GALEX In-Flight Calibration Plan

Version 1.3

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Contents

Chapter 1

Introduction

This document describes the GALEX In-Flight Calibration Plan. This includes calibration activities that begin during the in-orbit checkout (IOC) phases of the mission. The calibration plan describes the overall goals of the in-flight calibration and outlines a baseline set of calibration tasks. A *calibration task* is the observation, configuration and analysis required to calibrate a specific aspect of the instrument.

Modification to this plan will occur throughout the mission, in the form of revised calibration requirements and the addition of new calibration tasks proposed by GALEX scientists and engineers.

Approval of this document by the responsible signatures will certify that:

1) This plan meets the requirements for the GALEX mission as set forth by the project level 1 and science and project requirements document (SPRD).

2) This plan addresses the needs of the GALEX Science Operations and Data Analysis pipeline.

3) This plan addresses the means by which ammendments and/or calibration tasks can be submitted and approved

1.1 Scope

This document solely controls the design and development of the in-flight calibration plan for use by the GALEX science and operations team. Other GALEX controlling documents are referenced where applicable.

Chapter 2

Calibration Activities and Requirements

2.1 Introduction

The primary goal of GALEX in-flight calibration is to ensure that the scientific quantities obtained from the GALEX instrument conform to the requirements set forth by the SPRD as well as additional requirements which are re-captured within this document. Updates to the calibration requirements should be captured within successive versions of this plan.

The GALEX in-flight calibration is designed to allow automated processing of GALEX data by the pipeline with the goal of producing a calibrated set of maps and spectra which can be used for astronomical data analysis. Ultimately, it is the ability to calibrate the on-orbit performance of the instrument and spacecraft that will allow us to recover the as-built performance to the levels required for scientific investigations.

In the broadest terms, this activity can be broken up into the following list of calibrations:

- **Spectrophotometric calibration:** This is a measurement of the instrumental bandpass. Calibration will yield a conversion factor between a measured count rate and a monochromatic flux, and determine how this factor varies with respect to focal plane position, global count rate, local count rate or environmental factors. Calibration will also quantify the ratio in the count rates of two different monochromatic fluxes measured in the same band and the ratio when measured in the separate NUV and FUV bands and spectral orders. We will primarily determine these quantities for the spectroscopic mode.

- **Photometric calibration:** This is a measurement of the broadband source-independent and source-dependent flux. Calibration will yield a conversion of a measured count rate into a broadband flux and the conversion of ratios of count rates into a broadband colors. Calibration will also determine the effective wavelength and wavelength range for which this flux measurement is being made. These quantities will be determined for the imaging (or direct) mode. For certain specialized cases, source-dependent conversion factors will be determined as a function of object type, color or redshift.

- **Spectral Dispersion calibration:** This is a measurement of the deviation in the measured position of light from a point source as a function of wavelength. This calibration will also determine the angular deviation of the dispersion direction as a function of satellite roll angle and grism rotator angle.

- **Astrometric calibration:** This is a measurement of the offset in position between the centroid of point sources measured by GALEX and their positions in as listed in Tycho-II ICRS (absolute astrometry). We will determine how the projected angular distance between objects (within a single 1 degree GALEX image) compares to angular separations in an astrometric reference catalog. Astrometric calibration performance will be quantified by determining what fraction of centroids fall within a given radius of their position in an astrometric reference catalog.

- **PSF calibration:** This is a measurement of the FWHM, 80% encircled energy, shape and wings of the GALEX point spread function and its variation with position, count rate, temperature.

- **Unit conversion calibration:** These are measurements of the conversion factors between housekeeping telemetry (in DN) and useful engineering units. In most cases (paticularly for absolute quantities) these conversion factors must rely on ground calibration. On occasion, redundant measures and models will be used to refine the calibration of these quantities.

- **Background calibration:** This is a determination of the total and relative contributions of the sources of background for a point source measurement with GALEX. Calibration will determine if this contribution varies significantly vs. time, environmental, orbit state, and will quantify scattered light from off-field bright stars and objects observed within the GALEX field of view. Finally we will determine whether the variance in the background consistent with Poisson/Gaussian noise or if there an additional component (confusion limit).

- **Time calibration:** This is a measurement of the absolute time of a given measurement and the relative time interval between two measurements.?

- **Planning function calibration:** This is a measurement of the deviation between the models and simulations used in the planning system.

Some of these calibrations require a special set of observations and analysis exercises in order to generate the appropriate tables and settings for the pipeline to ensure that the data are calibrated to sufficient accuracy. Others can be obtained using data collected during the GALEX science surveys.

2.2 Performance requirements

During the GALEX development phase, performance requirements for GALEX mission were quantified in order to establish error/accuracy budgets. These budgets have been used to set performance requirements and goals for instrument and spacecraft subsystems as well as to set requirements for the GALEX calibration. In most cases only the highest level requirements are driven by the science requirements.

The requirements relevant to the in-flight calibration are reviewed in the tables and description in subsequent sections.

2.2.1 Angular Resolution Requirements

The GALEX angular resolution budget is driven by considerably more factors than the conventional diffraction limited optical system. The GALEX telescope/optical system and detector both contribute to the PSF which varies across the field of view, largely driven by nonuniformities in the detector resolution with gain. Additionally, the detector system requires ex-post facto correction of photon word positions based on the (stochastic) characteristics of the detector photon pulse event. These characteristics are described by the detector walk and wiggle functions and solutions for these have been obtained on spatial scales of $<15''$.

During scan or dither mode, additional factors may contribute to the size and shape of the PSF. Since a point source may be observerd at several locations across the detector, uncorrected distortion on scales smaller than the spatial separation between measurements can introduce a blur. Measurement jitter within the attitude control system (and following any subsequent attitude refinement steps) will also contribute to the blur. [include plot of spatial scales and relevant frequencies]

Thermal and magnetic field variation may also cause the PSF to vary. In-flight calibration and analysis tasks will make an attempt to quantify this variation.

Table 2.1: GALEX Angular Resolution Budget

Subsystem	FUV 80% E.E. Diam	NUV 80% E.E. Diam
Optics	$3.0''$	$3.0''$

Detector Resolution	4.5″	7.0″
Linearity (unc)	1.0″	1.0″
Thermal Stability	0.5″	0.5″
Aspect	1.5″	1.5″
Drift	0.2″	0.2″
dB/dt	0.2″	0.2″
Total	5.5″	7.5″

The critical tasks for in-flight calibration are to 1) obtain the best possible resolution from the detector system by determining corrections for wiggle and walk [rectification] 2) obtain the best possible solution for distortion in the telescope/detector system to minimize uncorrected spatial non-linearity [transform] 3) determine the performance of the attitude control system and revise astrometric refinement functions as necessary to recover the aspect solution with the minimum error. [aspect] 4) Quantify impact of angular resolution on spectral mode characteristics (spectral resolution and spectrum FWHM) 5) Track variation in PSF performance with temperature and magnetic field and develop parametric calibration solutions as necessary.

Once the point spread function has been characterized, these data will be analyzed to determine how best to use GALEX measurements to recover the true (or relative) flux of astronomical sources.

2.2.2 Spectral resolution, dispersion

DNL contributions to spectral shape It will be important to diagnose and remove DNL contribitions to the measured spectrum

2.2.3 Photometric Accuracy Requirement

GALEX will be the first space ultraviolet mission to cover the sky with enough depth and solid angle that it will obtain measurements of millions of astronomical sources. The usefulness of this large data set will be determined by the ability of the GALEX project to provide reliable fluxes for a broad set of astronomical targets. These requirements are principally driven by initial estimates from the primary science requirements. Performance estimates suggest that the photometric accuracy of GALEX measurements should be within this budget.

Absolute photometric accuracy is the ability to determine the true flux of an astronomical object. This flux can be determined as a broadband bandpass-averaged flux within the instrumental band, or as a source dependent monochromatic flux or SED-fit magnitude. Zero-point accuracy denotes errors in the conversion between a measured count-rate and a band-averaged instrumental flux. Color term accuracy relates to errors in the conversion between a band-averaged instrumental flux and either a monochromatic flux or a flux measured at a (source-dependent) effective wavelength through a (source-dependent) effective filter bandpass. Band shape accuracy relates to errors in the conversion between a band-averaged instrumental flux and the apparent magnitude of a source with a given SED. Color term and band shape errors are covariant—in general only one of the two (color terms or SED folded through band shape) will be used for analysis. Field dependent accuracy denotes errors in any quantity that vary with field position, possibly due to true instrumental variance or to deficiencies in the quality of calibration across the field. Reddening correction accuracy denotes approximate uncertainties in Galactic line of sight extinction over the UV passband. Dead-time and threshold errors result from the conversion of detector electronic count rates to detector head count rates.

Relative band-to-band accuracy denotes the error in the UV (f-n) color of an astronomical source. Color term correction or band shape errors are again relevant to the determination of source-dependent fluxes. Stability requirements track changes in instrumental throughput and band shape.

Table 2.2: GALEX Photometric Accuracy Budget

Component	Accuracy (mag)	Accuracy (mag)
Absolute	0.2	
Zero point		0.1
Color term (f-n)		0.1
Band Shape		0.1
Field Dependence		0.1
Galactic Reddening		E(B-V)
Dead Time/Threshold		0.02
Relative (NUV-FUV)	0.1 m	
Absolute		0.05
Color Term (f-n)		0.05
Band Shape		0.05
Field Dependence		0.05
Galactic Reddening		0.5*E(B-V)
Dead Time/Threshold		0.01
Stability	0.05 /yr	
Absolute		0.03 /yr
Relative		0.01 /yr
Band Shape		0.01 /yr

The critical tasks for in-flight calibration are to: 1) Measure the broad band flux of a spectrophotometric standard and obtain an approximate zero point, 2) verify the GALEX bandpass measurement from ground calibration using spectroscopic mode and cross-calibration 3) Determine/refine color terms and band shapes using secondary spectrophotometric calibrators and line sources. 4) Study Galactic reddening calibration using halo objects, number counts, spectroscopy observations. 5) Measure dead time in detector electronics system, 6) Track stability.

2.2.4 Spectrophotometric Accuracy Requirement

Spectrophotometric accuracy applies to the GALEX spectroscopy mode which will be calibrated to provide monochromatic flux measurements in each spectral bin. Because GALEX performs slitless grism spectroscopy, aperture effects are reduced allowing for straightforward comparison between spectroscopy and imaging measurements. GALEX spectrophotometric calibration will be tied to the HST WD scale for UV to NIR measurements (Bohlin, et al). WD standard stars with accurate models (and fields free of bright stars) are the highest priority targets.

Table 2.3: GALEX Spectrophotometric Accuracy Budget

Component	Accuracy (%)
Absolute	20
Relative (NUV-FUV)	5 (2 sig)
Relative (bin-to-bin)	5 (2 sig)
Relative (Im-to-Sp)	10
Galactic Extinction	E(B-V)
Field dependence	5
Stability	5/year

The critical tasks for in-flight calibration are to: 1) Obtain the absolute spectrophotometric calibration of GALEX spectroscopy mode traceable to and HST WD standard. 2) Extend the absolute calibration to the full field of view and for a number of grism rotations. 3) Determine bin-to-bin, NUV to FUV variance using measurements of several standards. 4) Generate conversion between spectroscopy mode and imaging mode using empirical/model bandpasses for both modes. 5) Refine Galactic extinction calibration (particularly to remove 2200Åbump from flat contimuum spectra. 6) Track stability.

2.2.5 Background Accuracy/Variance Requirements

Background/variance requirements are related to the ultimate performance of the GALEX instrument in three important ways: 1) The deepest GALEX measurements should be made in regions with the lowest astronomical backgrounds, 2) developing an accurate background model is crucial for planning surveys in regions where the highest signal to noise is to be obtained (Planning also requires on background knowledge for modelling satellite data load) 3) background variance that exceeds the statistical noise will ultimately limit the deepest GALEX surveys. It is the goal of the in-flight calibration to ensure that the planning background model is accurate, low background targets are observed, and background variance is kept to a minimum.

Table 2.4: GALEX Background/Variance

Component	Intensity (PHU)	Angular Scale
Cosmic	250 PHU	arcmin
Zodiacal	700 PHU	deg
Airglow	25 PHU	deg
Phosphorescence	25 PHU	deg
Scatter/Stray Light	25 PHU rms	arcsec/arcmin
Uncal Flat-Field	25 PHU rms	arcsec/arcmin
Spectroscopy	25 PHU rms	arcsec/arcmin

The spatial scales over which the background varies is of particular relevance to point source and spectral extractions. In general only arcsec scale fluctuations are relevant for point source extractions. However, arcmin scale flucutations can increase the background noise in rotation-averaged grism spectra.

2.2.6 Observation Efficiency Requirements

These requirements are largely planning requirements and are only shown for reference.

Table 2.5: GALEX Observation Efficiency

Component	Quantity
Mission Duration	20 Months
Observation Efficiency	90%
Survey Area	2 sq. deg (DSS)

EEDS Throughput	0.95
Abs. Pointing Control	5′
Margin	4 Months

2.3 Time

Relative event timing is essential to almost all GALEX processing tasks, whether it be trend monitoring, photon position-reconstruction or data-flagging. Any scientist wishing to conduct time-series astronomical photometry using GALEX data may require absolute timing information that far exceeds the mission requirements but which may be recoverable from the GALEX spacecraft time and a detailed knowledge of the satellite ephemeris (e.g. light requires 2 ms to travel between the satellite and the closest point on the earth). In this section we describe the various GALEX timing methods and the process by which relative and absolute times are constructed and calibrated.

2.3.1 DPU Time

The Command and Housekeeping handler on the DPU is activated at 200 Hz through a level-5 interrupt derived from 2kHz and 1Hz spacecraft clocks. The DPU Flight Requirements and Design Document (GAL-JPL-322) describes the details of this process.

2.3.2 Photon Event Timing

When a photon strikes the photocathode surface of the GALEX detectors, less than 100 ns of time passes before the detector front end electronics begins the process of digitizing the photon event information. Compared with all downstream measures, this process is instantaneous.

By contrast, the digitization of the photon event is relatively time-consuming requiring roughly 5 ms.

2.3.3 On-Board Photon Time-Tagging

Every 5 ms, buffered photons from each detector are queued and readied to be passed on to the spacecraft solid-state recoreder. Each 5 ms photon packet is preceded by a descriptor that gives spacecraft time (seconds and 5 ms slot number[0-199]) when the packet was started. Since a maximum of 125,000 photons per second may be delivered by either detector channel, a maximum of 675 photons per 5 ms per detector will be processed.

2.4 Photometry

Because GALEX will provide a vast photometric and spectrophotometric data set we will make every effort to provide continuity and consistency with other UV data sets (e.g. HST) and other large-angle photometric surveys (e.g. SDSS). Specific details relevant to GALEX photometric calibration are described below. The reader is referred to the bibliography at the end of this document for a further discussion of the various issues relating to photometric methods.

2.4.1 Notation

Galex magnitudes will be given in two bands f and n, and unless otherwise specified the magnitude or flux will be expressed as m_ν or f_ν, using the AB system (Oke, 1974) based on spectrum with a constant flux per unit frequency and a zero-point approximately based on the V magnitude of α Lyrae (Vega). These quantities will be given in broadband instrumental units unless otherwise indicated. On occasion we will express magnitude or flux as m_λ or f_λ, using the ST (Space Telescope) lambda system based on a spectrum with a constant flux per unit wavelength and approximate α Lyrae (Vega) zero-point. Again these quantities will be given in broadband instrumental units unless otherwise specified.

The two systems have zero points given by:

$$m_\nu = -2.5 \log f_\nu - 48.6 \quad \text{AB mag}$$

$$m_\lambda = -2.5 \log f_\lambda - 21.1 \quad \text{ST mag}$$

where f_ν is in units of ergs s^{-2} cm^{-2} Hz^{-1} and f_λ in units of ergs s^{-2} cm^{-2} $Å^{-1}$. As described in the Space Telescope Synphot guide, a source-independent relationship between these two magnitude systems can be determined at a *pivot* wavelength, λ_P for a bandpass B:

$$f_\lambda(B) = f_\nu(B) \frac{c}{\lambda_P(B)^2}$$

or

$$m_\nu(B) = m_\lambda(B) - 5 \log \lambda_P(B) + 18.70$$

where the pivot wavelength is given by:

$$\lambda_P = \sqrt{\frac{\int P_\lambda \lambda d\lambda}{\int P_\lambda d\lambda/\lambda)}}$$

and P_λ is the dimensionless passband throughput as a function of wavelength.

The definition of the pivot wavelength can be derived using the above relation between f_ν and f_λ and expressions for the conversion of broadband flux to count rates (e.g. zero-point) in the two systems:

$$\int f_\lambda(\lambda)P_\lambda\lambda d\lambda = CR(B) = f_\lambda(B)\frac{\int P_\lambda\lambda d\lambda}{\hbar c/\mathrm{Area}}$$

$$\int f_\nu(\nu)P_\nu d\nu/\nu = CR(B) = f_\nu(B)\frac{\int P_\nu d\nu/\nu}{\hbar/\mathrm{Area}}$$

where Area is the telescope collecting area.

The bandpass can be characterized by the effective wavelength, either wavelength or frequency averaged or

$$\bar{\lambda} = \exp[\frac{\sqrt{\int P_\lambda \ln \lambda d\lambda/\lambda}}{\sqrt{\int P_\lambda d\lambda/\lambda}}]$$

from Schneider, Gunn and Hoessel (1983) which is aesthetically pleasing because the similarly defined $\bar{\nu} = c/\bar{\lambda}$. The fractional bandwidth and fwhm:

$$\sigma = \frac{\sqrt{\int P_\lambda \ln(\lambda/\bar{\lambda})^2 d\lambda/\lambda}}{\sqrt{\int P_\lambda d\lambda/\lambda}}$$

$$fwhm = \sqrt{8\ln 2}\sigma\bar{\lambda}$$

The wavelength averaged effective wavelength is:

$$avglam = \frac{\int P_\lambda\lambda d\lambda}{\int P_\lambda d\lambda}$$

A flux sensitivity quantity is given by:

$$qflam = \int (P_\lambda d\lambda)/\lambda$$

$$uresp = (\hbar c)/(area\int P_\lambda\lambda d\lambda)$$

Source dependent quantities:

$$avglam = \frac{\int f_\lambda P_\lambda\lambda d\lambda}{\int f_\lambda P_\lambda d\lambda}$$

$$barlam = \exp[\frac{\sqrt{\int f_\lambda P_\lambda \ln \lambda d\lambda/\lambda}}{\sqrt{\int f_\lambda P_\lambda d\lambda/\lambda}}]$$

$$efflam = \frac{\int f_\lambda P_\lambda \lambda^2 d\lambda}{\int f_\lambda P_\lambda \lambda d\lambda}$$

$$effstim = (\hbar c)\frac{\int f_\lambda P_\lambda \lambda d\lambda}{\int P_\lambda \lambda d\lambda}$$

$$rmslam = \bar{\lambda}\frac{\sqrt{\int f_\lambda P_\lambda \ln{(\lambda/\bar{\lambda})^2} d\lambda/\lambda}}{\sqrt{\int f_\lambda P_\lambda d\lambda/\lambda}}$$

$$fwhmlam = \sqrt{8\ln 2} \times rmslam$$

Aperture/spectral bin sizes to be defined 80defined for photometry - consider specific radius width for photometry.

