or missed commands by requesting spacecraft power-off of the entire FEE through the DOFFEN mechanism, and it has a PSAFE command for various spacecraft anomalies that issues 'HVPWR 0' to the detectors (setting the HVPS output to 0 V) and rotates the optical wheel to the opaque position.

3.2 Detector Software Stress Testing

We have tested the FEE v17257 flight software in an attempt to characterize its response to out-of-limit conditions. For the most part, out-of-limits parameters are filtered by the Maestro system to make them appear *within limits* to the FEE. In other words, if the Maestro system receives a

#DESTIM 1000 command, it actually transmits a #DESTIM 232, which contains just the lower 8 bits required for proper command formation. This feature should not be able to damage the FEE; the only circumstance in which parameters are critical is when they control the high voltage, and in these cases the FEE software has its own error checking code. The following is a list of stress tests and their results using v17257 of the FEE software:

- High Voltage Power Supply OFF, DPU SAFED
  - #DHVPWR: DPU queues command.
  - #DHVLOW: DPU queues command.
  - #DHVNOM: DPU does not queue command.
  - #DHVDAC: DPU does not queue command.
- High Voltage Power Supply OFF
  - #DHVLOW: Command counters increment, no action.
  - #DHVNOM: Command counters increment, #DHVDAC is set to HVNOM level, although no high voltage is applied.
- High Voltage Power Supply at IDLE
  - #DHVLOW: Command counters increment, no action.
  - #DHVNOM: Detector ramps to HVNOM level.
- High Voltage Power Supply at NOMINAL
  - #DHVNM: Detector nominal voltage level is changed, but the actual voltage does not change until the next #DHVNOM command, regardless of whether the new value programmed is larger or smaller. Status bits are also unchanged.
- Attempt to command high voltage above HVMAX level
  - HVLOW > HVMAX: #DHVLOW ramps to HVMAX level and stops.
  - HVNOM > HVMAX: #DHVNOM ramps to HVMAX level and stops.
  - HVCMD > HVMAX: #DHVDAC ramps to HVMAX level and stops.

4 Procedures

4.1 Detector Turn-on and HV Ramp Sequence

This section is provided for general reference and is not intended to replace the detailed detector turn-on procedures listed in Section 10.

1. Turn on the FEEs by running jpl_detector_fee_pwr(BOTH,1) to power the two channels simultaneously (this script also accepts 'FUV' and 'NUV' parameters to power a single channel, and a '0' parameter to turn the FEE off). Verify that the spacecraft bus current rises by approximately 2.4 A (1.2 A per channel). After approximately 30 s, the FEE HK should begin updating. Verify the software version (v17217 is in the PROM). Verify that the temperatures are within the flight operating range as specified in Section 3.1.1 (or if not, verify the trend is in the right direction). In particular, you should monitor the TDC temperature, which is a

good indicator of the temperature of the hottest components in the FEE. This temperature is not allowed to go over 50 °C during normal operations. The detector heads are expected to operate in the range from 18 °C (FUV) → 28 °C (NUV) nominally; the full flight operating range is from 0 → 30 °C.

- *The temperatures in the FEE housekeeping may be evaluated with the following formula to convert the digital housekeeping temperature, T_{HK}, to physical units. This formula is valid to within 0.5 °C from 0→70 °C:*

$$\begin{aligned} T_{^\circ C} &= 112.21 - 0.84494 T_{HK} + 1.4986 \times 10^{-3} T_{HK}^2 \\ &\quad + 8.7346 \times 10^{-6} T_{HK}^3 - 4.1296 \times 10^{-8} T_{HK}^4 \; (^\circ C). \end{aligned} \tag{1}$$

  For example, if you were to read an FEE temperature of 0xA5, then you would insert $T_{HK} = 165$ *into the formula above to find* $T_{^\circ C} = 22.2\ ^\circ C$. *Note that* $T_{^\circ C}$ *goes up as* T_{HK} *goes down!*

2. Upload DIB code v17257 to each channel of the detector subsystem. The detector electronics have two uploadable code spaces, with the default being the lower space. The standard procedure is to upload the same code version to both spaces. The uploads must each be done from the opposite space (i.e. you must be in the lower code space to upload successfully to the upper code space), however they can be done simultaneously for both FEE channels. The Maestro scripts for the uploads are jpl_detector_v17257upper(BOTH) and jpl_detector_v17257lower(BOTH). After uploading, verify that the housekeeping reflects FEE software version 17257 and that the FEE timers each increment once per second. The CRC of v17257 is 0×9ED2 in the lower code space and 0×10F8 in the upper code space. The detector is generally operated from the lower code space. Due to a bug in the PROM version of the DIB code, uploads are expected to fail a few percent of the time. If an upload fails, the procedure is just to reattempt the load until it is successful.

3. Upload FEE programmable parameters to the FUV and NUV channels using the jpl_detector_setup.scr Maestro script (twice). This script will accept FUV or NUV parameters and will upload digitizer settings and DIB fault protection parameters. This script exits with STIM 4 turned on, and the operator should verify that the FEC, DEC and TEC levels all read 79 ± 1 cps. Note that this script initializes internal FEE temperature and voltage limit checking and will enable the FEE to request turn-off in an out-of-limit condition. These conditions are discussed in more detail in Section 3.1.

4. Verify that the detector system is in a safe operating environment for high voltage: the satellite must be in eclipse for full voltage, but the day-side of the orbit is safe for HVLOW. Verify that the spacecraft ATS does not contain any undesirable commanding. Re-verify the detector temperatures.

5. Ramp the HVPS to HVLOW in each channel: generally FUV first, then NUV. Use the script jpl_detector_hvlow.scr, which accepts an 'FUV' or 'NUV' parameter, as well as a current limit (in DN) that defines the maximum MCP bias current before triggering an FEE HVPS turn-off. Example limits ('HV current limit') are provided in the following table in italics. There is no danger in setting the current limit too low, other than increasing the possibility of nuisance safe events. The HVLOW script sets the STIM level to 4 (79 cps), uploads and verifies the correct HV limits for each detector, ramps the specified channel to the HVLOW level, and downloads 2 kB of FEE high speed MCP current sample data. As an additional

safety precaution, the script also programs the HVNOM level equal to the HVLOW level. Critical HVLOW settings are summarized in the following table:

GALEX HVLOW Housekeeping

	NUV01		FUV03	
HVLOW	1 DN	-2571 V	64 DN	-3670 V
HVNOM	1 DN	-2571 V	64 DN	-3670 V
HVMAX	152 DN	-5205 V	215 DN	-6303 V
HV current limit	*35 DN*	$\sim 20\mu A$	*50 DN*	$\sim 30\mu A$
#DPCNT	384 DN	98304 c	384 DN	98304 c
#DPINT	1 DN	1 s	1 DN	1 s

The operator should reference the tables in Section 8 during the high voltage ramp to verify nominal behavior.

