Mission & Instrument Overview

Based upon Martin et al. 2003, “The Galaxy Evolution Explorer”, SPIE Conf. 4854, Future EUV-UV and Visible Space Astrophysics Missions and Instrumentation.

1.ABSTRACT

The Galaxy Evolution Explorer (GALEX) is a NASA Small Explorer Mission launched April 28, 2003. GALEX is will performing the first Space Ultraviolet sky survey. Five imaging surveys in each of two bands (1350-1750Å and 1750-2800Å) range from an all-sky survey (limit m_{AB}~20-21) to an ultra-deep survey of 4 square degrees (limit m_{AB}~26). Three spectroscopic grism surveys (R=100-300) are underway with various depths (m_{AB}~20-25) and sky coverage (100 to 2 square degrees) over the 1350-2800Å band. The instrument includes a 50 cm modified Ritchey-Chrétien telescope, a dichroic beam splitter and astigmatism corrector, two large sealed tube microchannel plate detectors to simultaneously cover the two bands and the 1.2 degree field of view. A rotating wheel provides either imaging or grism spectroscopy with transmitting optics.

We will use the measured UV properties of local galaxies, along with corollary observations, to calibrate the UV-global star formation rate relationship in galaxies. We will apply this calibration to distant galaxies discovered in the deep imaging and spectroscopic surveys to map the history of star formation in the universe over the red shift range zero to two. The GALEX mission will include an Associate Investigator program for additional observations and supporting data analysis. This will support a wide variety of investigations made possible by the first UV sky survey.

2.SCIENCE OVERVIEW

With GALEX we seek to study the UV properties of galaxies in the local universe. We will measure the relationship of UV to star formation rate, extinction, starburst history, initial mass function, and metallicity. We will do this using studies of nearby, spatially resolved galaxies, and in large samples of more distant low redshift galaxies. We will combine UV images and spectra with data obtained from the Sloan Digital Sky Survey, 2dF, 2MASS, IRAS, ISO, and a suite of nearby galaxy surveys to determine the definitive relationship between global UV properties and physical properties of galaxies.

Using this local ``calibration", we will study distant galaxies over the redshift range $0.3<z<2$ to track the cosmic star formation history, the history of extinction, modes of star formation, and the starburst history of the universe, over a cosmic time of roughly 10 Gyr.

Finally, we will generate a legacy data set which will support studies of the statistical properties and evolutionary history of quasi-stellar objects, post-main-sequence stars, degenerate binary stars. A large database will definitely resolve nature of the UV rising flux in early-type galaxies. High redshift QSOs visible in the observed FUV and NUV will determine the rest EUV spectral energy distribution of quasars and provide sources for IGM studies with the HeII Gunn-Peterson test.

GALEX addresses these goals with a set of imaging and spectroscopic surveys. Five imaging surveys are underway in a Far UV band (1350-1750\AA) and Near UV band (1750-2800\AA) with 4.5-6 arcsecond resolution (FWHM) and 1 arcsecond astrometry, and a cosmic UV background map. Three overlapping slitless-grism spectroscopic surveys over the 1350-2800Å band with l/Dl~100, resulting in greater than 100,000 galaxies with redshifts (0<z<2), extinction, and SFR.

Imaging: Five imaging surveys in a Far UV band (1350—1750Å) and Near UV band (1750—2800Å) with 6-8 arcsecond resolution (80% encircled energy) and 1 arcsecond astrometry, and a cosmic UV background map.

[AIS:] An All-sky Survey to 20-21^{m} (AB), netting ~10,000 galaxies within 70 Mpc and 10 million galaxies overall for an unbiased local calibration of UV galaxy morphology, SFR, and extinction.

[MIS:] A Medium Imaging Survey over 1000 square degrees to 23^{m} (AB) to provide data on galaxies at intermediate distances and luminosities.

[DIS:] A Deep Imaging Survey over 80 square degrees to 25^{m} (AB) to provide photometric redshifts, extinction and SFR for faint and distant galaxies. DIS regions will overlap SIRTF Legacy SWIRE fields.

[UDIS:] An Ultra-deep Imaging Survey over 4 square degrees to 26^{m} (AB) to provide photometric redshifts, extinction and SFR for the faintest and most distant galaxies.

[NGS:] Nearby Galaxy Survey of 150 nearby galaxies with exposures of 1-2 orbits per galaxy.

Spectroscopy: Three overlapping slitless-grism spectroscopic surveys over the 1350—2800Å band with l/Dl~100, resulting in greater than 100,000 galaxies with redshifts (0<z<2), extinction, and SFR.

[WSS:] A Wide-field Spectroscopic Survey to 20^{m} (AB) over 80 square degrees to calibrate the global UV/SFR/Extinction relations and find the rarest and most luminous star-forming galaxies. WSS will overlap DIS fields.

[MSS:] A Medium-deep Spectroscopic Survey to 21—23^{m} (AB) over 8 square degrees to find star forming galaxies of intermediate SFR and redshift.

[DSS:] A Deep Spectroscopic Survey to 22—24^{m} (AB) over 2 square degrees to find the galaxies with the lowest SFR and highest z, overlapping the deepest ground-based surveys.