Photometry Basic Definitions and Considerations (II) ? Other issues Higher order spectra will be calibrated? Scattering/ghosts must be handled consistently throughout calibration process Saturation/high count-rate effects more complicated with full spectra than single point source We might need additional faint HST WD spectrophotometric standards in regions devoid of other bright objects at high ecliptic latitude, etc. In-Flight Calibration Task 1001

2.5 GALEX Definitions

GALEXCAL zone: A field angle/detector location that has been used to make an absolute calibration measurement, on the ground and in-orbit. Ideally several zones would be defined, spread across the detector. Ground calibration of these zones are NIST traceable to better than 5% accuracy.

Dither zone: The size of a spiral dither pattern in field angle/detector space. This defines the area over which response may be averaged.

Chapter 3

GALEX In-Flight Calibration Observation Plan

3.1 Overview

The current GALEX mission is 28 months in duration (approximately 12500 eclipses) following a one month in-orbit checkout (IOC). Roughly 150 eclipses during in-orbit check-out will be devoted to calibration observations and up to 500 eclipses during the nominal mission will be reserved for targeted calibration activities. This corresponds to one observation per day during the first six months of the mission and once every two days for the subsequent 22 months. It is only 5% of the total mission observing time—we might find that this allotment is inadequate. However, a significant portion of the calibration can be performed with data collected during the various GALEX surveys (self-calibrating).

Detector background measurements are particularly useful for monitoring and trending the state of health of the detector system and will be performed for one third of the calibration orbits (50 eclipses during IOC, 160 eclipses during the nominal mission). Absolute spectrophotometric and photometric calibration is also a high priority for targeted observations and will also comprise roughly 1/3 of the observations. The remaining 1/3 of the calibration eclipses will be devoted to specialized calibration activities.

Table 3.1: In-Orbit Checkout Calibration Observations

Task	Mode	Ecl	Rot	Pts.	Band
Specphot WD I	D	2	-	9	FUV + NUV
Specphot WD I	G	8	4	9	FUV + NUV
Specphot WD II	D	2	-	9	FUV + NUV

Task	Mode	Ecl	Rot	Pts.	Band
Specphot WD II	G	8	4	9	FUV + NUV
Specphot WD III	D	2	-	9	FUV only
Specphot WD III	G	8	4	9	FUV only
Secondary Field I	D	2	-	9	FUV + NUV
Secondary Field I	G	8	-	9	FUV + NUV
Secondary Field II	D	2	-	9	FUV only
Secondary Field II	G	8	-	9	FUV only
Disp. Symb St I	D	1	-	5	FUV
Disp. Symb St I	G	4	4	5	FUV
Disp. Symb St II	D	1	-	5	FUV
Disp. Symb St II	D	4	4	5	FUV
Disp. AGN/QSO I	D	1	-	5	FUV + NUV
Disp. AGN/QSO I	G	4	4	5	FUV + NUV
Disp. AGN/QSO II	D	1	-	5	FUV + NUV
Disp. AGN/QSO II	D	4	4	5	FUV + NUV
Zod Bkg/Dead Time	D	5	-	1	FUV + NUV
Gal Bkg/Dead Time	D	5	-	1	FUV + NUV
Limb/Earth Bkg	D	4	-	1	FUV + NUV
Moon Bkg	D	4	-	1	FUV + NUV
FOCA	D	4	-	1	FUV + NUV
FOCA	D	8	2	1	FUV + NUV
Dark Counts	O	50	-	-	FUV + NUV

Table 3.2: In-Flight Calibration Tasks by Mission Phase

Task	IOC	Img Surv.	Spec. Surv.	Special
	Special Targets			
Specphot stds	X			X (100)
Sec. Std fld	X			X (100)
Previous UV obs.	X	ALL	WSS	X (25)
High/low bkg targ	X	AIS		X (25)
Scatt/Stray Light	x	AIS	WSS	X (25)
Astrom. stds				X
High CR targ		AIS		X (25)
Extended Obj		AIS/NGS		X

Task	IOC	Img Obs.	Sp. Obs.	Special
Special Instrument Configuration				
Opaque	X			X (150)
Grism motion				X
HV Settings				X
FEE Settings				X
Special STIM				Day
Thermal Var				X
Special Satellite Configuration				
Special scan/slews	X			X
Roll angle var	x	DIS	ALL	X
Ram angle var	x	ALL	ALL	X
Tracker angle var	x	DIS	ALL	X
Mag field	x	ALL	ALL	X
Data during X-band	x	ALL	ALL	X
Nominal Surveys Self-Calibration				
Repeated Fields	X	ALL	ALL	
Overlap regions	X	ALL	WSS	
Stim Data	X	ALL	ALL	
Astrom. star fld	X	ALL	ALL	
Scanned Observations		AIS		
Galactic Extinction		AIS/MIS	WSS	

In-flight calibration observations fall in several categories:

In this chapter, a short description of some of the observations associated with each of these will be given.

3.2 Observation Modes

The time-tagged photon data stream from the GALEX spacecraft allows us to acquire data while slewing and reconstruct the image based on satisfactory knowledge of the spacecraft aspect solution. This reconstruction is designed to obtain as accurately as possible the instrumental point spread function.

To recover this PSF, we must apply a series of corrections to the photon data DN, converting these numbers to an angle relative to the instrumental boresite and a time-tag. From there, we apply the aspect solution to produce the sky position for each photon. The GALEX pipeline module responsible for applying the conversion from DN to sky position is the RTA module. This module takes as input a collection of calibration files which are used

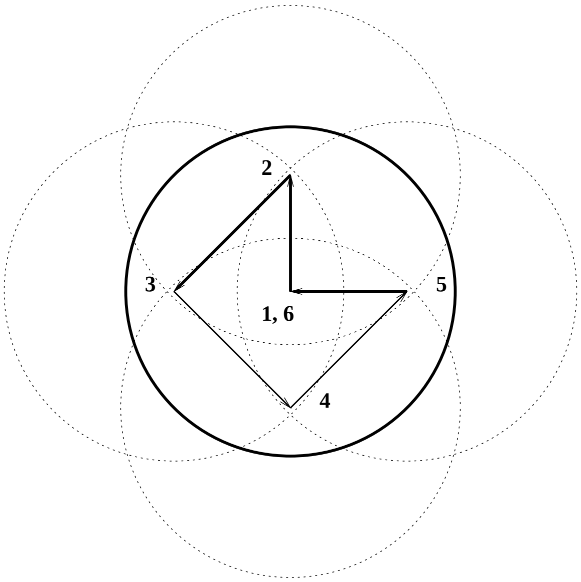


Figure 3.1: Six point observing cluster for special calibration modes. Circles indicate GALEX field of view. Points on cluster "star" are about 0.4 degrees from the center. At each point GALEX will execute a dither pattern. After ~250 seconds, the satellite will slew the boresite to to the next position and restart the dither.

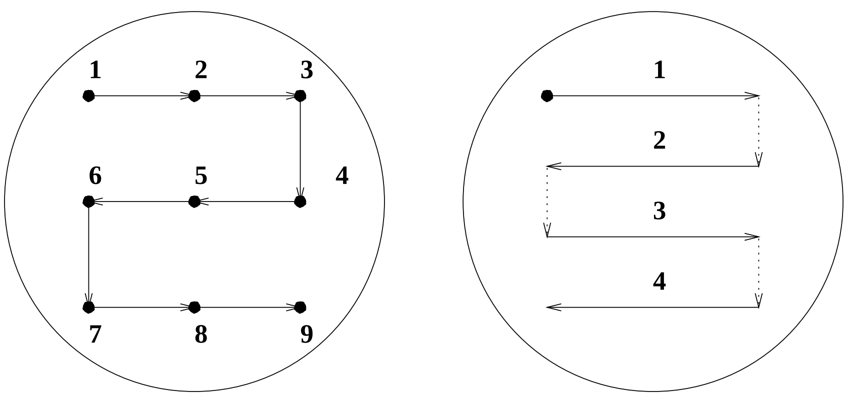


Figure 3.2: Two observing clusters for enhanced coverage. Left pattern is a nine-point cluster, with a dither executed at each point. The right pattern is a 4 scan maneuver, similar to the All-sky survey but with shorter scans.

to "rectify" the photon from a series of detector-specific quantities into an X, Y coordinate position, and then to apply the transformation from this coordinate into an instrumental boresight angle.

3.2.1 Astrometric Standards

GALEX does not have a strong requirement for excellent astrometric standards. The Tycho catalog and GSC2 provide all-sky standards that yield an average of 25 to 10,000 or more stars per field with accurate relative and absolute astrometry, with an average angular sampling rate of 15' to 45" in each catalog. Ultimate astrometric reference will be to the International Celestial Reference Frame.

Ideal astrometric standard fields contain a large number of stars with known positions, but with no stars which exceed the GALEX bright star limit within or close to the field. Ideally, proper motion or parallax corrections should not be required for the stars within this field, meaning that we should avoid fields with usable stars within 5-10 pc with large proper motions.

3.3 Calibration Stability

Table 3.3: GALEX Performance Stability Timescales

Effect	Sub-orbit	Orbit	Day-Week	Months	Anomaly
		Throughput			
Contamination	IOC/Heater	IOC	IOC/Decon	Outgas	Solarize
Atomic O				Ram	
Rad dam.				Gradual	
Dead Time	Br. St, bkg	Br. St, bkg	FEE drift	FEE drift	FEE upset
Detector gain sag	Bright Star	Tmp sag	Tmp/perm	Perm sag	Bright Obj
QE deg				Gradual	Leak
		Flat-Field			
Contamination	IOC/Heater	IOC	IOC/Decon	Outgas	Solarize
PHD - Gain Sag	Brt St	Tmp sag	Tmp/perm	Perm	Bright Obj
Distortion	B, T	B, T	B, T	B, T	Local CR
vs. Wavelength	Thermal	Thermal		Contam	Contam
		Background			
Gal/Zod	Scan	Target/lat	Plan	Plan	Poor Predict
PHD - Gain Sag	SAA	SAA	T, SAA	Hot spot	Hot Spot
Offband light	Limb	Limb	T	Atmos	Poor reject
Phosphorescence	SAA	Tau	Tau	Rad. deg	Poor predict
Scatt/Stray	Brstar	Brstar	Limb	Optics deg.	Deg
		Scattered/Stray Photon			

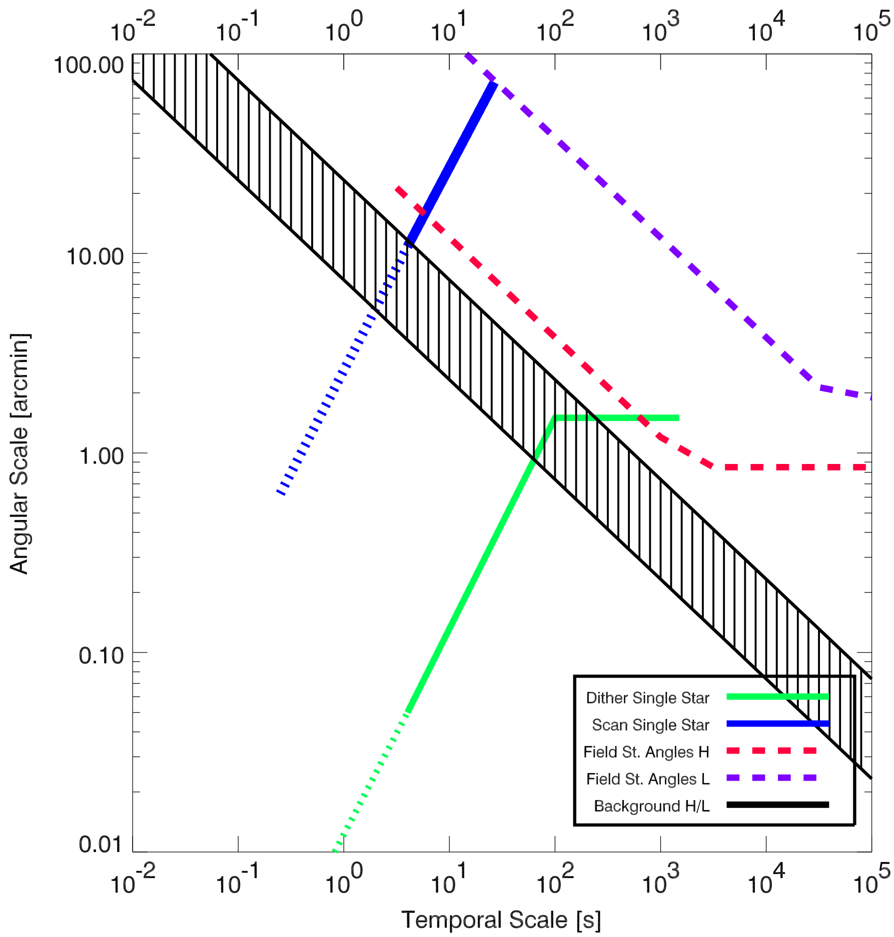


Figure 3.3: Relevant angular scales measured over different timescales for various observations during in-flight calibration and the nominal mission.

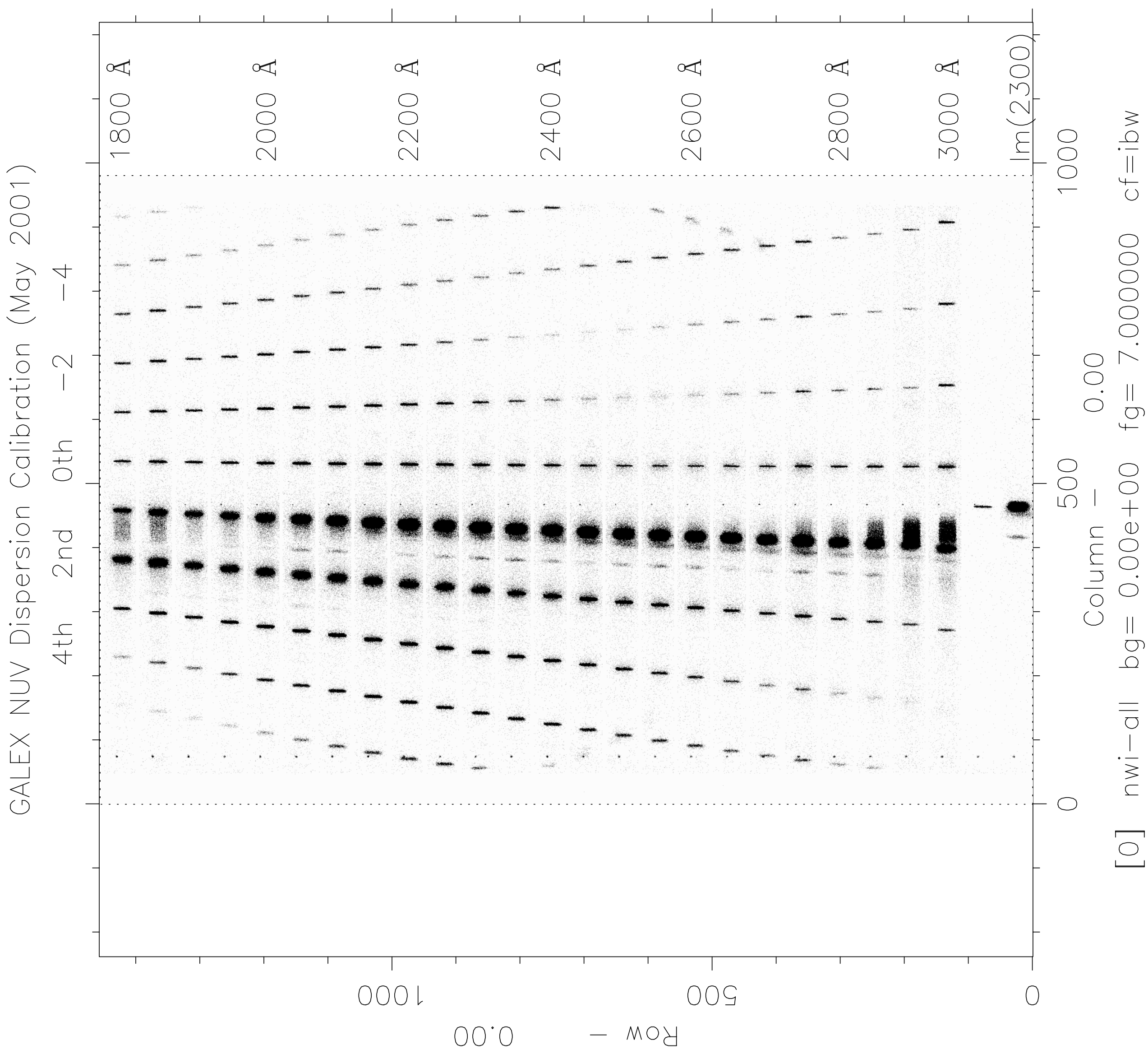


Figure 3.4: Dispersion data from ground calibration used to determine dispersion solution for NUV detector