- *The calibration for the commanded voltage (#DHVDAC) is:*

$$HV = -2553.74 - 17.44 \times \#DHVDAC\ V. \qquad (2)$$

  For example, a commanded voltage of 152 DN will produce an output of -5205 V into a 100 MΩ load, which is pretty close to the GALEX detector value. The actual voltage and current should be derived from the housekeeping monitors #DHVMON and #DHIMON.

- *The NUV01 detector will not be operated beyond a voltage of -5200 V, and the FUV03 detector will not be operated beyond a voltage of -6300 V to within the resolution of the HVPS, which is about 20 V.*

- *The maximum allowable count rate, CR_{MAX}, is defined by:*

$$CR_{MAX} = \frac{256 \times \#DPCNT}{\#DPINT}\ cps, \qquad (3)$$

  where #DPCNT and #DPINT are the programmable FEE count limit and count time housekeeping monitors. For example, if $\#DPCNT = 384$ and $\#DPINT = 1$ then the maximum rate is 98304 cps.

- *The HV low level (HVLOW) is the commanded HV level to change to when the FEE detects a count rate above CR_{MAX}.*

- *The very low HVLOW values have been selected to protect the detectors in the case of an inadvertent moon or earth-limb crossing on-orbit, and also to equalize the HVLOW → HVNOM ramp time for both detector channels.*

6. With the HVPS ramped to HVLOW, verify:

Nominal Voltage and Current at HVLOW
in flight conditions

	NUV01@24.5°C		FUV03@17.5°C	
HV_{window} (#DHVMON)	93 DN	-2526 V	135 DN	-3675 V
I_{MCP} (#DHIMON)	30 DN	15.7μA	43 DN	22.7μA

There should be no FECs, DECs, or TECs due to the detector voltage; only 79 cps from the STIM 4 pulser level.

- *The #DHVMON and #DHIMON calibrations are:*

$$HV_{window} = -27.5450 \times \#DHVMON + 0.5985 \times \#DHIMON + 18.261\ V \quad (4)$$
$$I_{MCP} = 0.9811 \times \#DHIMON - 0.1373 \times \#DHVMON - 0.9873\ \mu A, \quad (5)$$

where HV_{window} *and* I_{MCP} *are the applied voltage and current sourced by the HVPS. For example, if* $\#DHVMON = 230$ *and* $\#DHIMON = 90$ *then the measured voltage at the detector window is -6263 V and the measured current through the MCPs is 55.7* μA*. Inverting these calibrations we find:*

$$\#DHVMON = -0.0364 \times HV_{window} + 0.0222 \times I_{MCP} + 0.1150\ DN \quad (6)$$
$$\#DHIMON = 1.022 \times I_{MCP} - 0.0051 \times HV_{window} + 1.102\ DN, \quad (7)$$

which are useful for determining appropriate detector current limits.

7. The detector resistance, which varies with temperature, must be calculated once the detectors are ramped to HVLOW. The knowledge of the resistance allows optimal adjustment of the detector nominal high voltage as follows:

- *For NUV01, the nominal cathode gap voltage is -235 V, the nominal MCP voltage is -4065 V, and the nominal rear voltage, fixed by diodes, is -900 V. The cathode is tied to the front MCP surface by a 5 M*Ω *resistor. The MCP stack resistance* R_{NUV01}*, cathode voltage to achieve the gap limit,* $V^{lim}_{NUV01\,gap}$ *and cathode voltage to achieve the MCP gain limit,* $V^{lim}_{NUV01\,MCP}$ *(always choose the lowest limit!) are given by:*

$$\begin{aligned} R_{NUV01} &= \frac{-HV_{window} - 5.0 * I_{MCP} - 900}{I_{MCP}}\ M\Omega \\ V^{lim}_{NUV01\,gap} &= -\left(1135 + 47 \times R_{NUV01}\right)\ V \\ V^{lim}_{NUV01\,MCP} &= -\left(4068 \times \frac{5}{R_{NUV01}} + 4968\right)\ V \end{aligned} \quad (8)$$

For example, if we have ramped NUV01 to a commanded value of 1 DN, then we should see $HVMON = 95$ *and* $HVI = 29$ *corresponding to -2581 V and 14.4* μA *respectively. At this point we calculate an MCP stack resistance of 111.6 M*Ω*. This resistance provides gap and gain limits of -6378 V and -5150 V, at which point we select the lower limit and ramp to -5150 V. At the new voltage, we repeat the calculations and iterate the nominal voltage level setting* ***never exceeding the NUV01 nominal voltage level of -5200 V.***

- *For FUV03, the nominal gap voltage is -676 V, the nominal MCP voltage is -4724 V, and the nominal rear voltage is -900 V. In the case of this detector, the gap voltage is a much less critical parameter for safe detector operation since the fields involved are lower. However, since we do not predict there will be a significant overhead on orbit to adjusting the voltage to compensate for temperature, we will hold the gap voltage constant with the same methods applied to the NUV01 detector. The grid is tied to the front MCP surface by a 12.5 M*Ω *resistor. The MCP stack resistance* R_{FUV03}*, grid voltage to achieve the gap limit,* $V^{lim}_{FUV03\,gap}$ *and grid voltage to achieve the MCP gain limit,* $V^{lim}_{FUV03\,MCP}$ *(always choose the lowest limit!) are given by:*

$$R_{FUV03} = \frac{-HV_{window} - 12.5 * I_{MCP} - 900}{I_{MCP}}\ M\Omega$$

$$V^{lim}_{FUV03\,gap} = -\left(1576 + 54.1 \times R_{FUV03}\right)\ V \quad (9)$$
$$V^{lim}_{FUV03\,MCP} = -\left(4724 \times \frac{12.5}{R_{FUV03}} + 5624\right)\ V$$

The calculations are identical to the NUV case, although in the FUV03 case ***the nominal voltage not to be exceeded is -6300 V.***

8. Ramp the detectors to the appropriate HVNOM level using the script jpl_detector_hvnom.scr. Note that the last thing this script does after ramping to HVNOM is to command the detector back to HVLOW as required for on-orbit operations. This script takes five parameters: the detector channel ('FUV' or 'NUV'), the nominal voltage level in DN (calculated in physical units in Step 7 and converted to DN units using Equation 2), a current level limit in DN, a count rate limit in units of 256 counts-s^{-1} (for example, a value of 128 sets the FEC limit to 32768 counts-s^{-1}), and an enable parameter to allow actual HV ramping. The following table may be helpful for choosing appropriate current limits:

Background, Voltage and Current at Nominal Gain in Flight Conditions

	NUV01	FUV03
FEC	1250	390
TEC	283	150
DEC	283	150
#DHVDAC	151	210
#DHVMON	191	228
#DHIMON	73	81

These data indicate a reasonable current limit in the range of 80 – 85 DN for NUV01 and 90 – 95 DN for FUV03, where (as previously indicated in Equation 5) the current monitor scales at close to 1 μA-DN^{-1}. The appropriate current limit is a function of temperature since the internal resistance of the detectors is variable. **Reference the tables in Section 8 during the ramp to HVNOM.**

9. Clear the detector diagnostic stack by running jpl_detector_clear_diagnostics.scr.

10. Monitor the temperature of the detector heads periodically and adjust the voltage if necessary to stay within the limits defined in Equations 8 and 9. The jpl_detector_hvnom.scr script sets a narrow temperature range of ± 1 °C, or ± 3 DN, for NUV and ± 2 °C, or ± 5 DN for FUV to drift before an FEE shutdown request is generated. If a detector head temperature varies significantly, the nominal voltage must be recalculated and value updated by rerunning jpl_detector_hvnom.scr, which will also reset the temperature limits. Early on-orbit thermal data indicates that the NUV channel is very well controlled but that the range of variation in FUV is similar to the imposed limits, which were widened for this reason. In the case of FUV, the limits were chosen to match the granularity of the HVPS output, which relaxed the thermal requirement slightly.

4.2 On-orbit Detector Turn-on Sequence

The on-orbit turn-on sequence for the detectors follows the same procedure as outlined in Section 4.1, however, contacts with the satellite are only in the range of 5 – 10 minutes, so the procedures must be timed properly. A brief overview of the turn-on procedures is presented here for completeness. If at any time during either procedure the detector behavior is deemed questionable, the operator should run jpl_detector_hvoff.scr, which will command the HV to 0 V and download the FEE current sample buffers.

Once at HVNOM, subsequent contacts should be used to monitor the detectors and to adjust the voltage, count rate protection, and overcurrent limits accordingly. The current limit should be set as low as possible without introducing nuisance overcurrent detector shut-downs, and the global count rate limit may be increased up to the maximum level, 100,000 counts-s^{-1}.

4.2.1 Detector System Turn-On (No High Voltage)

This procedure is generally done as part of the GALEX instrument turn-on. Since the high voltage is off and the turn-on sequence is part of the general instrument thermal stabilization procedure, the only requirements are that the spacecraft is performing nominally, that commandability has been verified, and that the DPU flight software patch has been loaded before enabling the DOFFEN protection with the jpl_detector_setup.scr script. The FEE turn-on basically consists of three steps:

1. Power the FEE using jpl_detector_fee_pwr.scr (one contact).
2. Load the flight code version 17257 to both code spaces of each detector channel (two contacts). If a code upload fails (rare, but expected due to a bug in the FEE PROM code 17217), the procedure is to repeat the upload on the next available pass.
   - jpl_detector_v17257upper.scr
   - jpl_detector_v17257lower.scr
3. Verify that there are no thermal or limit check violations (reference Section 3.1.1), and then run the detector setup script, jpl_detector_setup.scr, for each channel. This programs the FEE and turns the STIM pulser on. There should be 79 FEC/DEC/TEC in each detector channel after the script completes (two contacts).

4.2.2 Four-Contact HV Turn-On

This procedure is meant to be used the first time the detectors are ramped to full voltage on orbit, or after extended periods of instrument/spacecraft safing. It is essentially a functional test, since it ends with the high voltage “OFF.” This procedure is run with the optical wheel in the OPAQUE position, and only one detector at a time. The procedure requires that telescope cover door has been open for at least a week, that the detectors are thermally stable, and that all of the steps in the Detector System Turn-On procedure were completed successfully. At least 8 eclipse-side, non-SAA orbit contacts are required to test both detectors at full voltage. It is generally assumed that the FUV detector will be ramped to nominal high voltage before the NUV detector. Note that the FEE current sample buffer is downloaded by all of the high voltage scripts, although it is listed as a step here for completeness; there are no additional scripts that need to be run other than those listed. The procedure outline is as follows:

1. First contact: Run jpl_detector_hvidle.scr at beginning of contact. Monitor voltage and current. Run jpl_detector_hvoff.scr. Download the SSR before the contact period ends using jpl_ssr_sci_dump_stream.scr.
2. Review data.

3. Second contact: Run jpl_detector_hvlow.scr at the beginning of contact. Compare the voltage and current to the values tabulated in Section 8. Download the SSR before the end of contact using jpl_ssr_sci_dump_stream.scr.

4. Review data. Calculate the HVNOM level for the detector.

5. Third contact: Run jpl_detector_hvnom.scr with a nominal voltage parameter 400 V (~20 DN) below the actual nominal voltage level and a FEC rate limit of 4096 counts-s^{-1}. Monitor voltage and current, and then reduce voltage to HVLOW using jpl_detector_hvlow.scr. Download the SSR before the end of contact using jpl_ssr_sci_dump_stream.scr.

6. Review data. Recalculate HVNOM level for the detector.

7. Fourth Orbit: Run jpl_detector_hvnom.scr with a voltage parameter no higher than the calculated nominal voltage level and with a count rate limit of 4096 counts-s^{-1}. Compare the voltage and current to the values tabulated in Section 8, and then reduce voltage to HVOFF using jpl_detector_hvoff.scr. Note that the HVNOM script will reduce the voltage to HVLOW before completing. Download the SSR before the end of contact using jpl_ssr_sci_dump_stream.scr.

8. Review data. Calculate the HVNOM level for the detector.

9. Repeat the procedure for the NUV detector system.

4.2.3 Two-Contact HV Turn-On

This procedure is meant to be used whenever a manual HV turn-on of the detectors is required and data indicates that the detectors are otherwise operating nominally. The initial requirements are the same as for the Four-Contact HV Turn-On.

1. First contact: Run jpl_detector_hvlow.scr at the beginning of contact. Compare the voltage and current to the values tabulated in Section 8. Download the SSR before the end of contact using jpl_ssr_sci_dump_stream.scr.

2. Review data. Calculate the HVNOM level for the detector.

3. Second contact: Run jpl_detector_hvnom.scr with a voltage parameter no higher than the calculated nominal voltage level and with a count rate limit of up to 100,000 counts-s^{-1}. Compare the voltage and current to the values tabulated in Section 8, and then reduce the voltage to HVLOW (with a single #DHVLOW command, to allow the ATS to proceed). Download the SSR before the end of contact using jpl_ssr_sci_dump_stream.scr.