Guest Investigator Program: Four months of dedicated associate investigator observations will be performed in the last eight months of the nominal 28 month mission for science complementary to the primary survey goals.

Table 1 – Survey Summary – see also Survey Summary

	Survey	**Survey Parameters**			**Science Objective**			**<z>**
		Area [deg^2]	**Length [Month]**	**Expos [ksec]**	**Mag. Lim [m$_{AB}$]**	**#Gals (est.)**	**Volume [Gpc^3]**	
Universe	All-sky (AIS)	40,000	4	0.1	20.5	10^7	1.5	0.2

SF History ⬇ ⬆Local	Wide Spectroscopic (WSS)	80	4	30	20	10^{4-5}	0.03	0.15
	Nearby Galaxies (NGS)	---	0.5	1.5	27.5 [mag arcsec^{-2}]	100	---	--
	Medium Imaging (MIS)	1000	2	1.5	23	3×10^{6}	~1	0.6
	Medium Spectroscopic (MSS)	8	2	300	21.5[R=100] 23.3[R=20]	10^{4-5}	0.03	0.5
	Deep Spectroscopic (DSS)	2	4	1500	22.5[R=100] 24.3[R=20]	10^{4-5}	0.05	0.9
	Deep Imaging (DIS)	80	4	30	25	10^{7}	1.0	0.85
	Ultra-Deep Imaging (UDIS)	4	1	150	26	3×10^{5}	0.05	0.9

3.MISSION

GALEX is performed with a wide-field (1.2 degree) UV-optimized instrument consisting of a 50 cm modified Ritchey-Chrétien telescope, a selectable imaging window or grism, a dichroic beam splitter and corrector, a far ultraviolet and near ultraviolet sealed tube microchannel plate detectors, and support electronics. The instrument is coupled to a Orbital Sciences Corporation spacecraft that is three-axis stabilized, with fixed GaAs solar panels, a NiH battery, an X-band transmitter and S-band transmitter and receivers. The satellite mass is 277 kg, and orbit averaged power is 279W. The satellite is shown during integration in Figure 1, with solar panels in the deployed position.

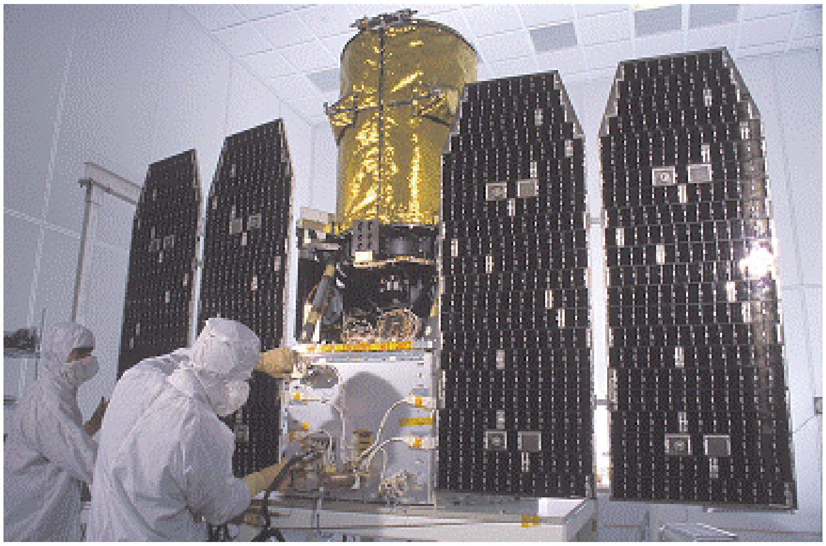
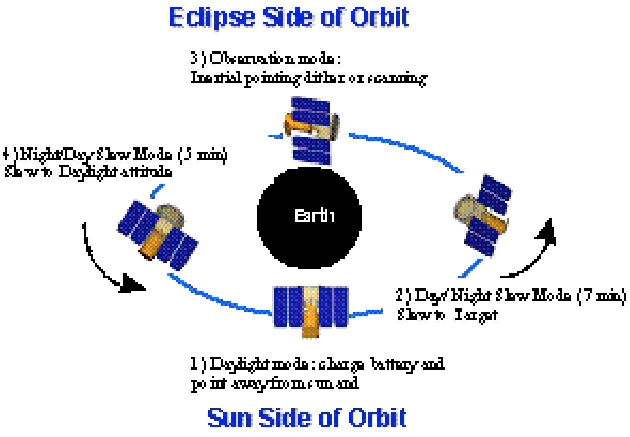


Figure 1 – GALEX satellite.

GALEX was launched by a Pegasus-XL vehicle into a 29 degree inclination, 690 km circular orbit on April 28, 2003. After a two month in-orbit checkout period, GALEX began nominal operations. The eight surveys listed in Table 1 are being performed concurrently for the first 28 months. Starting 1 October 2004 one third of mission time will be devoted to Guest Investigator observations. The mission design is simple. The standard orbital sequence for every target is shown in Figure 2. All science data is obtained only on the night side. On the day side of each 96 minute orbit, the satellite will face the solar panels toward the sun. As the satellite enters twilight, it will slew to one of the survey targets. The imaging window or grism will be selected for imaging or spectroscopic targets. If the target is spectroscopic, the grism rotation will also be selected. Once the target is reached, the detector high voltage will be ramped and the target observed.