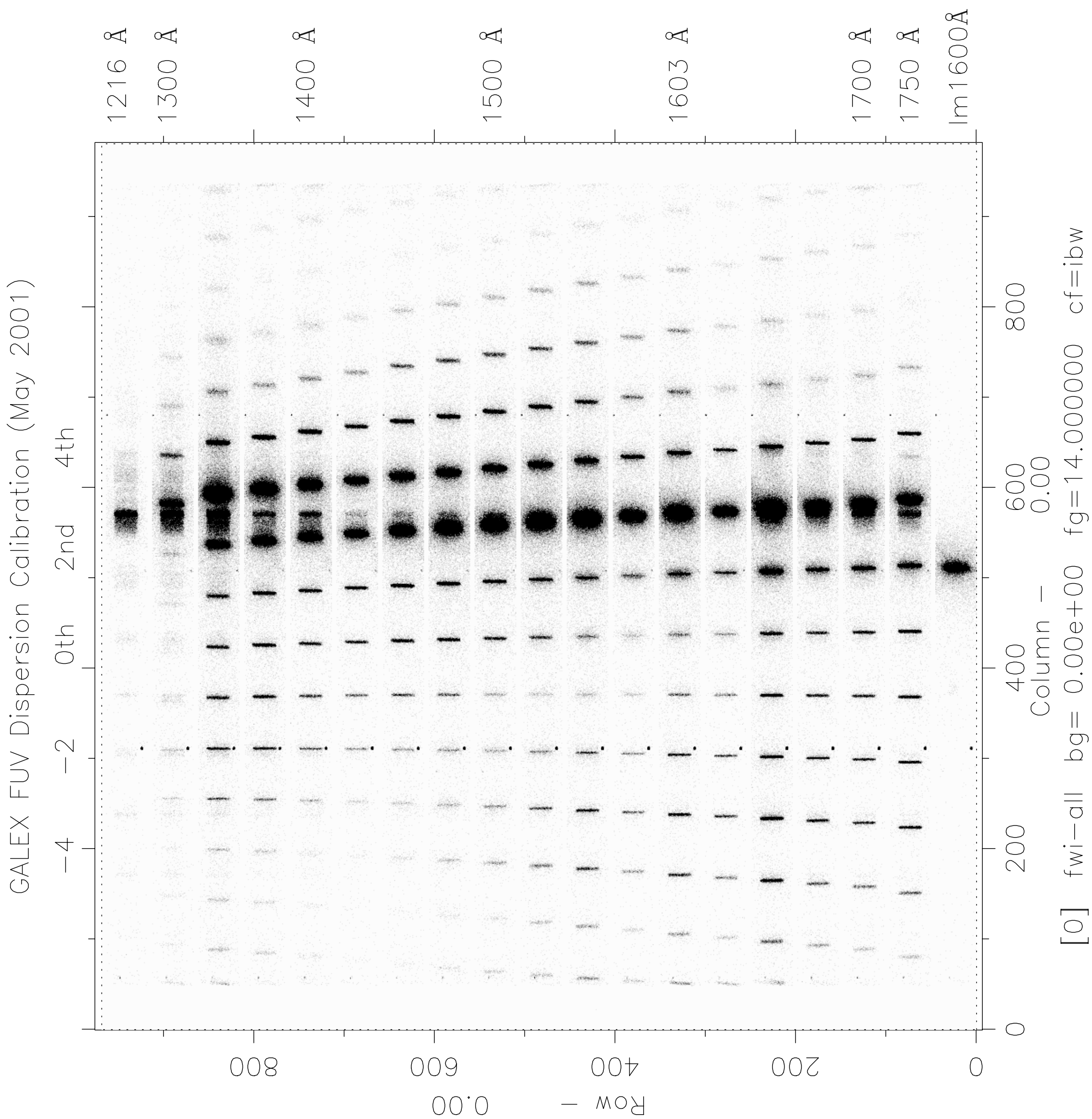


Figure 3.5: Dispersion data from ground calibration used to determine dispersion solution for FUV detector

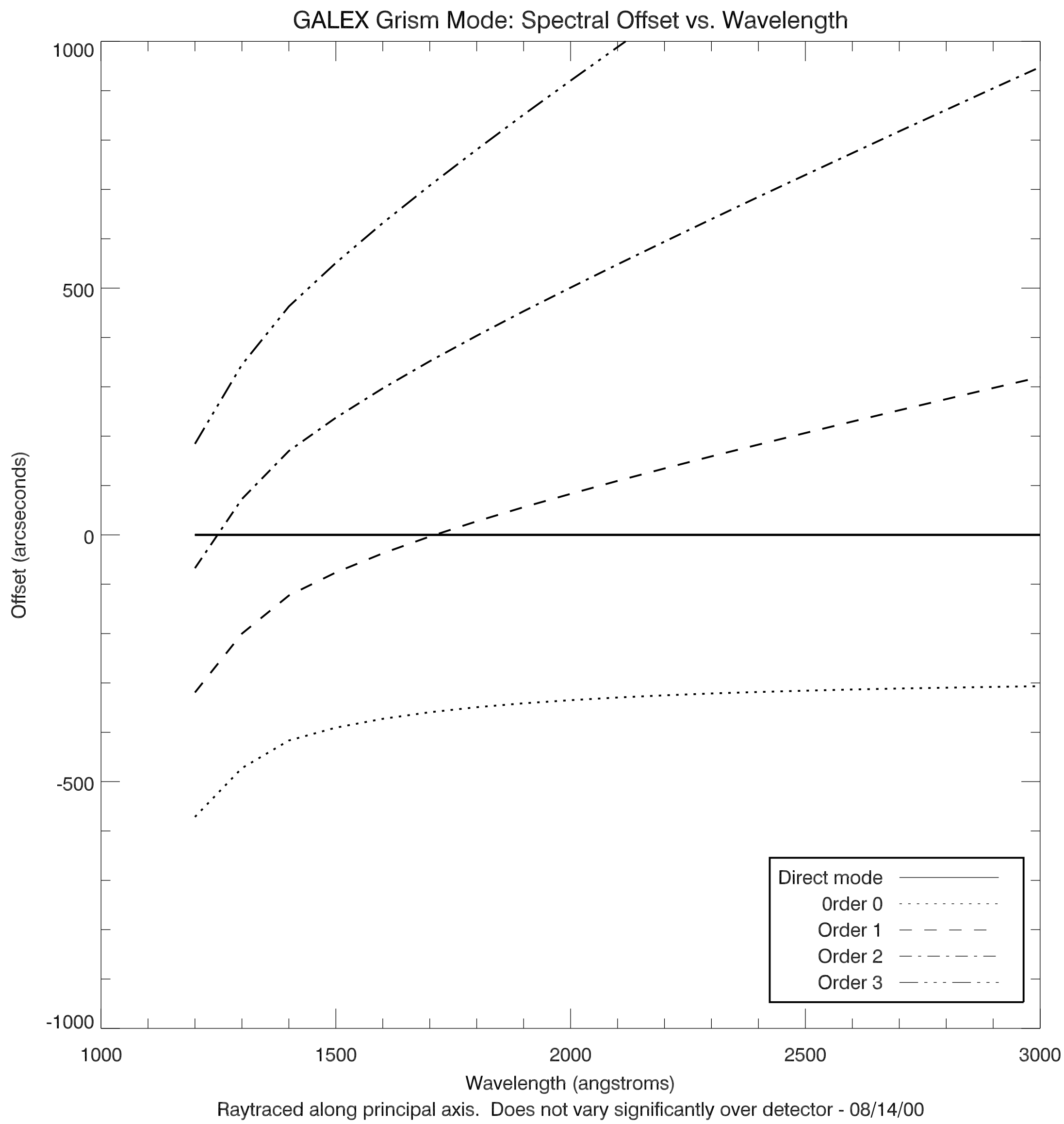


Figure 3.6: Dispersion data from ground calibration used to determine dispersion solution for NUV detector

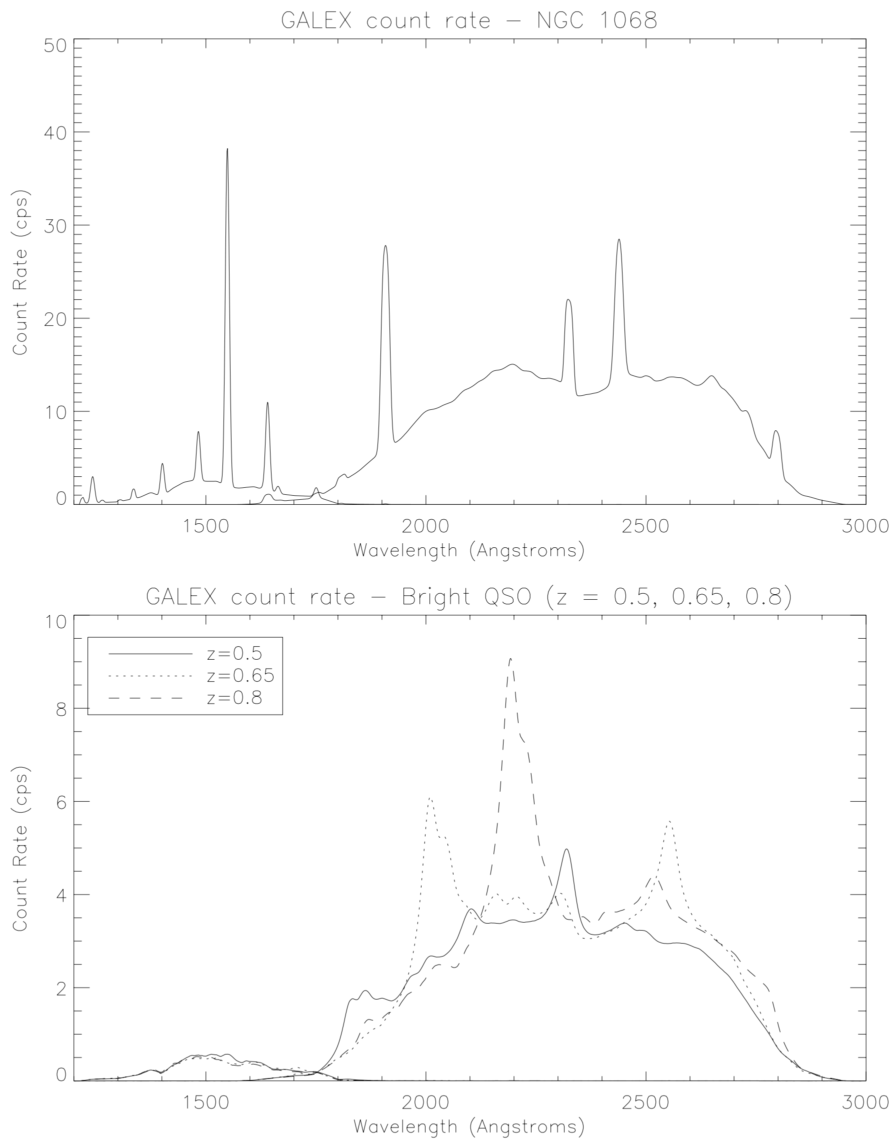


Figure 3.7: Predicted measured count rate from Seyfert galaxy 1068 and bright QSOs at redshifts between 0.5 and 0.8

Effect	Sub-orbit	Orbit	Day-Week	Months	Anomaly
Contam	IOC/Heater	IOC	IOC/Decon	Outgas	Contam
Opt degred				UV expos	rapid deg
Nearby star	scan pat	scan pat	plan	plan	Poor plan
Earth limb	scan pat	scan pat	plan	plan	Poor plan
Detect septa					HV setting
FEE High CR	Brstar	Brstar		Settings	Settings
Point Spread Function					
HV				HV change	HV change
RFI/Noise	RFI	RFI	FEE unstab	FEE unstab	
Telescope	T shock	shock	creep	creep	relax
Jitter	rate/noise	rate/drift	drift	drift	ACS fail
Uncor non-lin walk	dXX/dt	dXX/dt	many	many	
Absolute Pointing					
ST to bore shift	T shock	shock	drift	creep	perm
Bore - det shift	T shock	shock	drift	creep	perm
NUV - FUV shift	T/B diff	T/B diff	creep	creep	
ACS perf	slew	Scan rate	drift	New setting	Miscalib
Det Mag Field shift				Slow var	Poor predict
Det Therm shift	det/FEE var	det/FEE var			Poor predict
Scale, Distortion, Walk, Wiggle					
Anode prop	T shock	shock		FEE settings	
Det walk	Gain sag	Gain var		FEE settings	
High CR local	Brt Star	Scan	plan	plan	poor plan
B field		Earth	Earth	Mat. drift	
FEE	CR?			Setting change	Setting change
Telescope distortion	T shock	shock	creep	creep	

3.4 Absolute Throughput

3.4.1 UV Spectrophotometric Standards

Spectrophotometric standards have been collected from the list of HST spectrophotometic standards on the White Dwarf scale, that have been used by STIS and other ground-based and space-based instruments. These standards, and anticipated countrates are given in the table in Chapter 7.

3.5 Relative Throughput

The relative throughput measurement relates the throughput at one position in the field of view to throughput at other positions. The throughput in several locations in the GALEX field of view will be tied to an absolute reference.

The method used in flight will be similar to the one used during ground calibration (described by Wyder, DS). For ground calibration these data consist of out-of-focus images

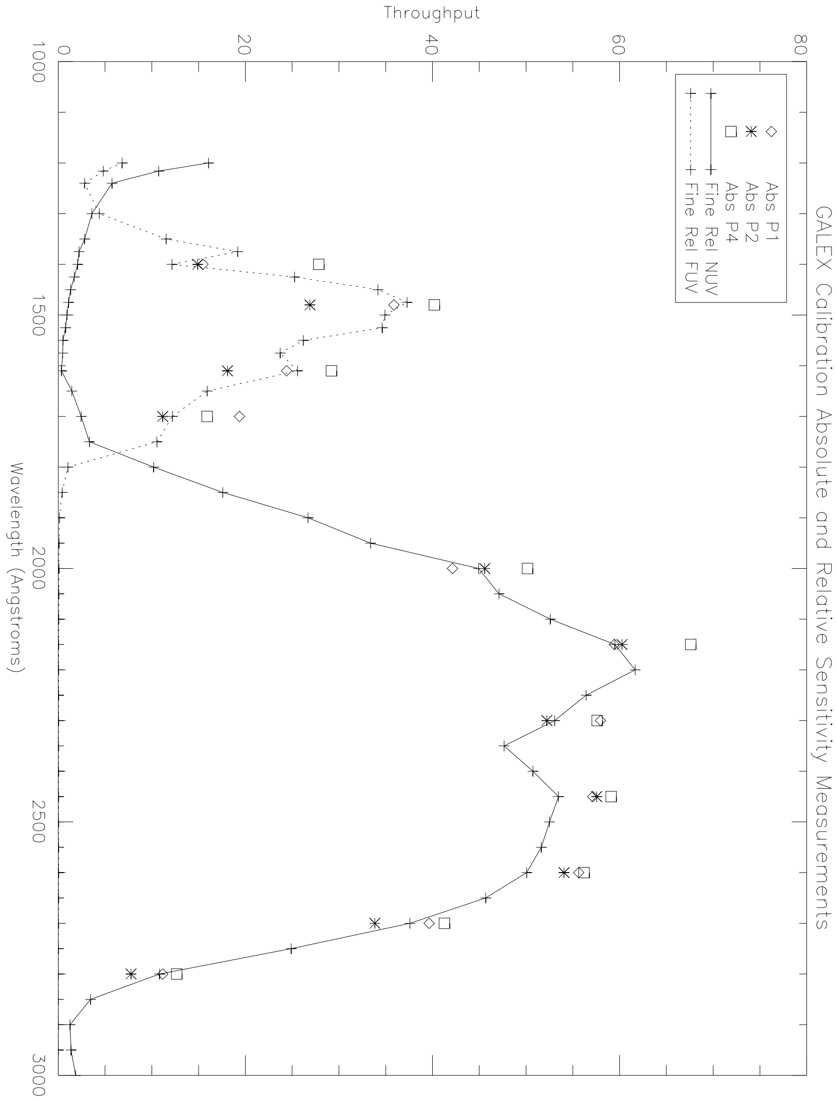


Figure 3.8: Absolute sensitivity data from ground calibration

of an array of pinholes. The spots are sufficiently out of focus that they all appear as rings. In each test, a set of exposures was taken at 2-3 wavelengths in the FUV and NUV each. At each wavelength, typically 8x300 sec exposures and one 1200 sec exposure were taken, each centered at a different point on the detector. A given spot falls on nine different positions on the detector.

One can solve for the relative sensitivity in a grid of points with the resulting relative sensitivities are all relative to this central point. The resulting matrix equation was then inverted using the singular-valued decomposition routine within IDL.

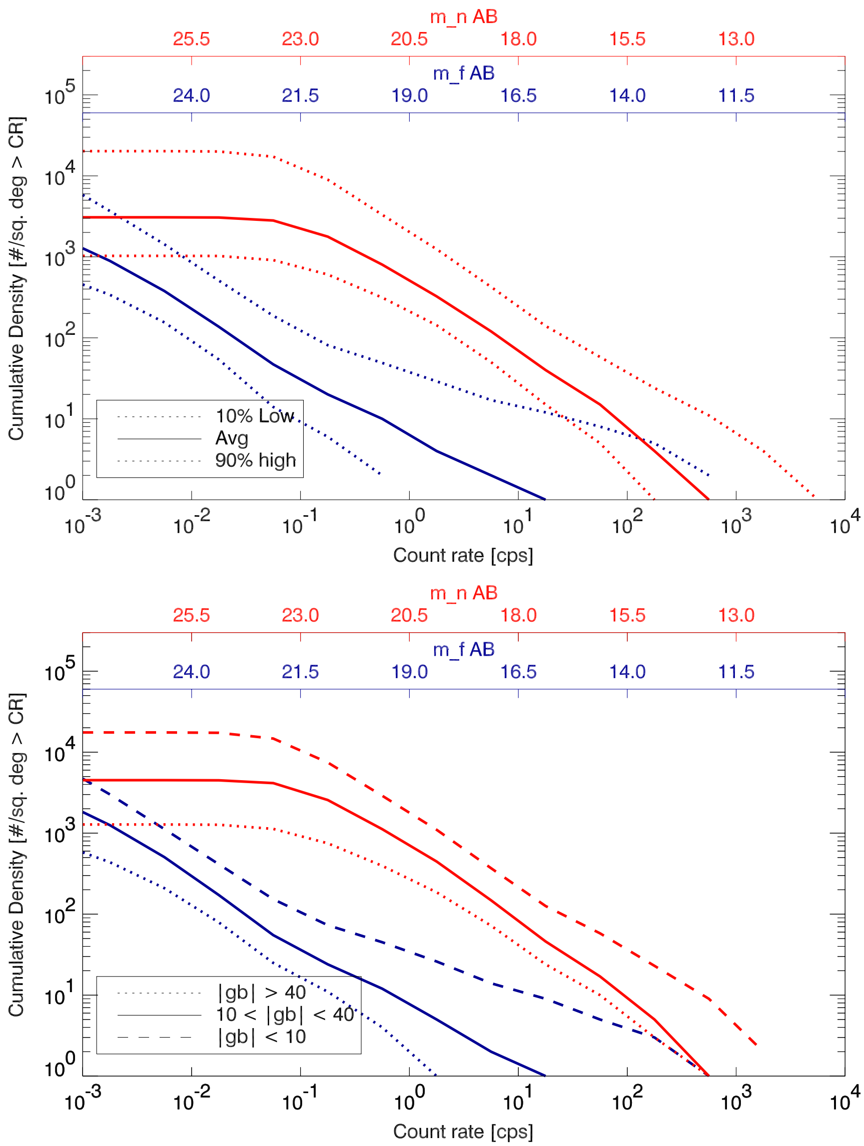


Figure 3.9: Cumulative star counts divided by quantile and by Galactic latitude.