4. Repeat the procedure for the NUV detector system.

4.2.4 Detector Head Thermal Limit Adjustment

It is expected that the temperatures of the detector heads will vary on orbit, especially in the FUV channel, since there is no instrument heater nearby the FUV side of the optical bench. Periodic recalculation of the HVNOM level will be required to offset this variation on orbit. One of the functions of the jpl_detector_hvnom.scr script is to reset the detector head temperature limits about the current temperature (±1 °C NUV, ±2 °C FUV), thus resetting the limits. This periodic update could be made either on the day or night side of the orbit, since there is no requirement to ramp the high voltage when the parameter adjustments are made.

4.2.5 DPU Operational Heater Nomenclature

While programming the DPU operational heater set points is beyond the scope of this document, there are some instrument nomenclature idiosyncrasies specific to the NUV detector head temperature set point that are worth noting. The late addition of an operational heater to stabilize the temperature of the NUV detector forced some awkward notation to be carried to the new system. Originally, there was to be a "Disk Shield" heater and temperature sensor, however the Disk Shield heater circuit is now used for a special heater on the instrument BFA next to the NUV detector. There is no Disk Shield heater. However, in order to program the temperature of the NUV detector, one needs to program the Disk Shield temperature. To make matters more confusing, the Disk Shield temperature sensor still exists, although it actually monitors the temperature of the Disk Shield, which is in the optical wheel mechanism. The actual temperature of the NUV detector is controlled by the NUV OBA temperature sensor.

4.2.6 Recovery from High Voltage or FEE Shutdown

There are three modes in which a high voltage shutdown could occur:

1. The FEE detects an MCP bias current over the programmed limit.
2. The DPU safes the instrument by executing a PSAFE command.
3. The spacecraft turns the FEE off either because of a load shed or as a result of instrument request.

In the first case, the detector could be ramped back to high voltage following either the two or four contact turn-on procedures. In the second, the DPU would first need to have its safing bits cleared, and then the two or four contact turn-on procedure could be run. In the last case, if the DPU was still on, the DPU status bits would need to be cleared and then the entire FEE turn-on sequence followed as described previously.

It is worth a few comments on recovery from DPU safing, since there are several known idiosyncrasies with the FEE-DPU fault protection. First of all, there are two types of DPU 'safing': PSAFE and DOFFEN. The DPU PSAFE routine commands the detector high voltage to 0, rotates the optical wheel to the opaque position, and sets the DPU SAFE bit in the status word. In order to recover from this state, the flight controller would issue a 'PSAFENA disable' followed by a 'PSAFENA enable' to clear the DPU status word before attempting to ramp the detector HV (otherwise the DPU would reject commands that change the state of the HV **with the exception of the #DHVPWR command that turns the HVPS on.**) The DOFFEN protection was written to protect against the consequences of an FEE crash by monitoring the FEE timer and command counters; if the timer or counters do not behave nominally, the DPU sets an 'FUV OFF' or 'NUV OFF' bit in its status word to request spacecraft turnoff of the appropriate FEE. The DOFFEN protection requires several flight rules in order not to be triggered inadvertently. In addition to DOFFEN, the FEE itself can request shutdown through the DIB exception mechanism, in which the FEE sets the DIB exception telemetry point to a non-zero value. In this case, the DPU will set the appropriate status bit to turn the FEE off. If a turn-off request status bit is set in the DPU, the procedure for recovery is to:

1. Disable DOFFEN.
2. Power the FEEs and wait for the timer to increment.

3. Clear all of the DPU status bits using the PSAFENA disable/enable sequence.

4. Reenable DOFFEN

The reason that the FEE needs to be powered and running before clearing the DPU status bits is because in the case of an FEE overcurrent, the non-zero DIB exception value is 'frozen' in the DPU until the FEE is rebooted (assuming the error condition has disappeared after reboot). Rather than have a contingency for just one case, we just choose to handle all of the safing events in the same manner. *Note that in order for this sequence to work, the instrument turn-off routines in the spacecraft software must not be rearmed until after all of the instrument turnoff bits are cleared.* The jpl_detector_fee_pwr.scr script disables DOFFEN both on power-up and power-down of the FEE. DOFFEN is reenabled by the jpl_detector_setup.scr script.

5 On-Orbit Idiosyncrasies

The following is a description of operational issues that have become apparent since the launch of GALEX in April 2003:

- **Space Weather and Detector HV Current spikes:** High voltage breakdown is a very fast and potentially catastrophic event for intensified systems such as the GALEX detectors, so special code is written into the detector software to monitor the MCP current at 5 ms intervals and to react if there are any deviations. A one-bin deviation generates a detector diagnostic 0x27. Two or more consecutive out-of-limit bins generates an HVOFF fault response and a 0x2A diagnostic. During over 1000 hours of ground operations the detector MCP bias currents were remarkably stable, generally within 1 μA of nominal. On only two occasions on the ground did the software report single-bin measurements of current over the 5 μA limit, and there was never a HV shutdown. Nonetheless, shortly after launch it became apparent that the detectors were responding to space weather events, in particular the apparent interaction of protons and X-rays from solar flares with the environment of low-earth-orbit. Solar data from NOAA clearly shows that 2003 has been an historic year for solar activity, including several of the largest flares on record. Thus far, we have had about a dozen events of varying significance and each time we return the detectors to nominal operation there is no evidence of performance degradation (at most we have identified some possibly new hotspots associated with the HV events). The fault protection is doing its job in a challenging environment, however the main impact of these events has been on mission efficiency, and after consulting with teams at Berkeley and Johns Hopkins we have developed the DPU 7.7 code, which is a compromise between opening the fault limits and improving mission efficiency. The DPU 7.7 code allows us to keep conservative fault limits (extinguishing HV overcurrents at very low levels), but then to partially automate the return to nominal operations by allowing the DPU to ramp the detector to HVLOW. Not insignificantly, the *detector* software, which is written in assembler, and which provides the critical detector fault protection verified by many hours of ground test, did not require any modifications at all for the DPU change to be implemented.

- **The FUV blob:** During one particularly notable solar flare event, one of the largest on record (October 28, 2003), the FUV detector developed a bright background feature localized to a $\sim 20'$ patch on the right side of the detector. The patch was so bright it caused several count rate shutdowns before the controllers were able to turn the detector high voltage off. Analysis showed that the feature was localized to a patch in the detector field of view where the "electron optics" of the grid-focal plane region were modified (as determined by out-of-band flat fields from ground test, where the grid features are visible in emission). This observation coupled with the fact that the tube background is known to be enhanced when objects are placed in proximity to the front of the window, as well as the observation that these enhancements lead to long-lasting features in the electron optics, lead to the model that the window (or conversely the spacecraft) had somehow become charged by the particle enhancements in low earth orbit, leading to window emission. The patchiness could be explained potentially by a residue on the window surface, or by some artifact of the grid deposition process. In the end, our strategy was to monitor the space weather and wait for it to improve, which it did in about a week. The patch was slightly visible in the functional test, but indications are that as long as the space weather does not return to high levels (during the event the operating environment of the satellite was equivalent in particle density to the South Atlantic Anomaly!) we do not expect further enhancements. The fault protection operated as designed and protected the detector system from the unpredictable environmental conditions.