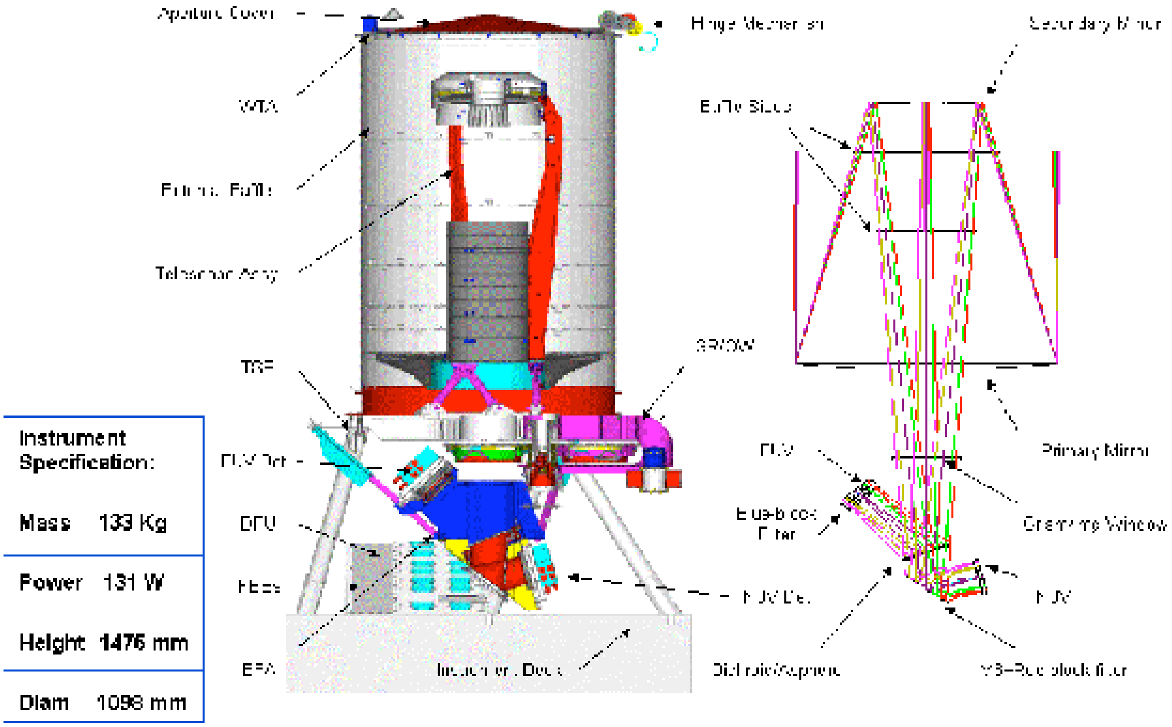


The attitude will be dithered in a 1 arcminute spiral for deep targets, while the AIS will be obtained by scanning at 200 arcseconds/sec. Dithering and scanning is performed to average over detector non-uniformities and to prevent microchannel plate detector gain fatigue by UV bright stars. During science data collection, individual photon events are collected by the far ultraviolet and near ultraviolet detectors and front-end electronics (FEE), formatted by the instrument Digital Processing Unit (DPU), and stored on the spacecraft solid-state tape recorder (SSR) along with housekeeping data. At the end of orbital night, detector high voltages are ramped to idle levels to protect them from damage and the spacecraft returns to solar array pointed attitude. Up to four times per 24 hour day the SSR is dumped via the X-band transmitter to ground stations in Hawaii or Perth, Australia, operated by Universal Space Networks

Figure 2 – GALEX Orbit sequence.

(USN). Real-time satellite health and safety monitoring is performed by the Mission Operations Center (MOC) at Orbital Sciences Corporation in Dulles, Virginia, during the ground pass. Science telemetry is shipped by ground network to the Science Operations Center at Caltech, with a latency of 4 hours for housekeeping and 48 hours for photon data. Science data will be processed at Caltech to produce images, object catalogs, and extracted spectra. Catalogs and spectra will be delivered to the Space Telescope Science Institute to be archived in a database developed by Johns Hopkins University for the Sloan Digital Sky Survey (SDSS).

4.INSTRUMENT



Instrument Specification:

Mass 133 Kg
Power 131 W
Height 1476 mm
Diam 1098 mm

Figure 3 – GALEX instrument and optical design.

4.1. *Optical Design*

The adopted design meets the challenging requirements of providing ~2-3 arcsec 80% encircled energy (80% EE; NB the system resolution is less and is limited by the detectors) optics resolution with a high throughput, large field of view (65 mm or 1.24 deg) in four different optical paths (two simultaneous UV channels, with selectable imaging and slitless spectroscopy modes), while keeping the instrument compact, simple to build and adjust. The pupil diameter is essentially limited to half a meter by the available volume in the Pegasus faring. As needed for a SMEX program, special attention has been paid in the design concept to maintaining tolerance to component positioning and orientation, especially for the moveable parts. The design minimizes the number of optical components and surfaces by employing components to serve dual purposes as correctors in the case of the grism, optical window, dichroic beam splitter and both detector entrance windows.