Chapter 4

Calibration and Monitoring Tasks

4.1 Introduction

Calibration tasks are the primary means by which the performance of the GALEX instrument is determined and calibration data products and reports are delivered to the science pipeline and science team. Some calibration tasks require special observations. Others use data from the nominal science mission, or archival data in order to generate the appropriate data products. There are four principal categories of tasks and some tasks may overlap several categories.

Table 4.1: GALEX Calibration/Monitoring Task Categories

Task	Obs. Request	Product	Report
Health/Monitoring Observations	Yes	No	Yes
Calibration Observation	Yes	Yes	No
Archival Analysis	No	Yes	No
QA/Trending	No	No	Yes

Health and monitoring observation requests are designed to obtain data which is used to show that the instrument and satellite performance is not showing signs of degredation. (e.g. detector background measurements.) These tasks will always result in a summary report. Calibration observations obtain data not normally collected during the nominal science surveys. (e.g. absolute spectrophotometric standards and target clusters). These tasks are always designed to generate a calibration product for the pipeline. Archival analysis uses previous calibration measurements and/or science survey data to generate pipeline calibration products. Most of the calibration activities will fall in this category. QA/Trending analysis uses previous calibration measurements and/or science survey data to generate a summary report. This summary report may recommend additional tasks and generation of new calibration products.

4.2 Calibration Task proposals

Every six months the science operations center will solicit calibration tasks from SODA staff and the science team. A time allocation committee comprised of science team and SODA staff members will accept/reject/prioritize the tasks and submit them to the SOC team for scheduling and to the SODA team for analysis input.

This initial plan is designed to outline calibration tasks for the nominal mission, but concentrates on those that will take place during the in-orbit checkout and the following six months. A special meeting of the TAC will take place during the first month of the nominal science mission to incorporate updates to this initial plan based on the results from the in-orbit checkout. The first set of proposals for the next calibration semester will be due at the beginning of August, 2003.

Roughly 75-100 eclipses of observations will be devoted to specialized calibration activities during each six month interval although the committee may recommend that this number be increased or decreased depending on the needs and requirements of the science surveys.

After anomalies or in urgent situations, additional calibration tasks may be added in between the six month cycles.

Each new semester of scheduled tasks will start at a new number, incremented by 1000 each time. The tasks in this plan begin with 1001. The next cycle will begin at 2001, etc.

Table 4.2: GALEX Calibration Task Scheduling Timeline

Semester	Start Date	Prop. Date	Task Number
IOC/Initial plan	4/03	n/a	1001-1999
Fall 03	9/03	8/03	2001-2999
Spring 04	3/04	2/04	3001-3999
Fall 04	9/04	8/04	4001-4999
Spring 05	3/05	2/05	5001-5999

4.3 Calibration Tasks

Subsequent pages in this plan describe an initial set of calibration tasks for use during the in-orbit checkout and early part of the science mission.

Table 4.3: Calibration Tasks

Task	Description
Tasks Requiring Special Observations	
1001	Photometric Zero-Point Calibration, Imaging Mode, FUV and NUV
1002	Absolute Spectrophotometric Calibration, Grism Mode, FUV and NUV
1003	Photometric Zero-Point Calibration
1004	Absolute Spectrophotometric Calibration, Grism Mode, FUV only
1005	Secondary Field Photometric Calibration, Imaging Mode, FUV and NUV
1006	Secondary Field Photometric Calibration, Grism Mode, FUV and NUV
1007	Secondary Field Photometric Calibration, Imaging Mode, FUV only
1008	Secondary Field Photometric Calibration, Grism Mode, FUV only
1009	Spectral dispersion solution I
1010	Spectral Dispersion solution II
1011	Zodiacal light/dead time calibration
1012	Galactic background, dead time, flat field
1013	Earth Limb background measurement
1014	Bright Moon background
1015	FOCA Cross calibration and grism observations
1016	Detector Background, Hot Spot, Phosphorescence, Health Monitoring
Tasks Using Survey Data	
1100	Point spread function calibration and stability
1101	Grism orientation angle calibration, stability
1102	Detector Gain Map
1103	Detector Wiggle Correction
1104	Cal Stim Data Analysis
1105	Detector Walk Calibration Table
1106	Detector Center, Rotation, Scale, Shear
1107	Distortion/Non-linearity
1108	Detector Global Dead Time
1109	Detector Local Gain Sag/Droop, Imaging/Grism
1110	Repeated field analysis - imaging mode
1111	Repeated field analysis - spectroscopy mode
1112	Overlap field analysis - imaging mode
1113	Overlap field analysis - spectroscopy mode
1114	Relative response from scanned observations
1115	Background analysis - imaging mode
1116	Background analysis - spectroscopy mode

Task	Description
1117	Near angle stray light contamination
1118	Wide angle stray light contamination
1119	Roll angle dependencies
1120	ACS gyro/tracker data calibration
1121	Absolute astrometric calibration—boresite to tracker
1122	Tracker angle dependencies
1123	Instrument Operations dependencies
1124	Thermal dependencies
1125	Magnetic field dependencies
1125	X-band transmitter dependencies
1127	SAA model
1128	Bright star model refinement
1129	Sky background model refinement

4.3.1 Task 1001: Photometric Zero-Point Calibration, Imaging Mode, FUV and NUV

Purpose: Determine photometric zero point in FUV and NUV, also a function of field position

Description: Measure the response of the GALEX instrument in direct mode at nine field positions (GALEXcal zones) using WD spectrophotometric standards.

Observation Plan: Observe two HST WD flux calibrated standards using two complementary 6-cluster patterns. Select targets to ensure acceptable global and local count rate limitations for absolute calibration.

Instrument/Satellite Configuration: NUV/FUV. Imaging. Nominal stim. GALEXcal set 1.0.

Predecessor: None

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once

Total Number of orbits: 8 total [4 IOC]

Priority: High 75/100

Analysis Plan: From total (>95%) raw count rate images and absolute flux determine zero points. Determine variation of response vs. field position.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 2-5% at GALEXcal positions.

Products: Zero-point setting for pipeline processing. Grid for relative reponse map.

Reports:

FTE: 1/2 week

Ground Analysis Comparison: Compare zero point with ground calibtarion measurements. Differences (>20%) are likely to be cause for additional investigation.

4.3.2 Task 1002: Absolute Spectrophotometric Calibration, Grism Mode, FUV and NUV

Purpose: Determine absolute spectrophotometric calibration of GALEX in grism mode in both channels

Description: Determine the response of the GALEX instrument vs. wavelength in grism mode at nine field positions (GALEXcal zones). Determine conversion between count rate in a given spectral resolution bin and absolute flux WD spectrophotometric standards.

Observation Plan: Observe two HST WD spectrophotmetric standards using two complementary 6-cluster patterns and four grism rotations. Select targets to ensure acceptable global and local count rate limitations for absolute calibration. Select grism and roll angles to minimize possibility for spectral overlaps.

Instrument/Satellite Configuration: NUV/FUV. Grism. Nominal stim. GALEXcal set v1.0.

Predecessor: Task 1001

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once.

Total Number of orbits: 32 total [16 IOC]

Priority: High 75/100

Analysis Plan: From raw count rate map generate conversion to absolute flux. Determine variation of response of integrated order light vs. field position. Determine aperture corrections to total flux in each band.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 2-5% at GALCAL positions within FWHM of GALEX band. Measure variance by applying solution from one calibrator to another.

Products: moea-gr table of effective area vs. wavelength for each grism order. Coarse sampling of spectral response cube.

Reports:

FTE: 1 week

Ground Analysis Comparison: Compare zero point and band shapes with ground calibtarion measurements. Differences (>20%) are likely to be cause for additional investigation.

4.3.3 Task 1003: Photometric Zero-Point Calibration, Imaging Mode, FUV only

Purpose: Determine photometric zero point in FUV, also as a function of field position.

Description: Measure the response of the GALEX instrument in direct mode at nine field positions (GALEXcal zones) using WD spectrophotometric standards. Use a field bright enough to get good S/N in the FUV channel, generally too bright for NUV.

Observation Plan: Observe one HST WD flux standard using two complementary 6-cluster patterns. Select target to ensure acceptable global and local count rate limitations for absolute calibration of the FUV detector only.

Instrument/Satellite Configuration: FUV only. NUV at hvlow. Imaging. Nominal stim. GALEXcal set 1.0.

Predecessor: None

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once

Total Number of orbits: 8 total [4 IOC]

Priority: Moderate 50/100

Analysis Plan: From total (>95%) raw count rate images and absolute flux determine zero points. Determine variation of response vs. field position.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 2-5% at GALCAL positions.

Products: Zero-point setting for pipeline processing. Coarse grid for relative reponse map.

Reports:

FTE: 1/2 week

Ground Analysis Comparison: Compare zero point with ground calibtarion measurements. Differences (>20%) are likely to be cause for additional investigation.

4.3.4 Task 1004: Absolute Spectrophotometric Calibration, Grism Mode, FUV only

Purpose: Determine absolute spectrophotometric calibration of GALEX in grism mode in FUV channel.

Description: Determine the response of the GALEX FUV channel vs. wavelength in grism mode at nine field positions (GALEXcal zones). Determine conversion between count rate in a given spectral resolution bin and absolute flux WD spectrophotometric standards. Select a field with sufficient S/N in FUV channel (generally too bright for NUV).

Observation Plan: Observe one HST WD spectrophotmetric standards using two complementary 6-cluster patterns and four grism rotations. Select target to ensure acceptable global and local count rate limitations for absolute calibration of FUV channel. Select grism and roll angles to minimize possibility for spectral overlaps.

Instrument/Satellite Configuration: FUV only. NUV at hvlow. Grism. Nominal stim. GALEXcal set v1.0.

Predecessor: Task 1003

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once.

Total Number of orbits: 16 total [8 IOC]

Priority: Moderate 50/100

Analysis Plan: From raw count rate map generate conversion to absolute flux. Determine variation of response of integrated order light vs. field position. Determine aperture corrections to total flux in each band.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 2-5% at GALCAL positions within FWHM of GALEX band. Measure variance by applying solution from one calibrator to another.

Products: moea-gr table of effective area vs. wavelength for each grism order. Coarse sampling of spectral response cube.

Reports:

FTE: 1 week

Ground Analysis Comparison: Compare zero point and band shapes with ground calibtarion measurements. Differences (>20%) are likely to be cause for additional investigation.

4.3.5 Task 1005: Secondary Field Photometric Calibration, Imaging Mode, FUV and NUV

Purpose: Obtain measurements of the flux of sources (tied closely to primary standard) to serve as a secondary spectrophotometric field. Use for relative response calibration as well as for band shape characterization when combined with grism data.

Description: Measure the response of the GALEX instrument in direct mode at nine field positions (GALEXcal zones) using secondary spectrophotometric standards in a relatively crowded field.

Observation Plan: Observe one secondary spectrophotometric field using two complementary 6-cluster patterns. Select targets to ensure acceptable global and local count rate limitations for absolute calibration and a high density of usable sources.

Instrument/Satellite Configuration: NUV/FUV. Imaging. Nominal stim. GALEXcal set 1.0.

Predecessor: None

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once

Total Number of orbits: 4 total [2 IOC]

Priority: Medium High 66/100

Analysis Plan: Use cluster patterns to tie measurements of identical objects in different positions using least-squares (or other) relative response calibration method. Use grism data to develop a set of secondary spectrophotometric standards (stars only) within this field and characterize band shape (also vs. position) using inverse method/maximum likelihood method.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 5

Products: Refined zero-point setting for pipeline processing. Grid for relative reponse map. Refinement of band shape, effective wavelength, width, and color terms as needed.

Reports:

FTE: 1/2 week

Ground Analysis Comparison: Compare with relative response map and look for changes >10

4.3.6 Task 1006: Secondary Field Photometric Calibration, Grism Mode, FUV and NUV

Purpose: Obtain measurements of the flux vs. wavelength of sources (tied closely to primary standard) to serve as a secondary spectrophotometric field. Use for relative response calibration (vs. position and wavelength).

Description: Measure the response of the GALEX instrument in grism mode at nine field positions (GALEXcal zones) using secondary spectrophotometric standards in a relatively crowded field.

Observation Plan: Observe one secondary spectrophotometric field using two complementary 6-cluster patterns and four grism rotations. Select targets to ensure acceptable global and local count rate limitations for absolute calibration and a high density of usable sources.

Instrument/Satellite Configuration: NUV/FUV. Grism. Nominal stim. GALEXcal set 1.0.

Predecessor: None

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once

Total Number of orbits: 16 total [8 IOC]

Priority: Medium High 66/100

Analysis Plan: Use cluster patterns to tie measurements of identical objects in different positions using least-squares (or other) relative response calibration method. Perform as a function of wavelength. Use grism data to develop a set of secondary spectrophotometric standards (stars only) within this field to use for photometric calibration.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 5

Products: Relative response cube. Catalog of secondary spectrophotometric standards.

Reports:

FTE: 1/2 week

Ground Analysis Comparison: Compare with relative response map and look for changes >10

4.3.7 Task 1007: Secondary Field Photometric Calibration, Imaging Mode, FUV only

Purpose: Obtain measurements of the FUV flux of sources (tied closely to primary standard) to serve as a secondary spectrophotometric field. Use for relative response calibration as well as for band shape characterization when combined with grism data.

Description: Measure the FUV response of the GALEX instrument in direct mode at nine field positions (GALEXcal zones) using secondary spectrophotometric standards in a relatively crowded field. Select a field with many usable FUV sources and keep NUV detector off.

Observation Plan: Observe one secondary spectrophotometric fields using two complementary 6-cluster patterns. Select targets to ensure acceptable global and local count rate limitations for absolute calibration and a high density of usable sources.

Instrument/Satellite Configuration: FUV only. Imaging. Nominal stim. GALEXcal set 1.0.

Predecessor: None

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once

Total Number of orbits: 8 total [4 IOC]

Priority: Moderate 50/100

Analysis Plan: Use cluster patterns to tie measurements of identical objects in different positions using least-squares (or other) relative response calibration method. Use grism data to develop a set of secondary spectrophotometric standards (stars only) within this field and characterize band shape (also vs. position) using inverse method/maximum likelihood method.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 5

Products: Refined zero-point setting for pipeline processing. Grid for relative reponse map. Refinement of band shape, effective wavelength, width, and color terms as needed.

Reports:

FTE: 1/2 week

Ground Analysis Comparison: Compare with relative response map and look for changes >10

4.3.8 Task 1008: Secondary Field Photometric Calibration, Grism Mode, FUV only

Purpose: Obtain measurements of the FUV flux vs. wavelength of sources (tied closely to primary standard) to serve as a secondary spectrophotometric field. Use for relative response calibration (vs. position and wavelength).

Description: Measure the response of the GALEX instrument in grism mode at nine field positions (GALEXcal zones) using secondary spectrophotometric standards in a relatively crowded field.

Observation Plan: Observe one secondary spectrophotometric field using two complementary 6-cluster patterns and four grism rotations. Select targets to ensure acceptable global and local count rate limitations for absolute calibration and a high density of usable sources.

Instrument/Satellite Configuration: NUV/FUV. Grism. Nominal stim. GALEXcal set 1.0.

Predecessor: None

SAA Constraint: No SAA

CalSemester 1 Repetition: repeated once

Total Number of orbits: 16 total [8 IOC]

Priority: Medium High 66/100

Analysis Plan: Use cluster patterns to tie measurements of identical objects in different positions using least-squares (or other) relative response calibration method. Perform as a function of wavelength. Use grism data to develop a set of secondary spectrophotometric standards (stars only) within this field to use for photometric calibration.

Accuracy Goals: Exposure time is determined so that measurement error should be less than 5

Products: Relative response cube. Catalog of secondary spectrophotometric standards.

Reports:

FTE: 1/2 week

Ground Analysis Comparison: Compare with relative response map and look for changes >10

4.3.9 Task 1009: Spectral dispersion solution I

Purpose: Measure spectral dispersion solution and "zero-deviation" astrometric offset.

Description: Obtain a measurement of the deviation in position vs. wavelength at several positions on the detector. Observe targets with significant signal in narrow lines.

Observation Plan: Observe two line sources in direct and grism mode using one 6-pt cluster. Observe symbiotic star[s] or other bright line-emitting point sources. Use 4 grism rotations.

Instrument/Satellite Configuration: NUV/FUV. GALEXcal ver 1.0. Imaging and Grism. Normal STIM.

Predecessor: Direct precedes Grism

SAA Constraint: No SAA

CalSemester 1 Repetition: Once

Total Number of orbits: 10

Priority: Medium High 66

Analysis Plan: Use line detections to determine dispersion vs. wavelength at several positions on detector. Consider using rotations separately if data quality is high enough. Fit polynomial solution to dispersion.

Accuracy Goals: Signal sufficient to centroid lines to < 2 Åin FUV and <4 Åin NUV (approx S/N 5) with at least 4 lines in each band for minimal fit, preferably many more. "Zero deviation" position established w.r.t. astrometric fit to stellar continuum spectra using stellar model and direct-mode positions and colors.

Products: Dispersion polynomial solutions. Refinement to stellar model, astrometric fit.

Reports:

FTE: 1 week

Ground Analysis Comparison: Compare with ground calibration solution. Determine whether update required based on flight measurement.