- **Count rate flares:** We observed one flare of 30000 cps in the NUV channel that has been correlated with a flare in the low earth orbit particle environment. Experimentally, bathing the detector in energetic particles results in an enhanced count rate distributed uniformly across the detector. These are likely Geiger-type events in the tube or possibly interactions of the particles directly with the channel plates.

- **Off-axis features:** Bright stars outside the field of view can cause reflections in the GALEX optics that appear as stretched and distorted out-of-focus pupil images. These are flagged by the pipeline.

- **Satellites:** It is not unusual for a satellite to fly through the GALEX field of view and generate thousands of counts per second. None have been bright enough to trigger the fault protection.

- **FEC without TEC:** On several occasions we have observed activity in the FEC without corresponding activity in the TEC. This has generally been traceable to hotspot activity, during which a hotspot becomes active enough to cause "gain sag" locally on the MCP. This causes events to fall below the detector charge threshold and be discriminated out of the data stream, thus an excess of fast events is the only record of the activity. To date the brightest hotspots have been in FUV, upwards of 1000 cps, and generally without any apparent consequences.

- **FUV temperature variations:** The temperature of the detector heads varies on orbit, although these variations are minimized by the BFA heaters. The nominal voltages must be recalculated and adjusted according to Equation groups 8 and 9 (to within the 20 V resolution of the HVPS) whenever the detector head temperature changes. The HVPS will provide essentially constant voltage output over the range of loads provided by the detector heads as the temperature changes; the current will vary accordingly. Based on JPL thermal-vacuum data, the resistance R_{MCP} of the detector MCP stacks is described by:

$$R_{MCP} = 128.9e^{-0.016\times T}\ \mathrm{M}\Omega, \tag{10}$$

which means that the resistance of the MCP stacks inside the detectors can vary from 80 $\rightarrow$ 129 MΩ over the 30 °C flight allowable operating range. This can lead to large voltage variations internally to the tube. For example, if the NUV01 temperature rises, the voltage at the cathode will remain constant but the voltage across the cathode-MCP gap will increase as the resistance of the MCP stack drops. Similarly, if the temperature were to drop the voltage across the MCP stack would increase while the gap voltage decreases. In order to protect against potentially dangerous excursions, the jpl_detector_hvnom.scr defines an FEE housekeeping monitor (#DDSTLIM) to place tight limits on the detector temperature before ramping to the nominal HV level. Based on the "maximum" recommended operating voltage provided by UC Berkeley (200 V above the "nominal" level), the exponential thermal dependence of the MCP resistance defines a range of ±3 °C before a detector *internal* voltage can drift to an unacceptable level. In the interests of conservatism, we set the detector temperature limits at the nominal HV level to ±1 °C in NUV and ±2 °C in FUV. This may be widened somewhat in the future, based on flight trending. By fiat, the externally applied voltage to the detectors shall never exceed the "nominal" level.

- **DPU-FEE Interface Corruption:** Due to a design error in the DPU digital interface board, a small amount of data from the detector to the DPU is corrupted. The amount of data lost is neglibible, and analysis has shown that there is no hardware at risk as a result of the problem. This idiosyncrasy was known well before launch, but because of the small impact of it relative to the cost of repair the project accepted it as is. One side effect that has become apparent in flight is that the corruption can have occasional consequences to the fault protection because it affects both housekeeping and photons. The effect is that rarely, a critical housekeeping point will become corrupted and this will cause the DPU to request power-down of the FEE. The potential solution to this problem is in a modification of the DPU code that would cause it to request a housekeeping refresh before FEE power-down if a bad telemetry point is identified. This may be implemented in a future version of the DPU code.

6 On-orbit Performance

Early assessments are that the detector system is performing to specification as measured on the ground. White dwarf standard stars have been used to assess the instrument throughput at several locations in the field of view, and the absolute throughput appears to be within about 10% of pre-flight predictions. Distortion-corrected flat fields are presented in Figures 5 and 6 for reference. These are a first attempt to measure the instrument flat field response using stacks of images to median-filter stars and galaxies, leaving sky background.

7 Detector System Flight Rules

The following is a list of rules developed for flight during GALEX ground testing:

- **The maximum applied voltage to FUV03 shall be -6300 V.**
- **The maximum applied voltage to NUV01 shall be -5200 V.**
- **The maximum FEE global count rate limit is 100,000 FEC.**
- **Do not attempt to command the FEE faster than 1 command per second.** In ground test, we have determined that the FEE can lose commands completely if commanded faster than the 1/second rate.