The concept, shown in Figure 3, is a slightly modified Ritchey-Chrétien telescope in which astigmatism is corrected by a low power fused silica aspheric window in the converging beam. This aspheric window bears a multilayer dichroic coating to separate the FUV (reflected) and NUV (transmitted) light. Its reflecting entrance side corrects the FUV channel, whereas the exit side cancels the entrance side effects and brings in the required amount of correction for the NUV channel. A small wedge on this aspheric window compensates for the coma it induces in the NUV convergent beam. A CaF_2 grism ahead of the aspheric corrector provides slitless spectroscopy over the whole GALEX FOV. Its wedge angle is adjusted to correct for the coma it induces in the converging beam[2], simultaneously for orders 2 and 1 spectra of the FUV and NUV channels respectively. It turns out that the resulting deviation is low, a primary advantage for switching between imaging and slitless spectroscopy. This switching is performed by exchanging the grism with a low power plano-convex CaF_2 imaging window. These two components are mounted on a rotatable wheel that also provides an opaque position. The grism and the imaging window positional tolerances are loose (0.5 mm) because they are dioptric components with only a low power. This low power is optimized to correct for the axial chromatism of all the transmissive elements. The field curvature is cancelled by the power in the detector windows, and the detectors are tilted to the best plane. A remarkable feature is that a single blaze angle on the grism facets is found to provide a well centered efficiency for both NUV and FUV channels, owing to the CaF_2 index variation with wavelength.

The design yields a field-averaged spot size of 1.6 arcsec (80%EE) for the FUV imagery and 2.5 arcsec (80%EE) for the FUV spectroscopy at 1600Å. NUV performance is similar. There is no in-flight refocus capability.

4.2. *Telescope*

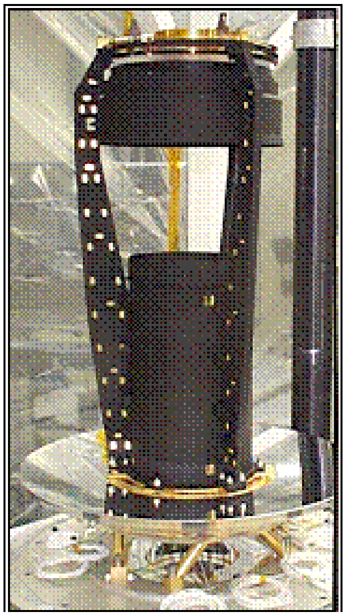


Figure 4 – GALEX Telscope.

The telescope, shown in Figure 4, is a 50 cm, f/6, modified Ritchey-Chrétien design optimized for the required 1.2 degree wide field of view. The telescope and flight spare (used as abeam collimator for optical testing) were originally designed and provided by Light Works Optical Corporation (LWO). The design requirements were comparatively modest, driven by overall mass, stiffness, and maintenance of the required 30 micron 80%EE spot size over flight operational temperatures with no active thermal control. The LWO design incorporates a Meinel strut arrangement with hub-mounted primary and secondary optics. Technical problems with the as-built LWO telescope required that JPL perform a complete redesign and retrofit of the primary mirror mount. The f/2 primary and the secondary were ground and polished on Fused Silica blanks by Brunasche, and overcoated with Al and 336Å MgF_2 by the Goddard Space Flight Center Coating Laboratory. The secondary is bonded with RTV 566 to a super-invar hub, which is turn mounted to an Invar 36 spider. The spider is attached to an Invar 36 tower and primary baffle assembly. The JPL-provided primary mirror mount is an Invar 36 flexured hexapod bonded to the primary with Epoxy 2216. The mount is quasi-kinematic and induces no more than 0.2 waves to the system performance over flight temperatures. The flight telescope was assembled and aligned at JPL, and was subjected to vibration and thermal vacuum testing beyond expected environmental conditions. A small amount of focus shift is present over temperature, roughly 5 microns/degree C, and due mostly to the secondary mirror mount. The secondary and primary mirrors are temperature controlled. A small amount of astigmatism (approximately 1 wave, and induced by the secondary mount) was discovered during end-to-end optical testing, but has remained stable. In spite of these deficiencies, the telescope contribution to the system angular resolution budget remains within specification.

4.3. *Window and Grism*

The dispersive component for the spectroscopy mode is a 75 groves/mm CaF_2 grism that can be inserted with loose tolerances into the convergent beam to produce slitless spectra. Both the grism and the imaging window that comes in place of the grism have been polished by STIGMA from a 180 mm diameter, high quality UV-grade monocrystalline CaF_2 ingot screened for low phosphorescence, provided by SOREM. Both the grism and imaging window have a low curvature entrance face and require a tight control of the differential thickness (±30mm) to keep in focus while switching between imaging and spectroscopy. Nevertheless the most difficult part was by far the grism ruling: although grisms are widely used in visible and near infrared ground-based astronomy, the UV cutoff of the resins involved in their manufacturing process prevents their use in the vacuum UV range. LAS and Jobin-Yvon developed a proprietary process to imprint the blazed profile into the CaF_2 crystal. Figure 5 shows the grism, the efficiency ratio of the flight grism to that of the imaging window, and a grism image. The absolute efficiency measurements reach 82% in the NUV and 61% in the FUV. Electromagnetic computations have shown the polarization is negligible. The GALEX grism was the first one ever built for the FUV[3]. The grism is mounted in a mechanism that can rotate the spectra to 872 position angles on the detectors and sky.