4.3.10 Task 1010: Spectral Dispersion solution II

Purpose: Measure spectral dispersion solution and "zero-deviation" astrometric offset

Description: Obtain a measurement of the deviation in position vs. wavelength at several positions on the detector. Observe targets with significant signal in narrow lines.

Observation Plan: Observe two line sources in direct and grism mode using one 6-pt cluster. Observe redshifted QSO/AGN to provide sufficient sampling in NUV band. Use 4 grism rotations.

Instrument/Satellite Configuration: NUV/FUV. Imaging and Grism. GALEXcal ver 1.0. Normal STIM.

Predecessor: Direct precedes Grism

SAA Constraint: No SAA

CalSemester 1 Repetition: Once

Total Number of orbits: 10

Priority: Medium High 66

Analysis Plan: Use line detections to determine dispersion vs. wavelength at several positions on detector. Consider using rotations separately if data quality is high enough. Fit polynomial solution to dispersion.

Accuracy Goals: Signal sufficient to centroid lines to < 2 Åin FUV and <4 Åin NUV (approx S/N 5) with at least 4 lines in each band for minimal fit, preferably many more. "Zero deviation" position established w.r.t. astrometric fit to stellar continuum spectra using stellar model and direct-mode positions and colors.

Products: Dispersion polynomial solutions. Refinement to stellar model, astrometric fit.

Reports:

FTE: 1 week

Ground Analysis Comparison: Compare with ground calibration solution. Determine whether update required based on flight measurement.

4.3.11 Task 1011: Zodiacal light/dead time calibration

Purpose: Improve zodiacal light model. Use higher count rate observations to measure dead time, flats

Description: Obtain a measurement of the Zodiacal background as a function of ecliptic latitude, elongation while keeping Galactic background constant. Use FUV measurement to determine and subtract off Galactic component.

Observation Plan: Observe 5 fields of different ecliptic coordinates. 3 latitudes (low, moderate, high) at elongation $\sim$160, 2 additional elongations 120, 140 at low ecliptic. Make every attempt to keep Galactic background constant (preferably high latitude with identical cirrus with no bright stars within 5-10 degrees). One visit for field

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal Stim

Predecessor: None

SAA Constraint: SAA O.K.

CalSemester 1 Repetition: None

Total Number of orbits: 5 [5 IOC]

Priority: Moderate 50

Analysis Plan: Measure background in each channel. As indicated above, use FUV to subtract off Galactic component in NUV channel.

Accuracy Goals: Match to model should be better than 20%.

Products: Improved zodiacal model

Reports:

FTE: 1 wk

Ground Analysis Comparison:

4.3.12 Task 1012: Galactic background, dead time, flat field

Purpose: Observe fields with different Galactic backgrounds with lowest possible zodiacal background. Use data to characterize dead times due to coincidence loss, and characterize flat field.

Description: Observe 5 fields of differing Galactic latitudes with low zodiacal light.

Observation Plan:

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXCal ver. 1.0. Nominal STIM.

Predecessor: None

SAA Constraint: No

CalSemester 1 Repetition: None

Total Number of orbits: 5

Priority: Medium High 66

Analysis Plan: Remove sources. Determine Galactic background and compare with models. Generate flat fields. Use STIMS to calculate dead time loss and compare with count rate.

Accuracy Goals: Galactic background to <20%. Linearity corrected flat field, avg 20 kcps $\sim$ 1500s yields 2% flats in single eclipse in $45''$ pixels. Plot output count rate vs. STIM loss (calculate to <2%. Compare with FEC cts and FEE model for consistency.

Products: Improved background model. Linearity corrected flat field using relatively flat Galactic spectrum. Compare with point source relative response solution.

Reports:

FTE: 2 wks.

Ground Analysis Comparison: Compare dead time, response with ground cal, look for $> 10\%$ deviations.

4.3.13 Task 1013: Earth Limb background measurement

Purpose: Earth Limb background measurement

Description: Make measurements at a constant sky position (over a single orbit) and observe variation in background with orbital parameters. Brightnesses of O I 1304 Å, 1356 Åand Lyman α will be most pronounced.

Observation Plan: Observe several targets which have different earth/bright earth limb angles during orbit. Monitor variation in background. Seek targets where variation in earth limb angle does not exactly track nightside de-excitiation timescales for observed atmospheric column. Seek targets free of nearby bright objects (5-10 deg)

Instrument/Satellite Configuration: NUV/FUV. GALEXcal ver 1.0. Nominal STIM

Predecessor: None

SAA Constraint:

CalSemester 1 Repetition: None

Total Number of orbits: 5

Priority: Medium 50

Analysis Plan: Calculate background vs. earth limb angle, bright earth limb angle. Also vs. ram vector angle. Estimate atmospheric de-excitation timescale and plot background vs. this timescale.

Accuracy Goals: Variations $<$ 5% background level over one minute timescales. Statistical accuracy of background should be more than sufficient. Variation in stray/scattered light glints could contaminate signal and should be checked for.

Products: Background model. Revised observing constraints.

Reports:

FTE: 1/2 wk

Ground Analysis Comparison:

4.3.14 Task 1014: Bright Moon background

Purpose: Measure background from moon at various angles

Description: Quick test of whether mission moon avoidance constraint is sufficient. May also show that constraint is a little too large.

Observation Plan: Attempt to keep other parameters relatively constant while changing angle to moon. Observations should be consecutive so that phase is nearly constant. Try to maximize distance from new moon without violating other constraints. Might be combined with earth limb or other non-background measurements.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM

Predecessor: None

SAA Constraint: None

CalSemester 1 Repetition: None

Total Number of orbits: 4

Priority: Moderate Low: 33

Analysis Plan: Determine variation in background vs. moon angle. Combine with other data if necessary

Accuracy Goals: Measure to $< 5\%$ if possible.

Products: Refined moon constraint.

Reports:

FTE: 1/2 wk.

Ground Analysis Comparison:

4.3.15 Task 1015: FOCA Cross calibration and grism observations

Purpose: Validate GALEX photometry and establish connection to previous FOCA measurements

Description: Observe several FOCA targets in direct and grism mode.

Observation Plan: Single orbit each. Consider cluster mode if will not violate bright star constraint.

Instrument/Satellite Configuration: NUV/FUV. Imaging/Grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: Direct before Grism.

SAA Constraint: No constraint.

CalSemester 1 Repetition: As needed

Total Number of orbits: 12

Priority: Moderate 50

Analysis Plan: Extract sources and compare with FOCA detections. Compare grism spectra at 2000Å.

Accuracy Goals: FOCA photometry believed to be good to <30%. Any deviation from this should be studied.

Products:

Reports: GALEX-FOCA match catalog and photometric comparison.

FTE: 1 month.

Ground Analysis Comparison:

4.3.16 Task 1016: Detector Background, Hot Spot, Phosphorescence, Health Monitoring

Purpose: Determine on-orbit detector background, hot spot activity and locations, phosphorescence w.r.t SAA

Description: Make frequent dark measurements to monitor the health of the detectors. Use this data in a variety of ways.

Observation Plan: Measure background periodically, typically once every 3-4 eclipses during IOC and then once every two to three days subsequently. Make measurements before and after SAA passages and during orbits with no SAA. Distribute to be as representative of nominal mission as possible. Make sure enough observations at 'equivalent' conditions have been made to monitor detectr health (5 min prior to SAA passage is reasonable, lowest phosphorescence baseline).

Instrument/Satellite Configuration: NUV/FUV. Opaque. GALEXcal ver 1.0. Nominal STIM.

Predecessor: None

SAA Constraint: Only as imposed by observation plan.

CalSemester 1 Repetition: Often.

Total Number of orbits: 125 [50 IOC]

Priority: High 90

Analysis Plan: Obtain deep detector background image under constant flight conditions. Detect hot spots extract into table and mask. Spline fit to 'smoothed' background map. Determine diffuse background rate w.r.t. SAA.

Accuracy Goals: For different surveys hot spots down to varying levels need to be removed. Masking levels will be down to 0.01 to 0.001 cps. To get reasonable signal requires data over $\sim$20 orbits, comparable to DIS duration.

Products: Detector Background and Gain Map. Detector Hot Spot table. Refinement to phosphorescence model.

Reports: Detector Health report

FTE: 2 wks.

Ground Analysis Comparison: Compare with detector background rate, gain, distribution, history and phosphorescence model.

4.3.17 Task 1100: Point spread function calibration and stability, GALEX in-flight focus measurement

Purpose: Determine GALEX point spread function in each band and track stability over timescales of minutes to months.

Description: Using data from stars of various brightnesses measure point spread function. Use brighter stars to measure wings of PSF (when possible) and PSF on short timescales. Use stars at different field positions to measure field dependent PSF.

Observation Plan: Use all available survey data and calibration data. Reasonable max count rates are 10-100 cps without detector saturation.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: For 10 cps star, deep single orbit exposure will yield 15000 counts. This will allow measurement of a profile to $\sim$ 3% in 15 radial bins out to 10-15$''$or about 6 FWHM diameters. It is expected that the profile will be reasonably well fit by a Gaussian (possibly double Gaussian) extending to a power-law profile at larger radii due to near-angle scattering. Ghosts may also create plateaus. Work as needed to remove contribution from aspect reconstruction and rectification/distortion correction steps.

Accuracy Goals: Measure out beyond 99% EE with better than 3% in each bin at each field position. Consider combining measurements from stars from multiple visits.

Products: GALEX PSF profile table, profiles vs. spatial position. 80% encircled energy, ellipticities.

Reports: GALEX in-flight focus measurement.

FTE: 2 wks.

Ground Analysis Comparison: Compare with focus test results. If 80% EE is significantly worse and shows astigmatism consider changing M2 temperature. If no astigmatism is seen consider adjusting detector to improve PSF.

4.3.18 Task 1101: Grism orientation angle calibration, stability

Purpose: Determine relationship between grism orientation and dispersion angle in focal plane.

Description: Grism observation data will be used to compare grism angle setting with dispersion angle in focal plane. Commanded angle and measured (encoder) angle will be calibrated vs. dispersion direction angle.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Measure 1-D correlation vs. rotation angle to generate angle. With data for 100 angles compare grism position vs. angle and look for deviations from linearity or possible hysteresis effects. Track stability and look for possible degredation in motor movements.

Accuracy Goals: Measure relation to better than $2'$

Products: Unit conversion encoder position to angle (degrees).

Reports: GALEX grism orientation calibration including angle function and hysteresis measurements

FTE: 2 wks.

Ground Analysis Comparison: Compare with ground measurements and look for significant deviations.

4.3.19 Task 1102: Detector Gain Map

Purpose: Determine modal gain vs. position across detector.

Description: Modal gain established primary detector reference frame for subsequent corrections. Calibrate and track stability.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging and/or grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Produce superflats with stars removed. Extract mode of pulse height distribution vs. position ($10''$ bins).

Accuracy Goals: Measure modal gain to <0.25 bin. With FWHM around 100% requires 1000-10000 counts per spatial bin. To get reasonably good S/N requires 50-100 eclipses (1 week) of observations in FUV. Use data subsets and monthly timescales to track trends in modal gain.

Products: Modal gain map, each detector.

Reports: Detector health report

FTE: 1 wks.

Ground Analysis Comparison: Compare with ground measurements and look for significant deviation in modal gain.

4.3.20 Task 1103:

Detector Wiggle Correction

Purpose: Calibrate detector photon offset vs. timing phase word. (wiggle correction).

Description: Use point sources to determine photon offset vs. timing phase word as a function of position. Track changes with temperature and time.

Observation Plan: Use standard survey and calibration observations.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Point source data used to determine offset vs. timing phase word, calibrated to midpoint of timing phase scale. Track changes in midpoint, scale width and phase offset vs. temperature and time. Measure as a function os spatial position.

Accuracy Goals: Measure offset to better than $0.5''$FWHM, requires 400 counts in each bin, or a 10 cps star observed for an entire eclipse. Sample enought spatial points to achieve accuracy in interpolation.

Products: Detector wiggle correction maps.

Reports: Detector health report

FTE: 1 wks.

Ground Analysis Comparison: Compare with ground measurements and look for significant shift in wiggle performance.

4.3.21 Task 1104: Cal Stim Data Analysis

Purpose: Use calibration stim data to track changes in the performance of the detector digitizers.

Description: Use stim calibration data to 1) track changes in detector timing and/or digitizer controller timing. 2) Track changes in amplitude of stims and/or gain measurements, 3) Track changes in digitizer A/D performance (scale, offset) vs. temperature and/or other parameters (e.g. count rate?)

Observation Plan: Use standard data collected on day side of each orbit.

Instrument/Satellite Configuration: NUV/FUV. Any mode. GALEXcal ver 1.0. Nominal misison plan.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Determine stim positions, gains vs. environmental conditions. Determine A/D scale, offset vs. environmental parameters.

Accuracy Goals: Measure offsets in position to better than 1 bin, same with scale factor.

Products: Inputs to detector scale size measurement, wiggle correction table. Parametric dependence if necessary.

Reports: Detector health report

FTE: 1 wks.

Ground Analysis Comparison: If behavior looks anomalous compare with ground cal.

4.3.22 Task 1105: Detector Walk Calibration Table

Purpose: Determine detector walk vs position.

Description: Use stars to measure deviation in measured position vs photon q value, with offset measured relative to position at detector modal gain. Measure vs. field position.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use star point source data to determine walk vs. position.

Accuracy Goals: Measure offset to better than $0.5''$FWHM, requires 400 counts in each bin, or a 10 cps star observed for an entire eclipse. Sample enought spatial points to achieve accuracy in interpolation.

Products: Detector walk map, each detector.

Reports: Detector health report

FTE: 2 wks.

Ground Analysis Comparison: Compare with ground measurements and look for significant deviation in walk which may signal significant change in FEE.

4.3.23 Task 1106: Detector Center, Rotation, Scale, Shear

Purpose: Determine relative detector center and scale offsets and relative rotations.

Description: Use detector reference fiducials and identical stars in both fields to determine offset quaternion between FUV and NUV detector. Also determine scale factor to convert measured time into microns and any cross-term between axes.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use star point source data to compare stars identical stars in each frame. Measure scale and shear near detector center.

Accuracy Goals: Measure offset to better than $< 10''$ and scale factor to better than 0.5%.

Products: Detector scale factor, offset quaternion and shear component.

Reports: Detector health report

FTE: 2 wks.

Ground Analysis Comparison: If significant changes, perform detailed comparison.

4.3.24 Task 1107: Distortion/Non-linearity

Purpose: Determine spatial distortion/non-linearity correction.

Description: Compare angles between known star positions projected into focal plane with measured detector positions to determine spatial distortion/non-linearity solution.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Using a reference center based on fiducials measure the deviation between measured star positions and their projected angle in the GALEX focal plane.

Accuracy Goals: Angles of stars across field should be known to considerably better than $0.3''$. Measure deviations on small and large angular scales. Measure offset to better than $0.5''$FWHM, requires 400 counts in each bin, or a 10 cps star observed for an entire eclipse. Sample enought spatial points to achieve accuracy in interpolation.

Products: Detector non-linearity correction table.

Reports:

FTE: 1 month.

Ground Analysis Comparison: If significant changes, perform detailed comparison.

4.3.25 Task 1108: Detector Global Dead Time

Purpose: Determine global dead time correction.

Description: Use stim drop-outs to calibrate dead-time vs. count rate.

Observation Plan: Use all available survey data and calibration data. During IOC use various global background measurements.

Instrument/Satellite Configuration: NUV/FUV. Imaging and grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: At a given output count rate measure STIM throughput. Periodic STIM data should be uncorrelated with (random) dead time lockout periods and should provide an accurate measure of loss fraction. Loss fraction will be expressed as a loss of exposure time in pipeline map generation stage.

Accuracy Goals: Measure dead time loss vs. countrate to better than $< 1\%$ accuracy to incur minimal impact on photometric accuracy.

Products: Detector dead time vs global photon countrate.

Reports: Detector/FEE health report

FTE: 2 wks.

Ground Analysis Comparison: If significant changes attempt to diagnose if change in FEE performance.

4.3.26 Task 1109: Detector Local Gain Sag/Droop, Imaging/Grism

Purpose: Determine local gain sag/droop based on bright star passage. In some cases may include a comet-like trail.

Description: Measure gain sag vs. point source and extended source/spectrum count rate. Analysis results in a time-dependent correction to response table if necessary.

Observation Plan: Use all available survey data and calibration data of brighter sources in imaging and spectroscopy mode.

Instrument/Satellite Configuration: NUV/FUV. Imaging and grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Gain sag should be evident in these brighter sources and a reasonable estimate for the loss of response can be measured. If trails need to be included requires a significant investigation of the nature and duration of the sag.

Accuracy Goals: To be determined. Only significant for scan data/bright calibrator data and for all-sky survey trails.

Products: Droop term

Reports: Detector/FEE health report

FTE: TBD

Ground Analysis Comparison:

4.3.27 Task 1110: Repeated field analysis - imaging mode

Purpose: Monitor stability of calibration and determine refinements using repeated observations of identical field.

Description: Use repeated observations of identical sources at multiple twist angles to verify accuracy and stability of photometric calibration.

Observation Plan: Use all available MIS/DIS data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare photometry of matched objects from multiple visits. Reject variable objects. Look for deviations vs. spatial position, count rate, background and/or other environmental parameters. Generate improved response map if appropriate.

Accuracy Goals: Look for repeatability to be better than 5%.

Products: Refined response map.

Reports:

FTE: 1 month.

Ground Analysis Comparison:

4.3.28 Task 1111: Repeated field analysis - spectroscopy mode

Purpose: Monitor stability of calibration and determine refinements using repeated observations of identical field.

Description: Use repeated observations of identical sources at multiple grism/twist angles to verify accuracy and stability of spectrophotometric calibration.

Observation Plan: Use all available WSS/MSS/DSS data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Spectroscopy. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare spectrophotometry of matched objects from multiple visits. Reject variable objects. Look for deviations vs. spatial position, count rate, background and/or other environmental parameters. Generate improved response cube if appropriate.

Accuracy Goals: Look for repeatability to be better than 5%.

Products: Refined response cube.

Reports:

FTE: 1 month.

Ground Analysis Comparison:

4.3.29 Task 1112: Overlap field analysis - imaging mode

Purpose: Monitor stability of calibration and determine refinements using observations of overlap fields.