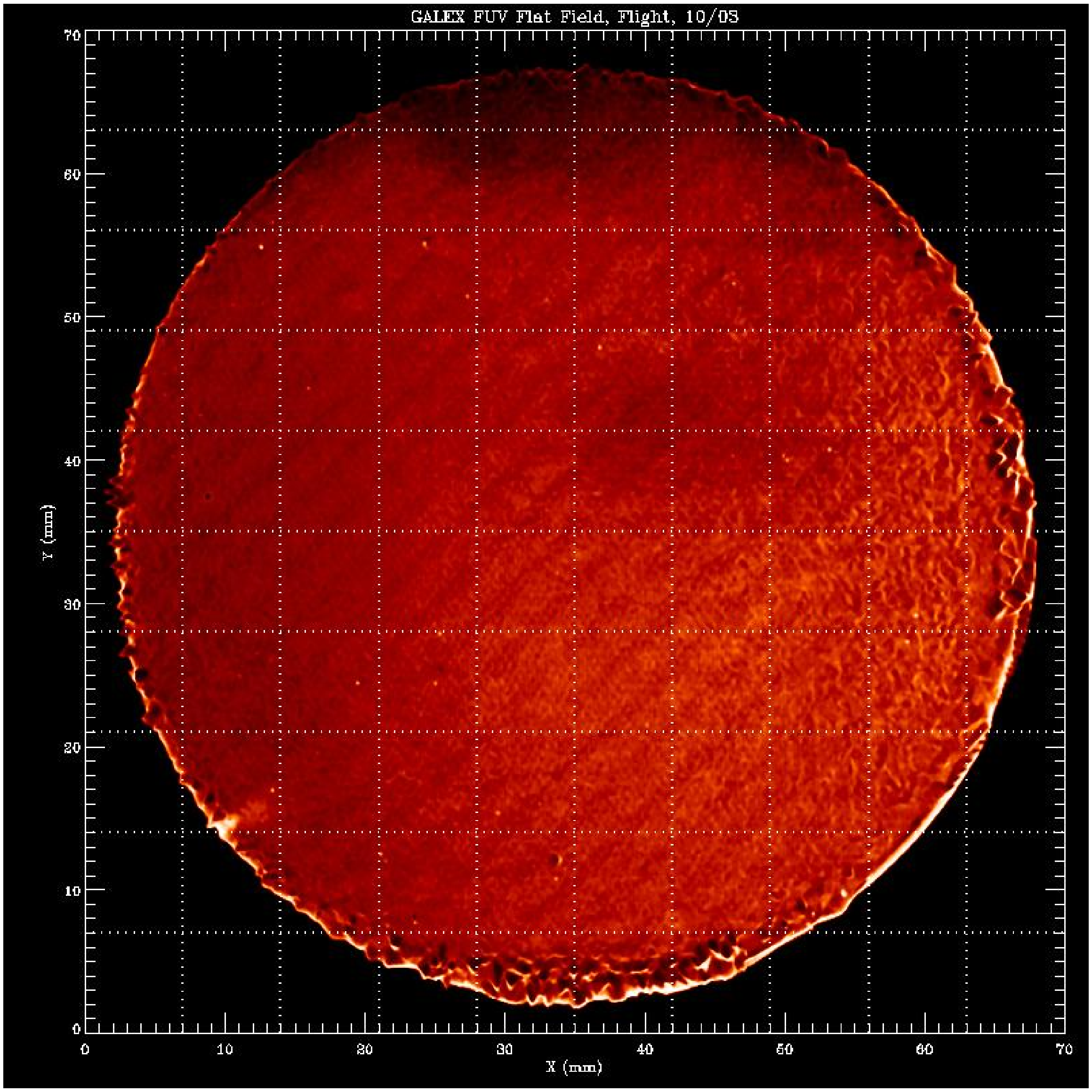

Figure 5: GALEX flight FUV flat field. Visible in this composite are shadows of the QE-enhancing grid wires (bands at 45°), distortion correction errors (edge ripples), MCP hex-bundle patterns ($\sim$ 1 mm period), and fairly significant sensitivity variations due to the large range of pulse heights present across the field.

- **Disable the FEE NUV digitizer controller temperature limits.** The NUV digitizer controller temperature sensor is malfunctioning, so setting the limits can result in a safing response from the spacecraft.
- **Power both FEEs before enabling the DPU DOFFEN fault protection.** Since this fault protection monitors the FEE timers, a powered-down FEE will trigger a turn-off request (for the unit that is already off).

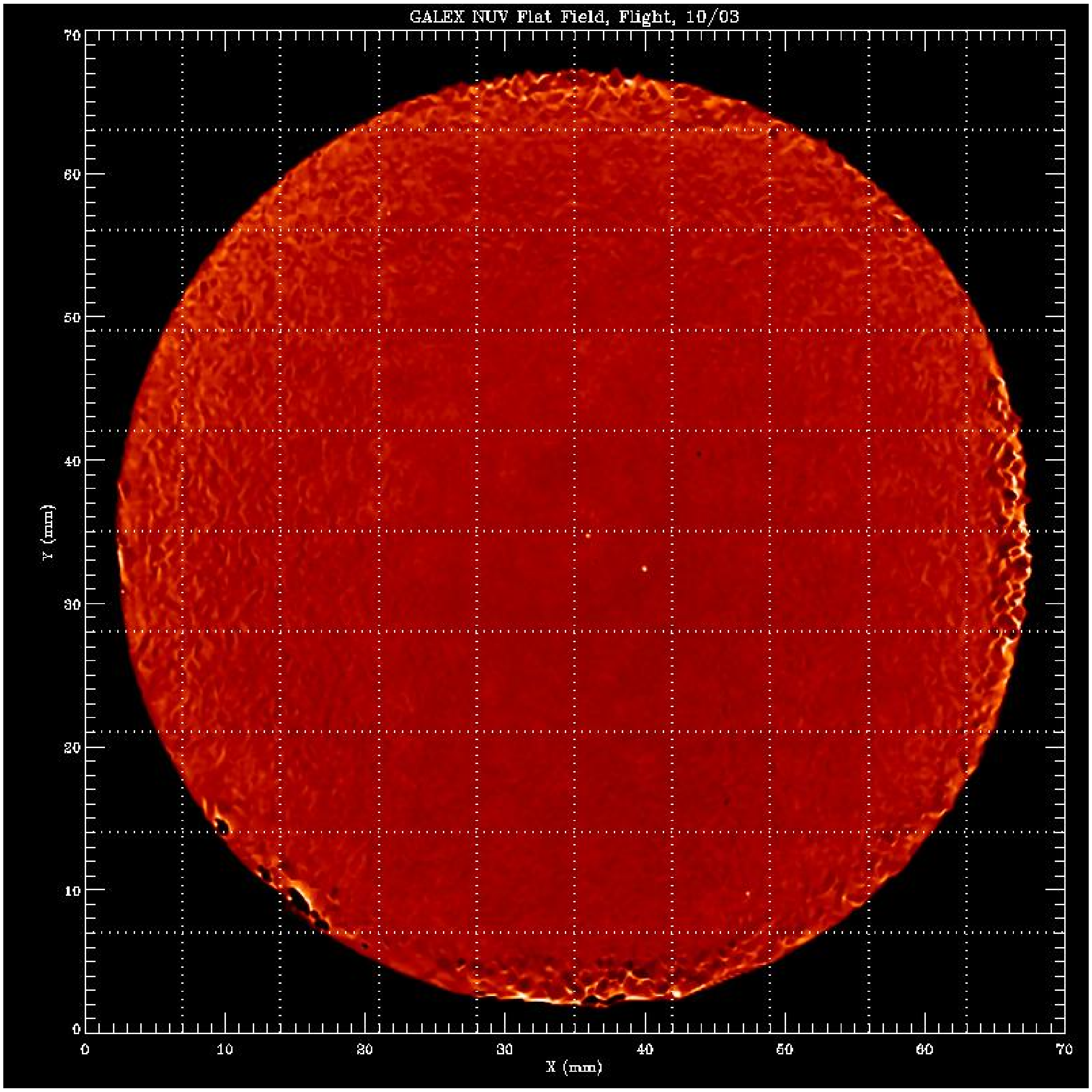

Figure 6: GALEX flight NUV flat field. Relatively speaking a very flat field with a pair of bright hotspots near the center and ripples around the edge resulting from errors in the non-linearity correction.