Slitless spectroscopy produces numerous overlapping object spectra and multiple orders. For this reason, all spectroscopic surveys are obtained using a different position angle for each orbit integration. The confusion problem becomes worse as the surveys deepen. At the same time the number of position angles increases, compensating. The deep spectroscopic survey will utilize all 872 distinct position angles. Simulations have shown that this method yields a confusion limit comparable to that of the imaging surveys when more than 100 angles are utilized. Satellite roll, which may also be used to control spectral position angle, is often otherwise constrained.

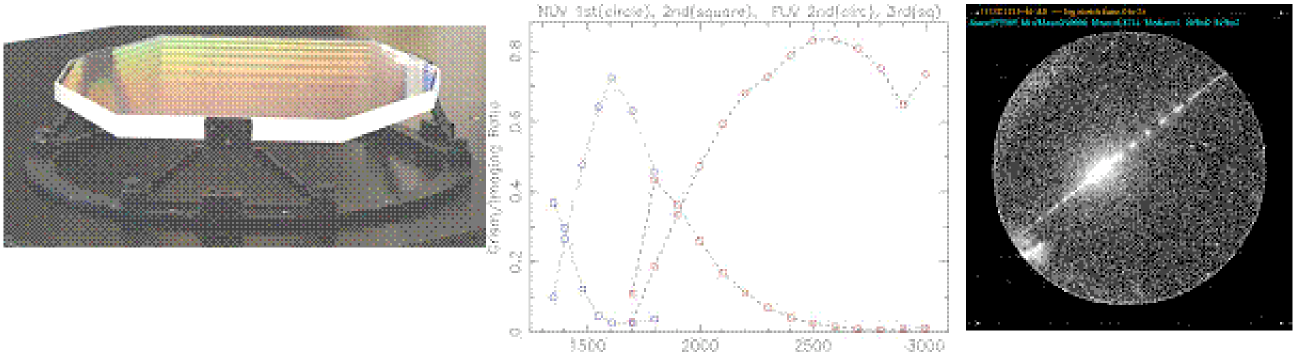


Figure 5 – LEFT: Grism. CENTER: Ratio of Grism to Imaging Window efficiency. RIGHT: Grism calibration image.

4.4. Dichroic Beam Splitter

The 110 mm diameter UV-grade fused silica aspheric corrector window (AS) is only 4 mm thick. Using its entrance face as a mirror sets tight manufacturing tolerances that already were challenging for polishing it flat on both faces, at the first manufacturing step. The AS is tilted at 22° to the beam to accommodate the FUV detector position, but the asphérization has been performed axisymmetrically to simplify manufacturing, with only marginal impact on the image quality. The required asphérization was 4.72µm for the first side and 11.4µm for the second. The two asphérisations were achieved at IOTA (University of Paris) by broad-beam ion milling with a carbon mask, a technique that combines a fairly good shape precision, conservation of the original smoothness comparable to that allowed by the classical flat polishing, and absence of any stress in the material thus preserving the shape of the side not being processed[4]. The FUV side has been eroded first, on the basis of a mask iteratively adjusted from calibration erosion on thick blanks. A significant part of the FUV residual departure from planarity after polishing has been corrected for by adjusting the erosion time. For the NUV side, the erosion has been performed in two steps, the second (~10% of the exposure time) being adjusted to optimally correct for the combined residuals of the FUV side and first NUV polishing. The overall residuals have been measured to 27 nm and 31 nm respectively on the FUV and NUV sides, bringing a negligible contribution to the global image budget.

The mechanical mount developed for the aspheric corrector window was used to hold the crystalline grism and imaging window with minimal strain in the thermal, vibration and shocks environment of Pegasus launchers. The three components were bonded to the heads of three titanium flexure bipods. The bipod leg angle was set to equally share the maximal stress in the thinned parts for the X, Y and Z directions of vibration. An o-ring linking the bipod bases to a suitably flexible telescope interface has proved very efficient in damping the sharp natural resonance during environmental testing.

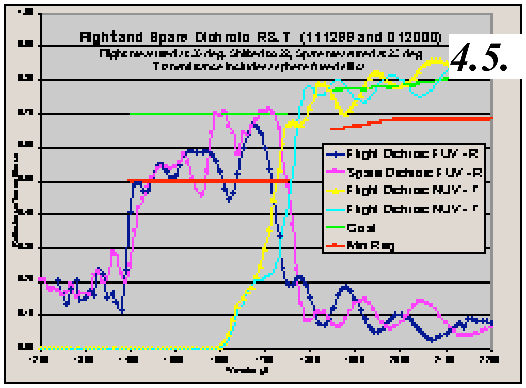


Figure 6 – Flight and spare Dichroic beam splitter reflectance and transmission.