Description: Use overlap observations of identical sources at multiple twist angles to verify accuracy and stability of photometric calibration.

Observation Plan: Use all available MIS/DIS data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare photometry of matched objects from overlap data from multiple visits to a region. Reject variable objects. Look for deviations vs. spatial position, count rate, background and/or other environmental parameters. Generate improved response map (especially at edge of field) if appropriate.

Accuracy Goals: Look for repeatability to be better than 5%.

Products: Refined response map.

Reports:

FTE: 2 wks.

Ground Analysis Comparison:

4.3.30 Task 1113: Overlap field analysis - spectroscopy mode

Purpose: Monitor stability of calibration and determine refinements using observations of overlapping areas.

Description: Use measurements of identical sources in overlapping regions at multiple grism/twist angles to verify accuracy and stability of spectrophotometric calibration.

Observation Plan: Use all available WSS/MSS/DSS data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Spectroscopy. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare spectrophotometry of matched objects from overlapping visits within a region. Reject variable objects. Look for deviations vs. spatial position, count rate, background and/or other environmental parameters. Generate improved response cube if appropriate.

Accuracy Goals: Look for repeatability to be better than 5%.

Products: Refined response cube.

Reports:

FTE: 2 weeks.

Ground Analysis Comparison:

4.3.31 Task 1114: Relative response from scanned observations

Purpose: Determine relative response by tracking count rate of sources in scanned observations.

Description: Use the variation in the count rate from stars as they move across the field of view to determine the relative response along the scan. Fit curve to relative response solution and look for systematic spatially dependent (or other) variation.

Observation Plan: Use all available scanned (AIS) survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use star point source data to track count rate across field of view. Overall scale factor (and color term) are unknowns. Scale factor may be included in fit to relative response function or a self-consistent solution may be attempted from complete set of streak data.

Accuracy Goals: Measure response to better than <5% at every field position. Combine data from many stars in bins across field.

Products: Self-consistent relative response solution and/or refinement to existing map.

Reports:

FTE: 2 wks.

Ground Analysis Comparison:

4.3.32 Task 1115: Background analysis - imaging mode

Purpose: Monitor background level fluctuations across field (at various depths) and show that fluctuations are consistent with noise estimates.

Description: Background fluctuations can be monitored to look for anomalous behavior, scattered light, significant cosmic variance in field.

Observation Plan: Use all available AIS/MIS/DIS data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use sextractor extracted background measurements or specialized analysis to track background levels in images of various depths. Compare with noise model.

Accuracy Goals: Look for observations that show excess variance.

Products: Flagged observations, refined background noise model.

Reports:

FTE: 1 wk

Ground Analysis Comparison:

4.3.33 Task 1116: Background analysis - spectroscopy mode

Purpose: Monitor background level fluctuations across field (at various depths) and show that fluctuations are consistent with noise estimates.

Description: Background fluctuations can be monitored to look for anomalous behavior, scattered light, significant cosmic variance in field.

Observation Plan: Use all available WSS/MSS/DSS data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use extracted background spectra to track background levels in integrated spectra of varying depths. Compare with noise model.

Accuracy Goals: Look for observations that show excess variance.

Products: Flagged observations, refined background noise model.

Reports:

FTE: 1 wk

Ground Analysis Comparison:

4.3.34 Task 1117: Near angle stray light contamination

Purpose: Determine sensitivity to ghosting and stray light from bright objects within 0.6-2°of field center.

Description: Compare catalog of known bright stars with image defects in both imaging and grism mode to assess influence of stars on measurements.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging and grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Determine number/level of image defects, glints, ghosts vs. bright star count rate, angle (phi, theta). If a significant portion of field of view becomes unusable (>90%) consider observing in different configuration or reducing target observing time. Measure at different roll/twist angles and radial positions. Consider replans as necesary.

Accuracy Goals: TBD.

Products: Constraints on bright star positions relative to field center, twist/roll, etc and/or analysis masks as appropriate.

Reports: Near angle stray light impact on GALEX mission.

FTE: 2 wks.

Ground Analysis Comparison: If significant changes, perform detailed comparison.

4.3.35 Task 1118: Wide angle stray light contamination

Purpose: Determine signal from bright sources at high off-axis angles (beyond 2-3 degrees).

Description: Wide angle stray light may produce enhanced diffuse background or glints in GALEX optical system. Quantify effects and loss of observing efficiency (usable area) that results.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging and grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Assess background increase due to bright objects. In some cases, "stellar halos" may be Galactic in origin and represent a substantial deviation from simple Galactic background model.

Accuracy Goals: Measure background increases of $\sim 10\%$ over nominal levels.

Products: Bright object constraints, improved Galactic background model.

Reports: Detector health report

FTE: 2 wks.

Ground Analysis Comparison:

4.3.36 Task 1119: Roll angle dependencies

Purpose: Determine any impacts on GALEX performance as a function of observed roll angle.

Description: An intermediate monitoring step to search for performance variation vs. observing roll angle or twist. Leads to report generation and attempt to determine cause of dependency.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare PSF, throughput, background, scale, distortion vs. roll angle. Generate report and attempt to determine root cause of variation.

Accuracy Goals: As needed for individual requirements.

Products:

Reports: Roll angle dependency report.

FTE: 1/2 wks.

Ground Analysis Comparison:

4.3.37 Task 1120: ACS gyro/tracker data calibration

Purpose: Convert gyro/tracker measurements into physical units.

Description: Improve on conversion of gyro/tracker measurements into aspect input for state file. Also determine delay times.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare outputs of pipeline attitude refinement steps with measured values. Determine corrections to scales and offsets to provide aspect input to state file. Determine any delay times between ACS and photon measurement.

Accuracy Goals: As accurate as possible. At minimum input should be consistent ACS requirements and ACS systems measured performance parameters.

Products: Conversions, scales and offsets for TM to state file conversion.

Reports:

FTE: 2 wks.

Ground Analysis Comparison: Should be consistent with ACS systems calibration

4.3.38 Task 1121: Absolute astrometric calibration—boresite to tracker drift

Purpose: Refine boresite to tracker measurement and quantify any drift

Description: Use higher S/N measurements and improved end-to-end calibration to refine boresite to tracker quaternion and track drift.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: After first end-to-end calibration, revisit boresite-tracker quaternion. Quantify drift. Compare in dither and scan modes which have different Kalman filter gains.

Accuracy Goals: Measure boresite-tracker quaternion to $<10''$if possible.

Products: Detector scale factor, offset quaternion and shear component.

Reports:

FTE: 2 wks.

Ground Analysis Comparison:

4.3.39 Task 1122: Tracker angle dependencies

Purpose: Determine any dependencies in performance on tracker roll/twist angle.

Description: Tracker roll/twist angle will include a different set of stars and possibly a different set of bright objects near the field of view. Look for attitude performance degredation variation.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare PSF of same field at various roll/twist angles. If variation seen look for trend with number of stars in tracker FOV, bright objects, etc.

Accuracy Goals: Determine that PSF does not degrade significantly with tracker angle.

Products:

Reports: Tracker performance report

FTE: 2 wks.

Ground Analysis Comparison:

4.3.40 Task 1123: Instrument Operations dependencies

Purpose: Search for variation in instrument performance with environmental/orbital conditions

Description: Study variation in instrument performance (GROW motion, voltages, current draw, detector ramp shape, count rate, current.

Observation Plan: Use all available data.

Instrument/Satellite Configuration: NUV/FUV. Imaging and or grism. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Compare trend data orbit by orbit and look for trends vs. orbital condition, temperature, time.

Accuracy Goals: Look to see that trends are consistent with predicted performance ranges.

Products:

Reports: Instrument performance report

FTE: 2 wks.

Ground Analysis Comparison: If significant changes, perform detailed comparison.

4.3.41 Task 1124: Thermal dependencies

Purpose: Determine trends vs. temperature

Description: Look for broad trends vs. temperature in all performance parameters and determine which tasks require refinement and/or parametric model based on thermal configuration.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use temperature trend data and generated catalog data to monitor significant thermal performance trends.

Accuracy Goals: As needed per calibration requirements.

Products: General parametric model which may need refinement.

Reports:

FTE: as needed

Ground Analysis Comparison: If significant changes, perform detailed comparison.

4.3.42 Task 1125: Magnetic field dependencies

Purpose: Determine dependency in instrument performance vs. magnetic field.

Description: Study detector offset, distortions vs. magnetic field based on TAM sensors and/or model.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Track position of detector image w.r.t. stims as a function of magnetic field direction/strength. Look for evidence of distortion.

Accuracy Goals: As needed to meet PSF, distortion/spatial non-linearity requirements.

Products: Parametric model of detector shift/distortion vs. magnetic field.

Reports:

Ground Analysis Comparison:

4.3.43 Task 1126: X-band transmitter dependencies

Purpose: Determine if X-band transmitter has an effect on PSF

Description: Compare measurements made with X-band on vs. X-band off and look for variation in PSF. Shouldn't be any. Could result in planning constraint.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use star point source data to study PSF¿

Accuracy Goals: Look for any measureable degredation of PSF.

Products:

Reports: X-band downlink impact on PSF

FTE: 1 wks.

Ground Analysis Comparison:

4.3.44 Task 1127: SAA model

Purpose: Determine relative detector center and scale offsets and relative rotations.

Description: Use detector reference fiducials and identical stars in both fields to determine offset quaternion between FUV and NUV detector. Also determine scale factor to convert measured time into microns and any cross-term between axes.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Use star point source data to compare stars identical stars in each frame. Measure scale and shear near detector center.

Accuracy Goals: Measure offset to better than $< 10''$ and scale factor to better than 0.5%.

Products: Detector scale factor, offset quaternion and shear component.

Reports: Detector health report

FTE: 2 wks.

Ground Analysis Comparison: If significant changes, perform detailed comparison.

4.3.45 Task 1128: Bright star model refinement

Purpose: Refine bright star model used for planning purposes

Description: Compare observations of bright stars just below bright star threshold (in 100-5000 cps range) with model fluxes and develop correction terms. Apply to entire star catalog for improved bright star avoidance in planning.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Extract measured flux for brightest stars in images and compare with bright star catalog model UV fluxes.

Accuracy Goals: Determine fluxes to within 50%.

Products: Improved bright star model.

Reports:

Ground Analysis Comparison:

4.3.46 Task 1129: Sky background model refinement

Purpose: Refine Galactic, Zodiacal and Terrestrial background model based on survey measurements.

Description: Measurements at various Galactic, ecliptic and orbital positions will enable a decomposition of the contribution of the various components and a refinement of the models which predict the background levels as a function of coordinate.

Observation Plan: Use all available survey data and calibration data.

Instrument/Satellite Configuration: NUV/FUV. Imaging. GALEXcal ver 1.0. Nominal STIM.

Predecessor: n/a

SAA Constraint: n/a

CalSemester 1 Repetition: n/a

Total Number of orbits: 0

Priority: n/a

Analysis Plan: Measure background levels and plot vs. other dependent parameters. Use decomposition to create Galactic background map and refine model.

Accuracy Goals: Total background prediction will be to better than 10%.

Products: Improved background model for planning.

Reports: Sky Background levels.

FTE: 2 wks.

Ground Analysis Comparison: Compare with original models.

Appendix A

Relative Throughput Calculation

Assume a distribution of N_q sources with flux S_q where $0 \leq q \leq N_q$. N_p measurements are made where the source is located at position $x_{p,q}, y_{p,q}$. The relative flux measured at that point is:

$$N_{p,q} = T(x_{p,q}, y_{p,q})S_q$$

where $T(x_{p,q}, y_{p,q})$ is the throughput of the instrument at the position of the source.

In the absence of noise, the N_p measurements of the source would yield,

$$1/S_q = T(x_{p,q}, y_{p,q})/N_{p,q}$$

for all p. In the presence of noise we seek to find a solution for T that minimizes the following sum:

$$\chi^2 = \sum_{q=1}^{N_q} \sum_{p_1=1}^{N_p} \sum_{p_2=1}^{N_p} (T(x_{p_1,q}, y_{p_1,q})/N_{p_1,q} - T(x_{p_2,q}, y_{p_2,q})/N_{p_2,q})^2$$

It is most convenient to solve for T on a regular $M \times N$ grid of points $T_{i,j}$. We can define an arbitrary T(x,y) in terms of a bilinear interpolation of the regularly gridded values T(i,j). This can easily be done by transforming the coordinates x,y using

$$x' = M \times (x - x_{min})/(x_{max} - x_{min})$$

$$y' = N \times (y - y_{min})/(y_{max} - y_{min})$$

so that

$$i_x = Trunc(x')$$

$$\alpha_x = x' - i_x$$

$$j_x = Trunc(y')$$

$$\beta_y = y' - j_y$$

Leading to bilinear interpolation:

$$T(x,y) = T_{i_x,j_y}(1-\alpha)(1-\beta) + T_{i_x+1,j_y}\alpha(1-\beta) + T_{i_x,j_y+1}(1-\alpha)\beta + T_{i_x+1,j_y+1}\alpha\beta$$

Expressing $T_{i,j}$ as a 1-D array T_k using the transformation

$$k = i + M \times j$$

we then can write,

$$T(x,y) = T_{k_{x,y}}(1-\alpha)(1-\beta) + T_{k_{x,y+1}}\alpha(1-\beta) + T_{k_{x,y+M}}(1-\alpha)\beta + T_{k_{x,y+M+1}}\alpha\beta$$

Define a vector c_k with the four non-zero elements given above and express

$$T(x,y) = \sum_{k=1}^{M\times N} c_k T_k$$

giving uss

$$T(x_p,y_p) = \sum_{k=1}^{M\times N} c_{k,p,q} T_k$$

where T_k are the gridded values for the throughput that we intend to solve using N_p measurements of N_q sources.

The minimization problem now becomes a set of $N_k = M \times N$ equations:

$$d\chi^2/dT_\lambda = 2\sum_{k=1}^{M\times N}\sum_{q=1}^{N_q}\sum_{p_1=1}^{N_p}\sum_{p_2=1}^{N_p}[c_{k,p_1,q}c_{\lambda,p_1,q}/N^2_{p_1,q} + c_{k,p_2,q}c_{\lambda,p_2,q}/N^2_{p_2,q}$$
$$-((c_{k,p_2,q}c_{\lambda,p_1,q}/(N_{p_1,q}N_{p_2,q}) + (c_{k,p_1,q}c_{\lambda,p_2,q}/(N_{p_1,q}N_{p_2,q}))]T_k = 0$$

which can be written as a matrix equation

$$\sum_{\kappa,\lambda} A_{\kappa,\lambda}T_\kappa = 0$$

with

$$A_{\kappa,\lambda} = \sum_{q=1}^{N_q}\sum_{p_1=1}^{N_p}\sum_{p_2=1}^{N_p}[c_{\kappa,p_1,q}c_{\lambda,p_1,q}/N^2_{p_1,q} + c_{\kappa,p_2,q}c_{\lambda,p_2,q}/N^2_{p_2,q}$$
$$-((c_{\kappa,p_2,q}c_{\lambda,p_1,q}/(N_{p_1,q}N_{p_2,q}) + (c_{\kappa,p_1,q}c_{\lambda,p_2,q}/(N_{p_1,q}N_{p_2,q}))]$$

In order to solve this equation (by inverting the matrix) it is important to remove those rows and columns that contain all zeros. These correspond to values of T_k that were not sampled by any of the sources. After eliminating these degeneracies, it is important to remove the last degeneracy by setting one element of the vector $T_{k'} = 1$ or to any value (possibly corresponding to the absolute throughput at that point. It might be convenient to use a point near the center of the field.

A.0.47 Color Term

The appropriate treatment of the color term makes this calculation somewhat more challenging when using a star field with a distribution of sources of unknown flux and color.

A.0.48 Cross Check - "Star Streaks"

The relative calibration will be cross checked using "Star Streak" images of the relative count rates of objects moving across the detector field of view normalized as in the previous method to a single point in the field.