- **Load the FEE initialization script and verify nominal STIM pulser throughput before powering the detector high voltage.** The FEE digitizer must be programmed properly in order to provide valid science data, a requirement before powering the high voltage.
- **Upload DIB software version 17257 before powering the high voltage.** There are numerous bugs in the PROM version of the DIB code (17217) that make it undesirable for high voltage operations, including slow housekeeping when the high voltage is on and an unnecessarily long overcurrent reaction time. These errors have been fixed in version 17257.

- **Upload the FEE code patch to both sides of the FEE code space.** There have been at least two instances in ground test when the FEE jumped autonomously from one code space to the other. Since both code spaces share the same variables, any potential problems with this error should be avoided in principle by having the code patch uploaded to both sections of the DIB memory.

- **Do not assign an FEE STLIM monitor to the TDC-15 V housekeeping.** There is a bug in the FEE flight software that causes erroneous out-of-limit conditions if this telemetry point is monitors internally by the FEE.

- **Do not send an FEE NOOP command with the DPU DOFFEN fault protection enabled.** The NOOP will cause the FEE packet and command counters to fall out of sync, triggering a DOFFEN shutdown of the FEE that was commanded.

- **Ground-controlled ramping of the high voltage must be done in non-SAA eclipse-side passes.** This rule will allow sufficient time to monitor the HV before the instrument is allowed to autonomously control its own safing. Note that because of the locations of the GALEX ground stations (Hawaii and Australia), there is not actually a possibility of commanding during SAA passage. However, the SAA should be considered during use of NASA's TDRSS system.

- **Clear the DPU command queues before powering the FEE.** Commands may reside in the DPU command buffer after an FEE turn-off, and these commands would be issued to the FEE after power-on if they were not cleared first with the DPU PCLRFEEQ command.

- **The most recent project-approved DPU software must be loaded prior to turning on the FEE.** In particular, version 7.3 implements a new PSAFE routine, which turns the detector high voltage OFF instead of to HVLOW. Also, it does not monitor the FEE BUSY line (as previous DPU software versions did), which allows FEE code to be uploaded without disabling the DOFFEN fault protection. Later versions of the code have added enhancements to resolve issues that have arisen in flight.

- **Disable DPU DOFFEN fault protection before FEE turnoff, and do not reenable it until the FEE is back on with its timer ticking.** One of the things the DPU DOFFEN protection monitors is the FEE timer update. If the FEE power is cycled, the DPU will request FEE turnoff *immediately after the FEE is turned off,* because the FEE timer will stop ticking. This condition would need to be cleared by disabling and reenabling DOFFEN and PSAFENA prior to turning the FEE back on, otherwise it would not be possible to successfully repower the FEE. The DOFFEN fault protection is reenabled by the jpl_detector_setup script after power-on.

- **The DPU must be on and initialized before the FEE.** This is because without the DPU there is no FEE telemetry and thus no information about the health of the detector system.

- **The DPU must (at a minimum) be commanded to use the RS422 clock from a powered FEE.** The DPU command interface uses an incoming clock from the FEE to synchronize commands on its own outgoing line. The DPU can use the clock from either side of the FEE, however if the clock is not present (ie if the FEE is off or malfunctioning), the command interface will crash, possibly requiring reboot of both the DPU and FEE. In most scripts, the convention is to set the clock to the side of the FEE that is being commanded.

- **Do not use the following FEE commands: #DDTEST, #DPOVRRD, #DDGOTO, #DPDIS, #DDDAY, #DDNITE, #DDIDLE, #DDPRMOF and #DDPEEK.** These commands have either not been tested adequately to demonstrate reliability, or have known errors.
- **The only allowable high voltage commands in the spacecraft ATS are #DHVNOM and #DHVLOW.** Other commands could defeat some of the instrument fault protection. For example, while the instrument is in SAFE mode, it will still accept a command to power the HVPS, because the same command powers the supply on and off.

8 Flight Voltage-Current Predictions

The following tables of data are from flight functionals during which the FUV detector was 17.5 °C and the NUV detector was 24.5 °C. These tables should be referenced during on-orbit ramping operations to verify nominal detector operation.

NUV01 Flight Voltage and Current Predictions, T=25 °C

#DHVDAC DN (V)	#DHVMON DN (V)	#DHIMON DN (μA)	FEC c-s^{-1}	TEC c-s^{-1}
0 (-2553)	93 (-2524)	30 (15.7)	79	79
1 (-2570)	**94 (-2551)**	**31 (16.5)**	**79**	**79**
5 (-2640)	96 (-2606)	32 (17.2)	79	79
10 (-2727)	99 (-2688)	33 (17.8)	79	79
15 (-2814)	103 (-2798)	34 (18.2)	78	79
20 (-2902)	106 (-2879)	36 (19.8)	79	79
25 (-2989)	109 (-2961)	37 (20.3)	79	79
30 (-3076)	112 (-3043)	38 (20.9)	79	78
35 (-3163)	115 (-3124)	40 (22.5)	79	79
40 (-3250)	119 (-3234)	41 (22.9)	79	79
45 (-3338)	122 (-3316)	42 (23.5)	78	78
50 (-3425)	125 (-3398)	43 (24.0)	79	79
55 (-3512)	128 (-3480)	45 (25.6)	79	79
60 (-3599)	132 (-3589)	46 (26.0)	79	79
65 (-3686)	135 (-3671)	48 (27.6)	78	78
70 (-3774)	138 (-3753)	49 (28.1)	79	79
75 (-3861)	141 (-3835)	50 (28.7)	78	78
80 (-3948)	145 (-3944)	52 (30.1)	79	79
85 (-4035)	148 (-4026)	53 (30.7)	79	78
90 (-4122)	151 (-4080)	55 (32.2)	79	79
95 (-4210)	154 (-4189)	56 (32.8)	80	79
100 (-4297)	157 (-4271)	57 (33.4)	82	80
105 (-4384)	161 (-4380)	59 (34.8)	88	83
110 (-4471)	164 (-4462)	60 (35.4)	102	86
115 (-4558)	167 (-4544)	62 (36.9)	100	86
120 (-4646)	171 (-4653)	63 (37.3)	122	86
125 (-4733)	174 (-4735)	65 (38.9)	161	112
130 (-4820)	177 (-4817)	66 (39.5)	165	112
135 (-4907)	180 (-4898)	68 (41.0)	237	132
140 (-4994)	183 (-4980)	69 (41.6)	326	157
145 (-5082)	186 (-5062)	70 (42.2)	496	193
150 (-5169)	190 (-5171)	72 (43.6)	734	253
151 (-5186)	190 (-5170)	74 (45.5)	710	262