4.5. Filters

Three of the GALEX back focal assembly optics are coated with multilayer filters designed to enhance the in-band throughput and off-band rejection of the GALEX instrument. The dichroic coating applied to the entrance face of the fused-silica aspheric corrector plate separates the FUV (reflection) and NUV (transmission) optical paths. This all-dielectric dichroic coating provides a significant improvement over conventional 40%-40% UV beam splitter coatings, with a mean reflectance of 61% over the 1400-1700 Å band and a mean transmittance of 83% over the 1800-2750Å band. A transmissive blue-edge filter coated on MgF_2 provides 10% rejection of the OI 1304 airglow line for the FUV channel. A reflective broad-band red-blocking filter on the M3 folding mirror has an edge at 2800Å. This edge yields an additional factor of 10-20 rejection for the NUV zodiacal light background above and beyond the natural Cs_2Te detector photocathode cut-off.

4.6. Detectors and Front-End Electronics

The GALEX detector system is composed of two large-format, microchannel plate amplified, sealed tube detectors with delay line readouts and associated electronics. The detectors have 65 mm diameter active areas and is the largest of their kind on orbit. They were fabricated at UC Berkeley by the Experimental Astrophysics Group in collaboration with members of the Caltech Space Astrophysics Laboratory. The FUV channel has a CsI photocathode deposited directly on the MCP and a MgF_2 window for UV transmission down to the instrument cutoff at approximately 1350Å. A voltage applied to wires deposited on the window surface enhances the quantum efficiency (QE) of the detector by approximately 50%. The NUV channel has a Cs_2Te photocathode deposited on the surface of its fused silica window, which is proximity-focused on the MCP. The Cs_2Te photocathode requires a sealed tube to protect it. We made the strategic decision to seal the FUV detector as well for operational simplicity during integration and test. In spite of the significant associated costs, the strategy has proven to be tremendously worthwhile because no ground or flight worthy vacuum pumping was required and because we could operate the detectors at any time.

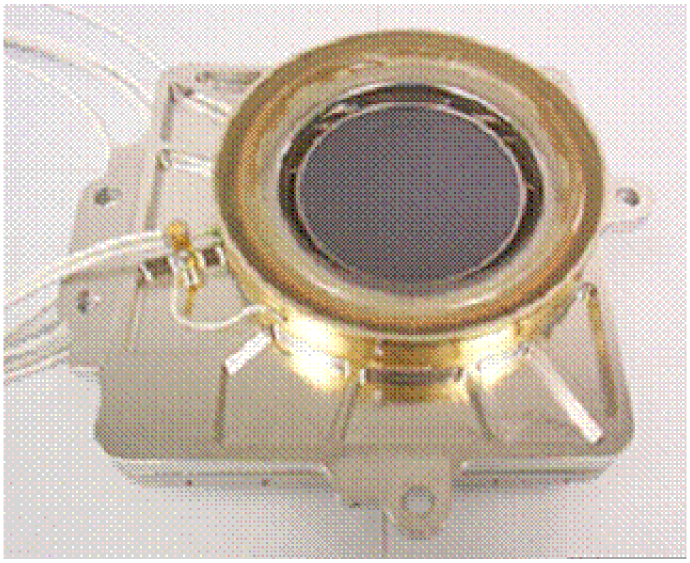


Figure 7 -- Flight NUV Detector

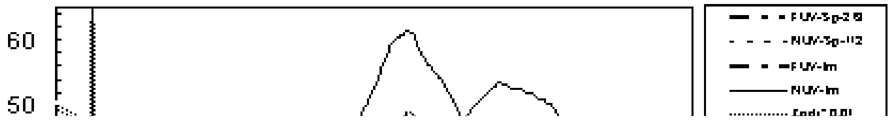
The electronics for each detector include high and low voltage power supplies adapted from the SOHO program, an 8051-based controller, four high speed timing amplifiers, and an FPGA-based signal processing board and dedicated controller. Commands, housekeeping and science data are communicated between the detector and instrument via RS422 interfaces. Each detector has its own entirely independent set of electronics, with total power consumption by the dual system being approximately 75 W. The electronics were developed by a large collaboration including Battel Engineering (power supplies), Southwest Research Institute (digitizer) and UCB (controller and amplifiers), with systems engineering and testing performed jointly by Alias Aerospace, Baja Technology and Caltech.

As of this writing the tubes have each accumulated approximately 1000 operating hours with no sign of performance degradation. They were life-tested at Berkeley prior to delivery to JPL/Caltech, undergoing approximately a week each of high count rate burn-in that was intended to be representative of approximately 10% of the mission-integrated dose estimate. These tests and our subsequent experience indicate the detectors should be relatively immune to the permanent pulse height reduction commonly observed in other microchannel plate based systems; we attribute this to the extensive UV scrubbing process required prior to sealing the getter-pumped tubes, which is of order 0.1-0.2 C/cm^2. The system has been vibrated and thermally cycled numerous times during component, instrument, and satellite tests, including an extensive calibration program described in section 2.12. Similarly, the electronics have undergone extensive testing (and some modification) at JPL, having accumulated approximately 500 failure-free hours with the flight software version and current flight configuration. There is a single set of spare electronics and two spare detectors (one for each channel) and that are monitored periodically for functionality and background stability at JPL as part of the instrument test bed. This test bed will become one of the primary means of debugging problems and new command scripts after GALEX is on orbit.