Appendix B

Spectrophotometric Calibrators

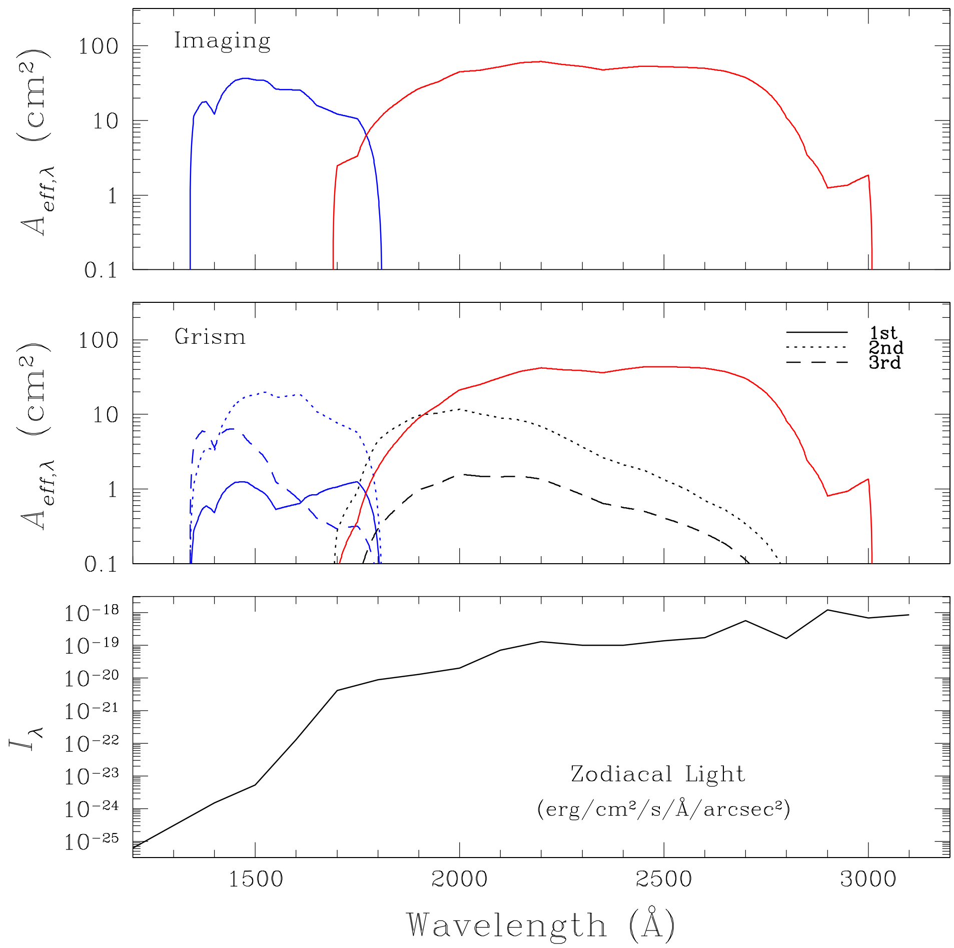
Table B.1: Spectrophotometric standards

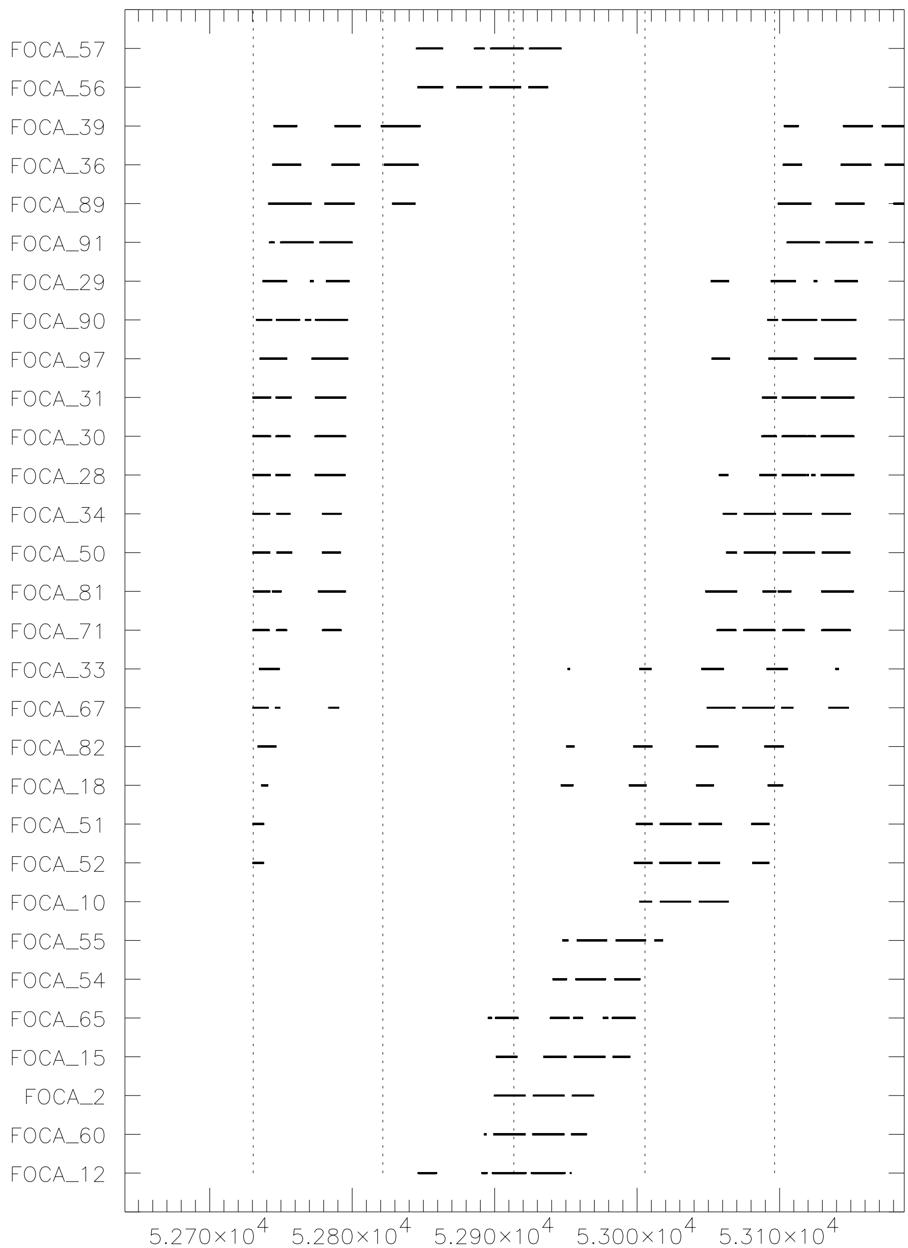
ID	V	$B-V$	R.A.	Dec.	Countrate		$I_{100\mu m}$[1]	Note
					FUV	NUV	(MJy/sr)	
BPM 16274	14.16	−0.02	00:50:03.2	−52:08:17.4	142.7	393.6	0.8212	
GD 50	14.06	−0.28	03:48:50.1	−00:58:28.5	545.9	1011.3	7.0371	
HZ 4	14.51	+0.09	03:55:21.7	+09:47:18.7	51.9	171.1	6.6465	
LB 227	15.32	+0.06	04:09:28.8	+17:07:54.4	31.4	92.5	13.7694	
HZ 2	13.88	−0.09	04:12:43.5	+11:51.50.4	241.0	542.3	16.4763	
G 191B2B	11.77	−0.33	05:05:30.6	+52:49:51.9	5222.0	9249.5	12.4422	
GD 71	13.03	−0.25	05:52:27.5	+15:53:17	1155.2	2232.9	9.0019	
BD +75°325	9.55	−0.33	08:10:49.5	+74:57:57.9	30916.0	70353.1	1.4879	(O5pvar)
AGK +81°266	11.94	−0.34	09:21:19.2	+81:43:27.6	4341.6	8331.4	1.1105	(B2)
GD 108	13.56	−0.22	10:00:47.3	−07:33:31.2	371.1	843.5	2.5512	
Feige 34	11.18	−0.34	10:39:36.7	+43:06:09.3	8482.6	16669.7	0.6298	
HZ 21	14.69	−0.33	12:13:56.4	+32:56:30.8	323.1	606.9	0.6028	
Feige 66	10.51	−0.29	12:37:23.5	+25:03:59.9	8951.5	20723.5	0.7175	(Bp)
Feige 67	11.82	−0.34	12:41:51.8	+17:31:19.8	4159.7	8730.4	1.1373	(Op)
GD 153	13.35	−0.29	12:57:02	+22:02:00	987.0	1859.3	1.5297	
HZ 43	12.91	−0.31	13:16:21.9	+29:05:55.4	1693.6	3073.8	0.5420	
HZ 44	11.67	−0.29	13:23:35.3	+36:07:59.5	3315.1	8424.7	0.5696	
GRW +70°5824	12.77	−0.09	13:38:50.5	+70:17:07.6	657.0	1504.1	0.6517	
BD +33°2642	10.83	−0.17	15:51:59.9	+32:56:54.3	2110.8	7020.3	1.3806	
LDS 749B	14.68	−0.04	21:32:15.8	+00:15:13.6	19.9	140.9	2.3232	
BD +28°4211	10.51	−0.34	21:51:11.0	+28:51:50.4	18828.3	31466.7	5.1382	
G 93–48	12.74	−0.01	21:52:25.4	+02:23:19.6	468.8	1194.4	3.1524	
BD +25°4655	9.69	−0.31	21:59:42.0	+26:25:57.4	21411.1	45001.4	3.0578	(var)
NGC 7293	13.53	−0.37	22:29:48.4	−20:49:26	1432.6	2251.2	2.4638	(PNe)
LTT 9491	14.10	+0.03	23:19:35	−17:05:30	12.3	159.4	1.6735	
Feige 110	11.83	−0.30	23:19:58.4	−05:09:56.2	3502.5	7802.2	1.9891	

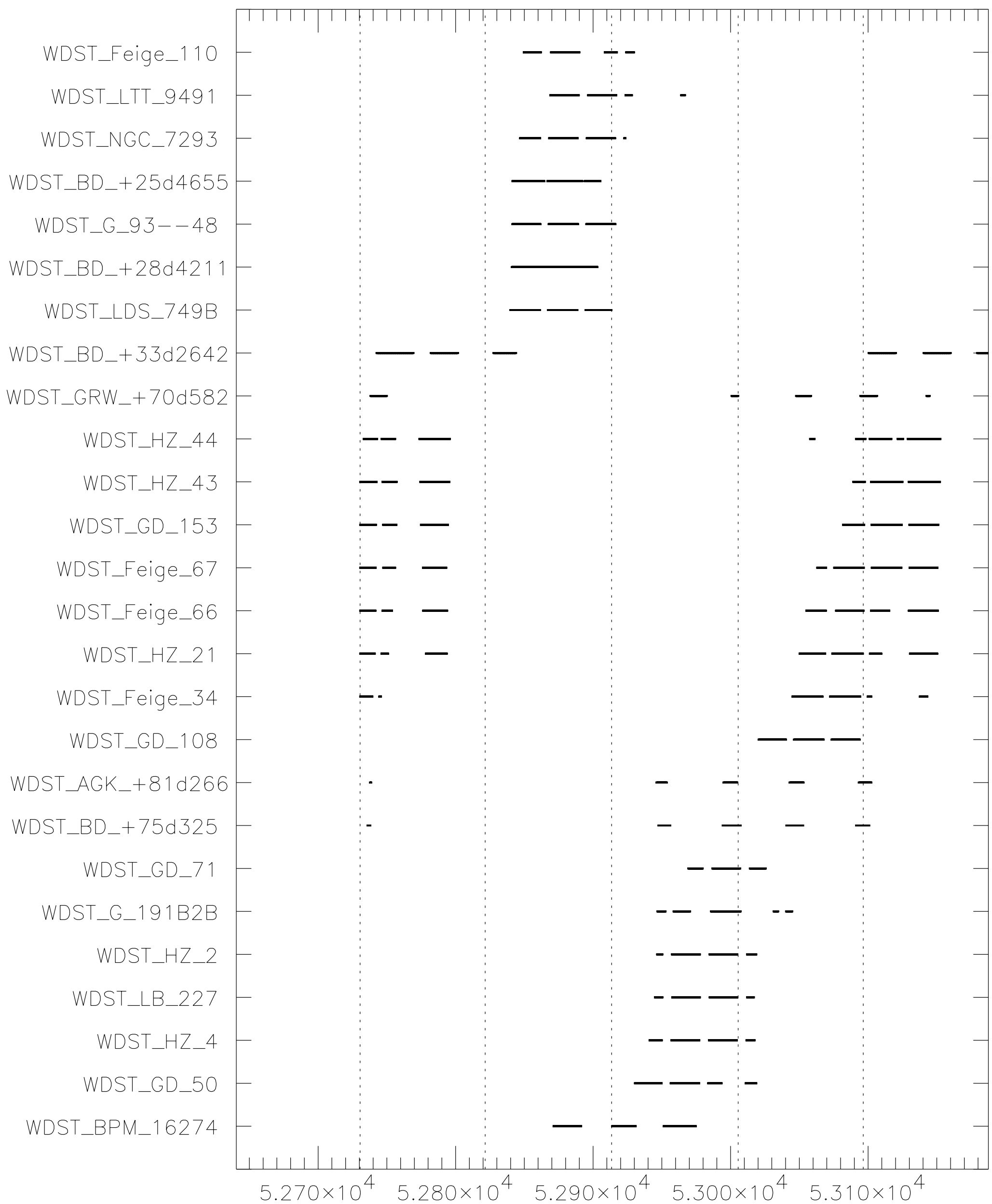
(1) $I_{100\mu m}$ within the GALEX FOV (Schlegel et al. 1998, ApJ, 500, 525).

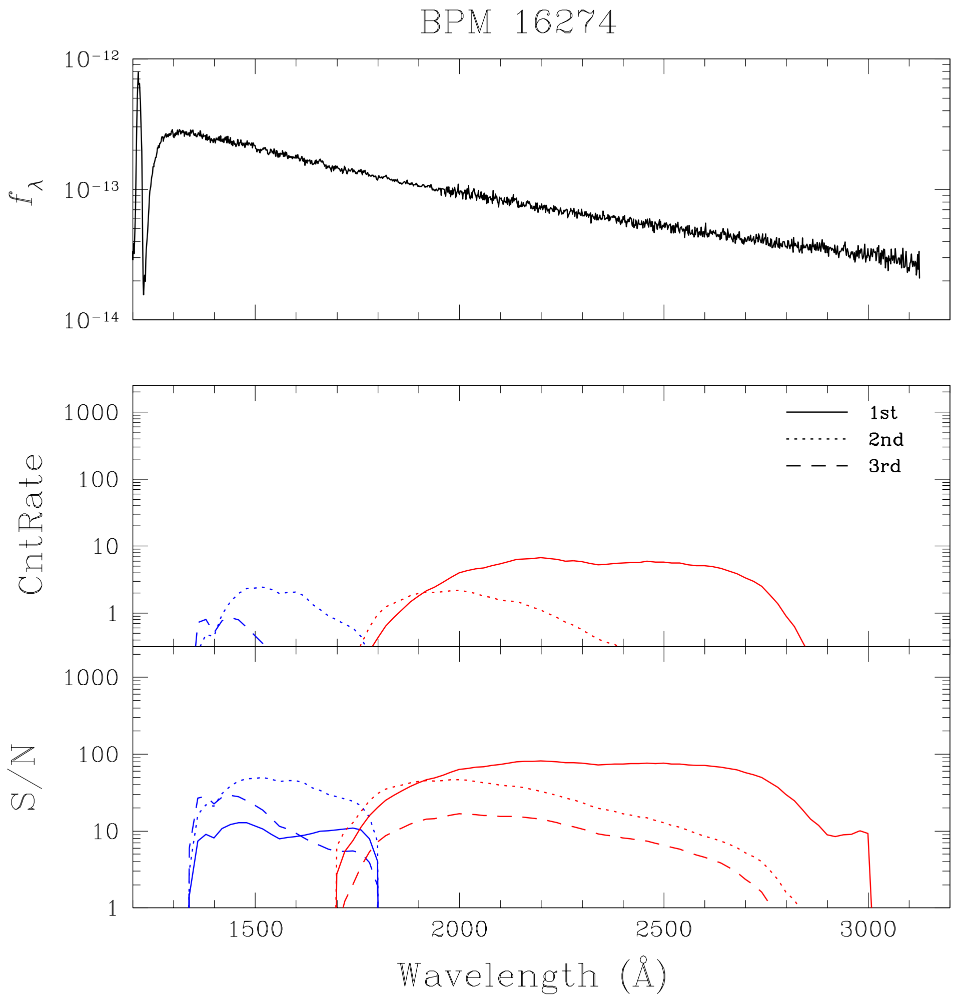
Table B.2: FWHM and dispersion

	Imaging	Grism
FUV	3.″5	8Å
NUV	4.″5	20Å




FOCA_57
FOCA_56
FOCA_39
FOCA_36
FOCA_89
FOCA_91
FOCA_29
FOCA_90
FOCA_97
FOCA_31
FOCA_30
FOCA_28
FOCA_34
FOCA_50
FOCA_81
FOCA_71
FOCA_33
FOCA_67
FOCA_82
FOCA_18
FOCA_51
FOCA_52
FOCA_10
FOCA_55
FOCA_54
FOCA_65
FOCA_15
FOCA_2
FOCA_60
FOCA_12
5.270×10^4
5.280×10^4
5.290×10^4
5.300×10^4
5.310×10^4


WDST_Feige_110
WDST_LTT_9491
WDST_NGC_7293
WDST_BD_+25d4655
WDST_G_93--48
WDST_BD_+28d4211
WDST_LDS_749B
WDST_BD_+33d2642
WDST_GRW_+70d582
WDST_HZ_44
WDST_HZ_43
WDST_GD_153
WDST_Feige_67
WDST_Feige_66
WDST_HZ_21
WDST_Feige_34
WDST_GD_108
WDST_AGK_+81d266
WDST_BD_+75d325
WDST_GD_71
WDST_G_191B2B
WDST_HZ_2
WDST_LB_227
WDST_HZ_4
WDST_GD_50
WDST_BPM_16274
5.270×10^4
5.280×10^4
5.290×10^4
5.300×10^4
5.310×10^4

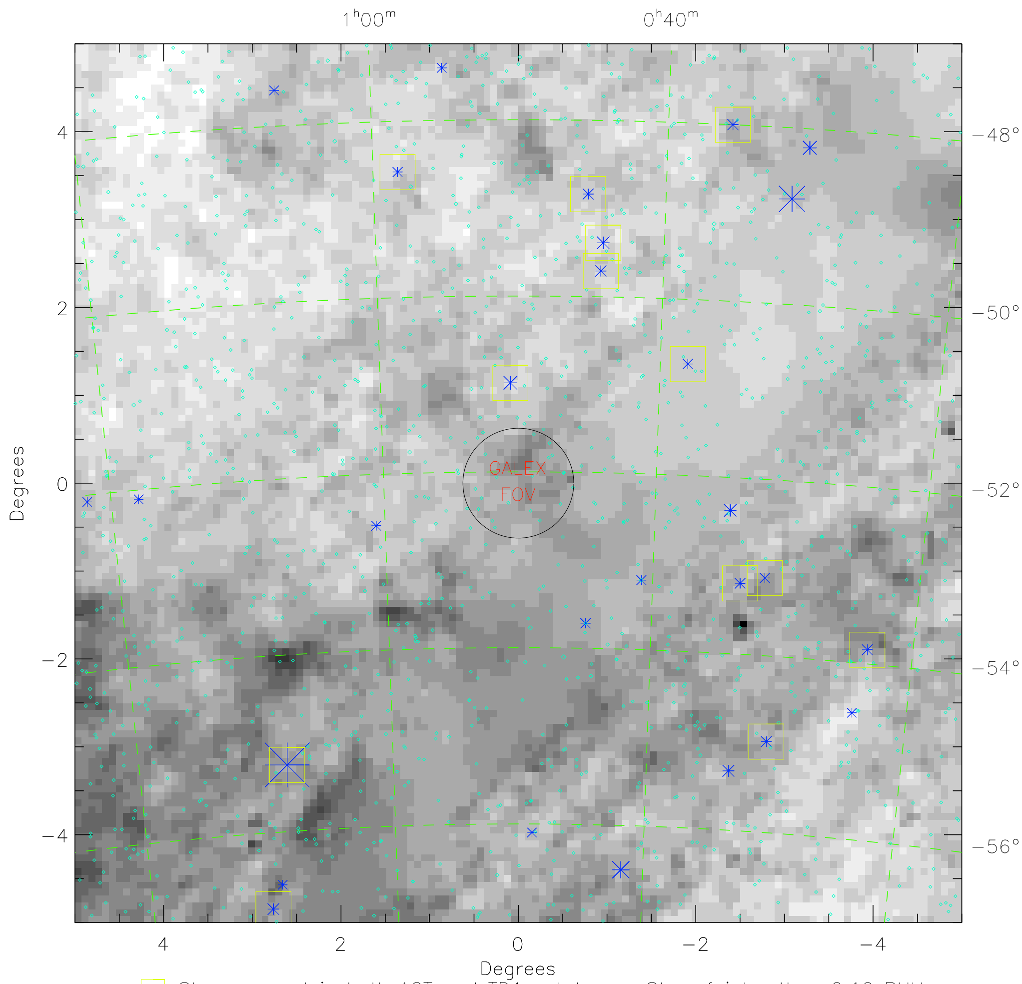

BPM 16274
10^{-12}
f_λ
10^{-13}
10^{-14}
1000
100
10
1
CntRate
1st
2nd
3rd
1000
100
10
1
S/N
1500
2000
2500
3000
Wavelength (Å)