FUV03 Flight Voltage and Current Predictions, T=17.5 °C

#DHVDAC DN (V)	#DHVMON DN (V)	#DHIMON DN (μA)	FEC c-s^{-1}	TEC c-s^{-1}
0 (-2553)	93 (-2526)	27 (12.7)	79	79
5 (-2640)	96 (-2608)	29 (14.3)	79	79
10 (-2727)	100 (-2717)	30 (14.7)	79	79
15 (-2814)	103 (-2799)	32 (16.3)	79	79
20 (-2902)	106 (-2881)	33 (16.8)	79	79
25 (-2989)	109 (-2963)	34 (17.4)	79	79
30 (-3076)	113 (-3045)	35 (18.0)	79	79
35 (-3163)	116 (-3154)	36 (18.4)	79	79
40 (-3250)	119 (-3236)	37 (19.0)	78	79
45 (-3338)	122 (-3318)	39 (20.5)	79	79
50 (-3425)	125 (-3400)	40 (21.1)	79	79
55 (-3512)	129 (-3510)	41 (21.5)	79	79
60 (-3599)	132 (-3592)	42 (22.1)	79	79
64 (-3669)	**135 (-3674)**	**43 (22.7)**	**79**	**79**
65 (-3686)	135 (-3674)	43 (22.7)	79	79
70 (-3774)	139 (-3755)	45 (24.2)	79	79
75 (-3861)	142 (-3865)	46 (24.6)	79	79
80 (-3948)	145 (-3946)	48 (26.2)	78	78
85 (-4035)	148 (-4029)	48 (25.8)	79	79
90 (-4122)	151 (-4110)	50 (27.3)	79	79
95 (-4210)	155 (-4220)	51 (27.8)	79	79
100 (-4297)	158 (-4302)	52 (28.3)	79	79
105 (-4384)	161 (-4384)	53 (28.9)	79	79
110 (-4471)	164 (-4465)	55 (30.5)	79	79
115 (-4558)	168 (-4547)	56 (31.0)	79	79
120 (-4646)	171 (-4657)	57 (31.5)	79	79
125 (-4733)	174 (-4739)	58 (32.0)	78	78
130 (-4820)	177 (-4820)	60 (33.6)	79	79
135 (-4907)	180 (-4902)	61 (34.1)	78	78
140 (-4994)	184 (-4984)	62 (34.7)	79	79
145 (-5082)	187 (-5093)	64 (36.1)	79	79
150 (-5169)	190 (-5175)	65 (36.7)	82	79
155 (-5256)	193 (-5257)	66 (37.3)	81	79
160 (-5343)	196 (-5339)	67 (37.8)	92	83
165 (-5430)	200 (-5448)	69 (39.2)	94	85
170 (-5518)	203 (-5530)	70 (39.8)	94	86
175 (-5605)	206 (-5613)	71 (40.4)	106	92
180 (-5692)	209 (-5694)	73 (41.9)	114	85
185 (-5779)	212 (-5776)	74 (42.5)	126	94
190 (-5866)	216 (-5886)	75 (42.9)	142	97
195 (-5954)	219 (-5967)	77 (44.5)	198	121
200 (-6041)	222 (-6049)	78 (45.1)	197	115
205 (-6128)	225 (-6130)	80 (46.6)	242	139
210 (-6215)	228 (-6211)	83 (49.1)	254	158

9 FEE Diagnostics

The following is a list of detector diagnostics reproduced from the Detector to Instrument Interface Control Document (GAL-JPL-303-F).

FEE Diagnostic Codes

Code	**Description**
0x01	UPLOAD bad length
0x02	UPLOAD bad CRC
0x03	DUMP bad length
0x04	Wrong command MSB, should be 1
0x05	Command byte must have proper complement
0x06	Command parameters must have proper complements
0x07	Stack Alarm
0x08	HV not enabled
0x09	HV already enabled
0x0A	*disabled*
0x11	Illegal command
0x12	Bit alignment error
0x13	Command did not complete execution
0x14	Function not implemented
0x15	*disabled*
0x16	CRC changed in U7
0x17	CRC changed in U2
0x18	CRC changed in lower RAM
0x19	CRC changed in upper RAM
0x1A	CRC changed in ROM
0x1B	Watchdog reset (expected)
0x1C	Unexpected watchdog reset
0x1D	Watchdog reset test failed
0x1E	Hardware reset failed
0x1F	*disabled*
0x22	CRP shutdown
0x23	HV restored autonomously after CRP shutdown
0x24	Semaphore still busy
0x25	Command timed out
0x27	Measured HV overcurrent
0x29	Breadboard DIB detected
0x2A	HVPS turned off because of overcurrent
0x2C	Wild code trapped
0x30	PMON limit exceeded
0x80-8F	HK upper limit exceeded
0x90-9F	HK lower limit exceeded

10 References

The following documents contain the detailed procedures to be followed in flight when operating the detector system:

GALEX Detector-Related Procedures

Number	Description
9J70-OP0200	Update Detector Voltage and Thermal Limits
9J70-OP0204	Instrument Initial Turn-On
9J70-OP0207	Clear Detector Diagnostic Stack Procedure
9J70-OP0208	Four Contact High Voltage Detector Turn-On
9J70-OP0209	Two-Contact High Voltage Detector Turn-On
9J70-OP0211	One Week Mini-Mission
9J70-OP0212	One Day Mission ATS HV Off
9J70-OP0213	One Day Mission ATS HV On, No Light
9J70-OP0214	One Day Mission ATS HV On, With Light
9J70-OP0215	GALEX First Light
9J70-OP0220	FEE Turn-On and Initialization
9J70-OP0226	Dump Detector Memory
9J70-OP0421	Detector System Turn-off

11 Acronyms

ATS	Absolute Time Sequence
CRC	Cyclic Redundancy Check
DEC	Digitized Event Counter
DIB	Data Interface Box
DN	Digital Number
DPU	Data Processing Unit
FEC	Fast Event Counter
FEE	Front End Electronics
FUV	Far Ultraviolet
GALEX	Galaxy Evolution Explorer
HK	Housekeeping
HVPS	High Voltage Power Supply
HV	High Voltage
LVPS	Low Voltage Power Supply
MCP	Microchannel Plate
MSB	Most Significant Bit
NUV	Near Ultraviolet
OBA	Optical Bench Assembly
PROM	Programmable Read-Only Memory
RAM	Random Access Memory
ROM	Read Only Memory
RTS	Relative Time Sequence
SSR	Solid State Recorder
TDC	Time to Digital Converter
TEC	Telemetered Event Counter
UV	Ultraviolet