Detector resolution tests could only be performed during end-to-end optical tests, because of the presence of the thick, curved entrance windows. The detector resolution varies significantly with position and pulse amplitude. Based on full aperture tests corrected for optical contributions to the point spread function, and sub aperture tests in which the optical contributions can be ignored, the median resolution is 75 microns for the FUV and 107 microns for the NUV detectors (80% encircled energy diameter), which corresponds to 50 microns and 70 microns FWHM, respectively. NUV resolution is somewhat wavelength dependent because of photoelectron gap spread transiting the proximity-focused gap. Post-tube processing detector QE is 10% at 1500Å (FUV) and 8% at 2300Å (NUV).

4.7. Instrument Ground Calibration and Performance

From April 20 through May 13, 2002 the GALEX JPL instrument and Caltech science teams performed a thermal-vacuum ground calibration of the



GALEX instrument. We operated around the clock in three overlapping, equivalent shifts per day. We made measurements continuously at cold, nominal, and hot operational thermal plateaus, and during transitions between them. We successfully obtained required data and did not have any failures that required us to break vacuum. We collected 100 GByte of data during ~500 hr when at least one detector was at high voltage. We encountered no surprises and there was no damage to the instrument.

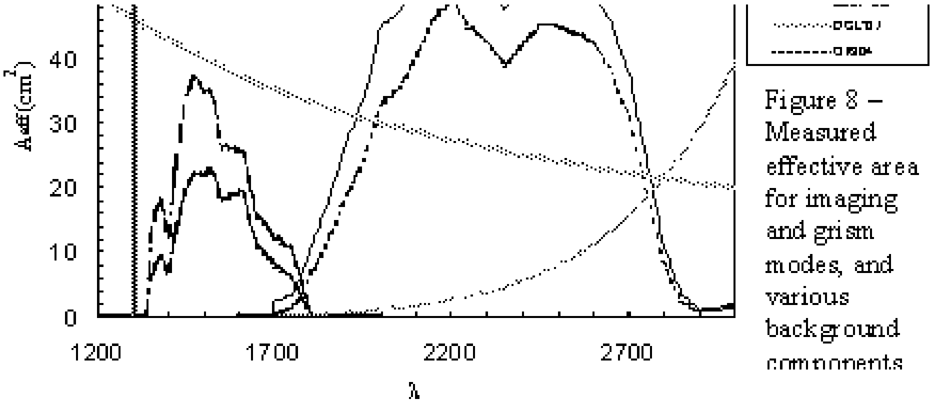


Figure 8 – Measured effective area for imaging and grism modes, and various background components

The primary purpose of the calibration thermal vacuum test was to make detailed measurements of GALEX instrument performance characteristics. The flight data-analysis pipeline requires these as inputs. The second purpose was to look for anomalies while thoroughly exercising the instrument over a range of targets, light levels, count rates, temperatures, bus voltage, and detector high voltage. The third purpose was to verify performance of parameters including proper focus and optical alignment, point spread function (PSF), detector spatial nonlinearity, and thermal stability, as required by our requirements matrix. The fourth purpose was to test a modification of a survival heater thermostat and to perform two thermal vacuum cycles (of four total) at the instrument level to demonstrate thermal robustness and to look for workmanship problems. The fifth purpose was to exercise the science operations and data analysis team, the instrument team, and the data analysis tools. The sixth purpose was to select table values for operating the detector front end electronics (FEE).

Among calibration parameters, we gave priority primarily to those that were more difficult to measure in flight. We adhered to the principle "test it like we fly it," to the extent practical. We commanded the instrument and downloaded data using the Orbital Sciences Corp. MAESTRO command and telemetry software that we will use in flight. The MAESTRO system communicated with a spacecraft simulator, which communicate with the instrument via a 1553 bus, and included a solid-state recorder simulator, which read science data through an RS-422 bus. We illuminated the instrument with a full aperture beam produced by a flight-spare telescope with a target wheel at its focus. A Roper Scientific Acton Research VM-502 0.2-m vacuum monochromator with a deuterium lamp provided UV illumination.

Our top priority calibration items were relative sensitivity versus wavelength, flat field, imaging-to-spectroscopic differential sensitivity versus wavelength, and spatial nonlinearity. The middle priority were absolute sensitivity (3 pencil beam locations in the aperture), grism dispersion function compared to imaging, high count rate tests (local and global), and a sky-simulation target. The lowest priority were PSF characterization, near-angle stray light, deuterium spectrum (monochromator at zero order), and detector background. At daily status/scheduling meetings, we adjusted the time allocation between tests based on their priority, on considerations of granularity and signal-to-noise, on the need to repeat certain tests at different environmental or detector temperatures, and on the relative efficiency of particular tests. Of the tests listed above, the local high count rate and near-angle stray light tests were reduced in scope because of operational difficulties. All other tests were performed satisfactorily. Much of the data has been analyzed and all critical parameters are adequately known and acceptable. Key performance results are summarized in Table 2.

Table 2 – Instrument Design & Performance Summary (based on Ground Calibration)

Telescope Aperture	50 cm
Optical Design	Modified Ritchey-Chrétien with 4 channels: FUV & NUV Imaging, FUV & NUV Spectroscopy. FUV & NUV obtained simultaneously using dichroic beam splitter also acting as a field aberration corrector.
Field of View	1.2 degrees, circular
Focal Length	3 m
Telescope coatings	Al+MgF$_2$
Imaging/Grism Modes	Optics wheel with (1) CaF$_2$ Imaging window, (2) CaF$_2$ transmission grism; (3) Opaque position.

Grism Rotation	Grism position angle may be selected with a resolution of 0.3 degrees, independent of S/C roll	
Dichroic/Corrector	Aspheric astigmatism corrector Ion-etched fused silica (aspheric surfaces on both sides) Dichroic beam splitter with dielectric multilayer coating on input side	
	FUV Channel	NUV Channel
Band	1350-1750 Å	1750-2800 Å
Beam path	Reflected from dichroic	Transmitted through dichroic
Filters	Blue edge filter (blocks OI, Ly a - transmission)	Red block filter/Fold mirror (blocks red Zodaical light)
Detectors	Sealed tube Z-stack microchannel plate with crossed delay-line anodes	
Detector Window	MgF_2 includes power for field flattering	Fused Silica includes power for field flattering
Detector Photocathode	CsI, opaque, repeller grid on window	Cs_2Te, semitransparent 300 mm proximity gap
Detector peak QE	12%	8%
Detector maximum local countrate w/o temporary saturation within PSF	~100 c/s	~1000 c/s
System angular resolution	6.0 arcsec (80% EE diam) 4.0 arcsec (FWHM)	8.0 arcsec (80% EE diam) 5.6 arcsec (FWHM)
Spectral Resolution	250-300	80-150
Imaging Effective Area	25 cm^2	44 cm^2
Photometric Zero Point [1 ct/s] m_{AB}	18.1	20.1
Spectroscopy Effective Area	20 cm^2	39 cm^2

5.MISSION AND SCIENCE OPERATIONS AND DATA ANALYSIS

Mission Operations will be performed at Orbital Science Corporation's Mission Operations Center (MOC) in Dulles, VA. Ground contacts will occur four times per day over the Universal Space Networks (USN) Perth and Hawaii stations. Satellite and instrument housekeeping will be monitored during ground contacts. Real time commanding will be used only during In-Orbit Checkout (IOC) and during infrequent critical command sequences-including anomaly recovery.

GALEX is in a low-earth orbit (690 km altitude, 29 deg inclination, 99 minute orbital period). Low-background requirements limit science observations to orbital night. During a typical orbit, the GALEX detectors are ramped to their nominal high voltage at night entry and ramped down to a safe low state prior to night exit. GALEX detectors are also ramped to safe levels during South Atlantic Anomaly passages, and during scans over bright stars during the All-sky Survey. Bright objects such as the sun, moon, earth limb and bright planets are avoided during observation intervals.

Science observations for the GALEX mission are planned at the Science Operations Center at Caltech in Pasadena, CA. Once per week, an observation description file containing a time-ordered sequence of pointing and instrument setting commands is sent to the Mission Operations Center. GALEX science mission planning software is designed to schedule the science surveys as efficiently as possible while ensuring that no operational or scientific observing constraints are violated. During each observation the GALEX instrument stores time-tagged photon positions for each detector on the spacecraft solid-state recorded. The ~5 GB of science data collected each day will require four 25 Mbps X-band downlink contacts to transmit to the ground for processing.

The GALEX data analysis pipeline operated at the Science Operations Center receives the time-tagged photon lists, instrument/spacecraft housekeeping and satellite aspect information within two days of the ground contact. From these data sets, the pipeline reconstructs the aspect vs. time and generates images, spectra and source catalogs. The first pipeline module corrects the photon positions for detector and optical distortions and uses a maximum-entropy algorithm to calculate an optimal aspect solution based on the time-tagged photon data. A photometric module accumulates the photons into count and intensity maps and extracts sources from images. A spectroscopic module uses image source catalog inputs to extract spectra of these sources from the multiple slitless grism observations. Realistic processing simulations indicate that eight installed 1-2 GHz dual processor servers running under the Linux operating system will process the complete set of data from a 24 hour period in considerably less than the 12 hour maximum requirement.

Final GALEX images and catalogs are to be released to the public at the Multimission Archive at Space Telescope (MAST) using a queriable database schema. The GALEX archive design is based on the Sloan Digital Sky Survey (SDSS) SkyServer architecture. This is a natural match, both because the GALEX science depends on SDSS corollary data and since the structure and the format of the data has remarkable similarities to the SDSS (multiwavelength, combination of imaging and spectroscopy, etc.). The Archive will be implemented using Microsoft SQL Server, and much of the front end will be web-based, probably implemented using SOAP and .NET, and adhering to the National Virtual Observatory standards.

6.REFERENCES

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