BPM 16274

Greyscale is 100μm emission   0.263 (white) to 1.827 (black) MJy/sr

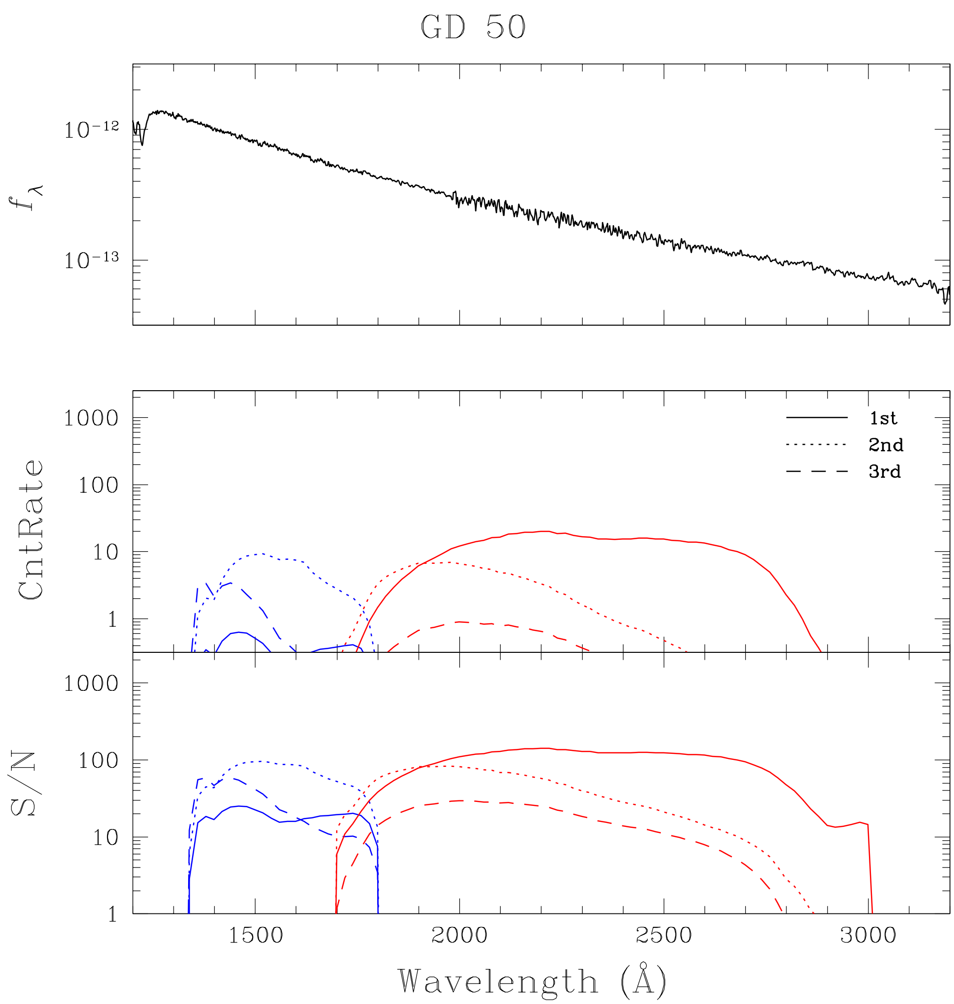
Limit: $I_{100} \leqq 0.75$ Median = 0.680 MJy/sr

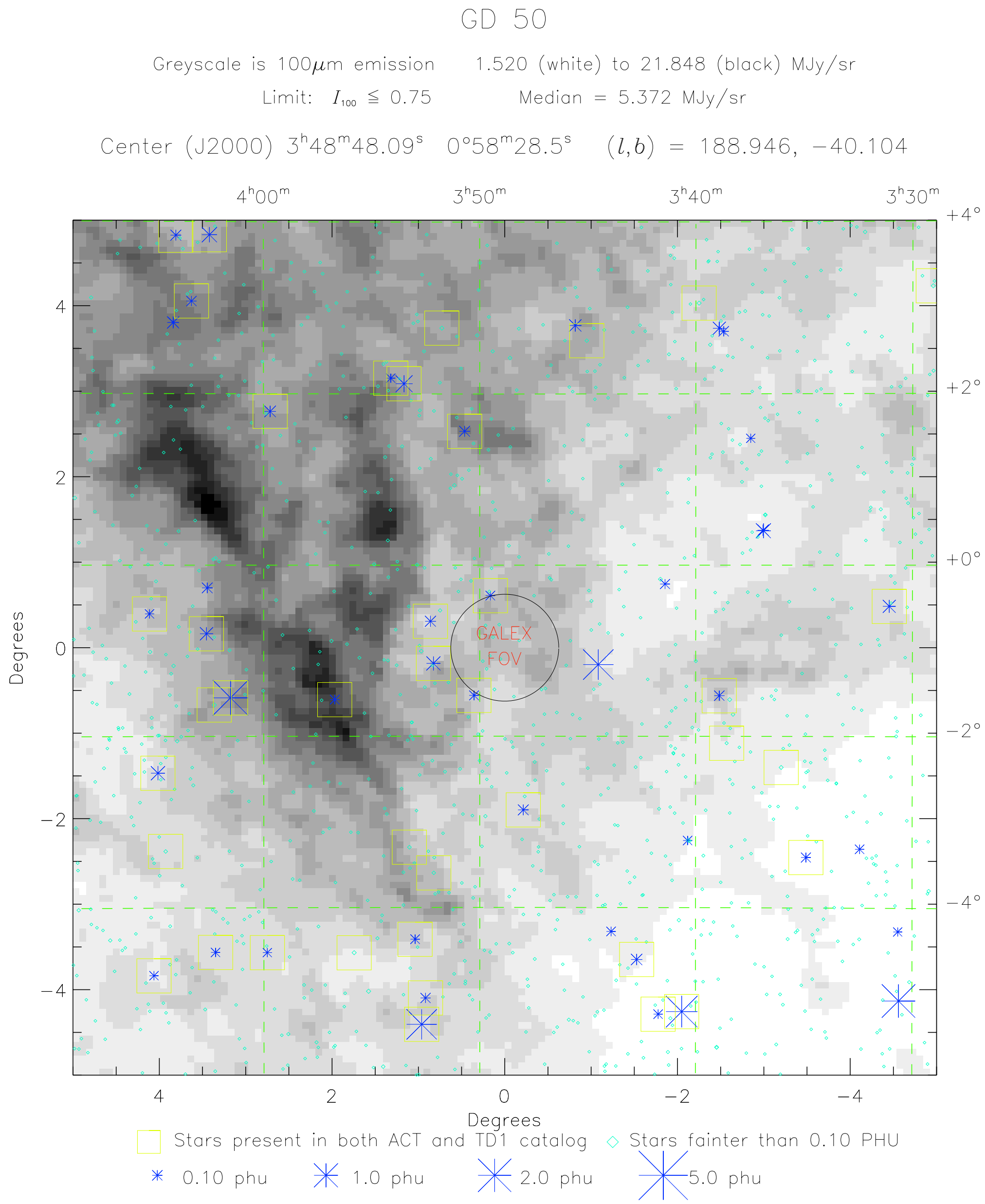
Center (J2000) $0^h50^m3.07^s$ $-52°08^m17.5^s$ (l,b) = 303.435, −64.989

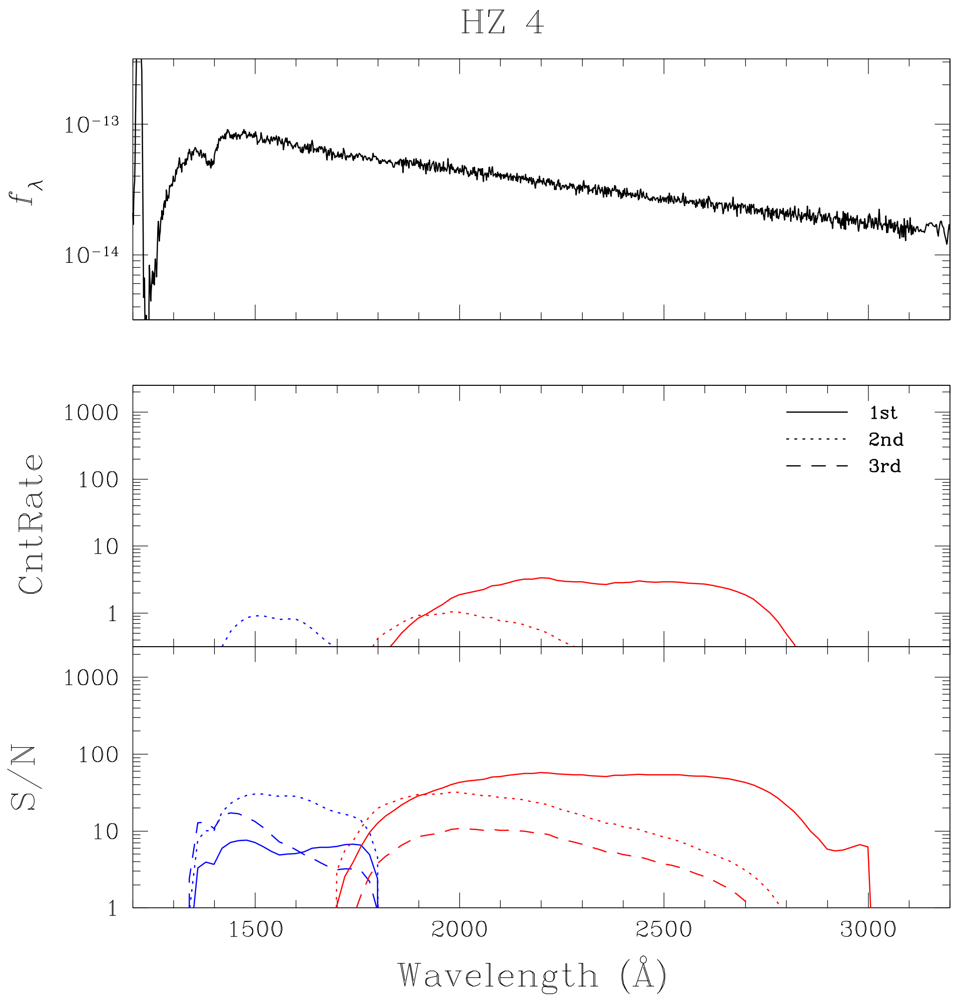


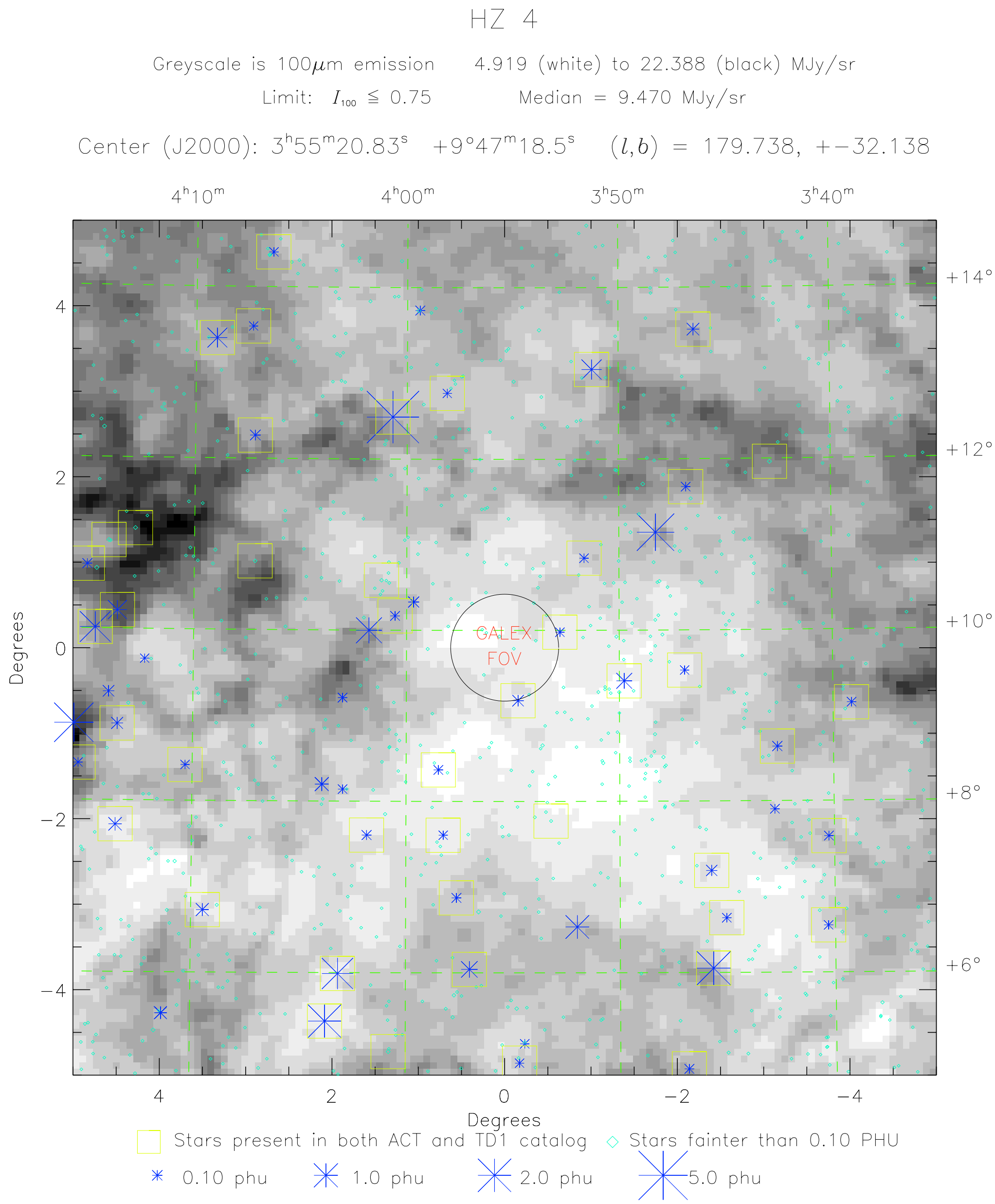
Stars present in both ACT and TD1 catalog ◇ Stars fainter than 0.10 PHU

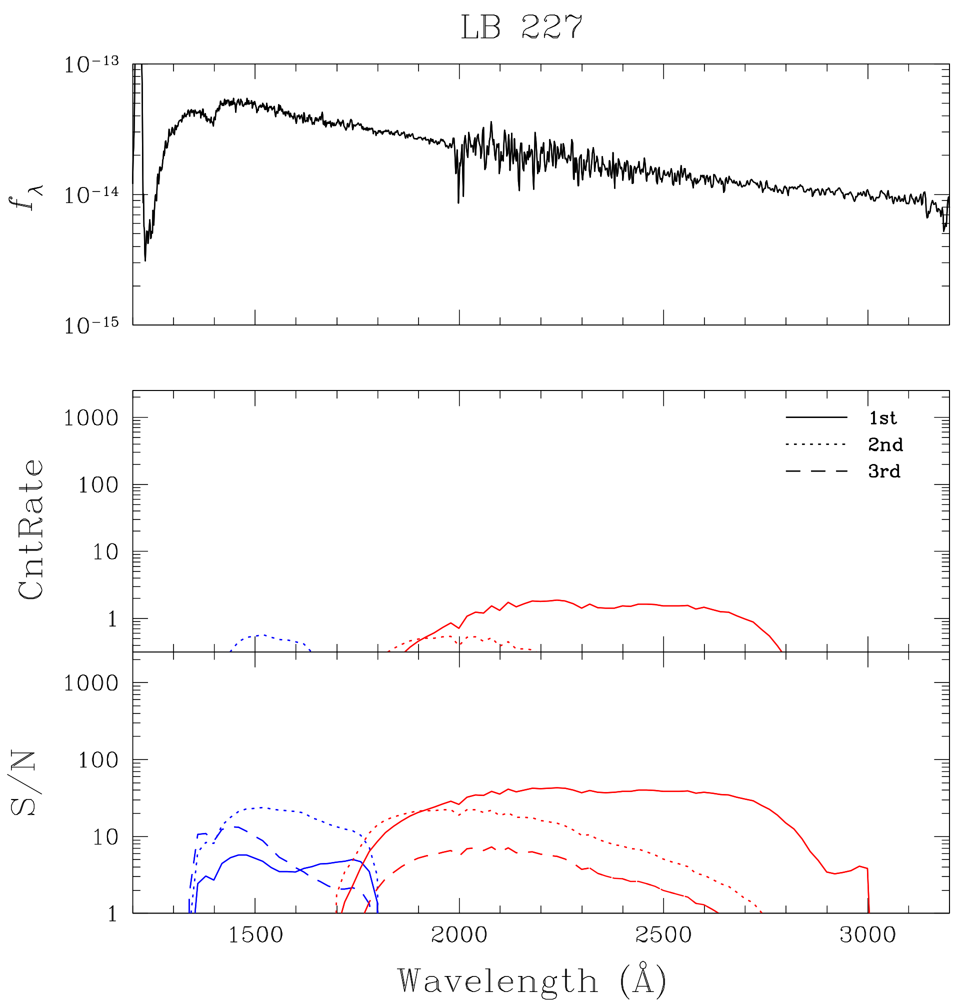
0.10 phu 1.0 phu 2.0 phu 5.0 phu

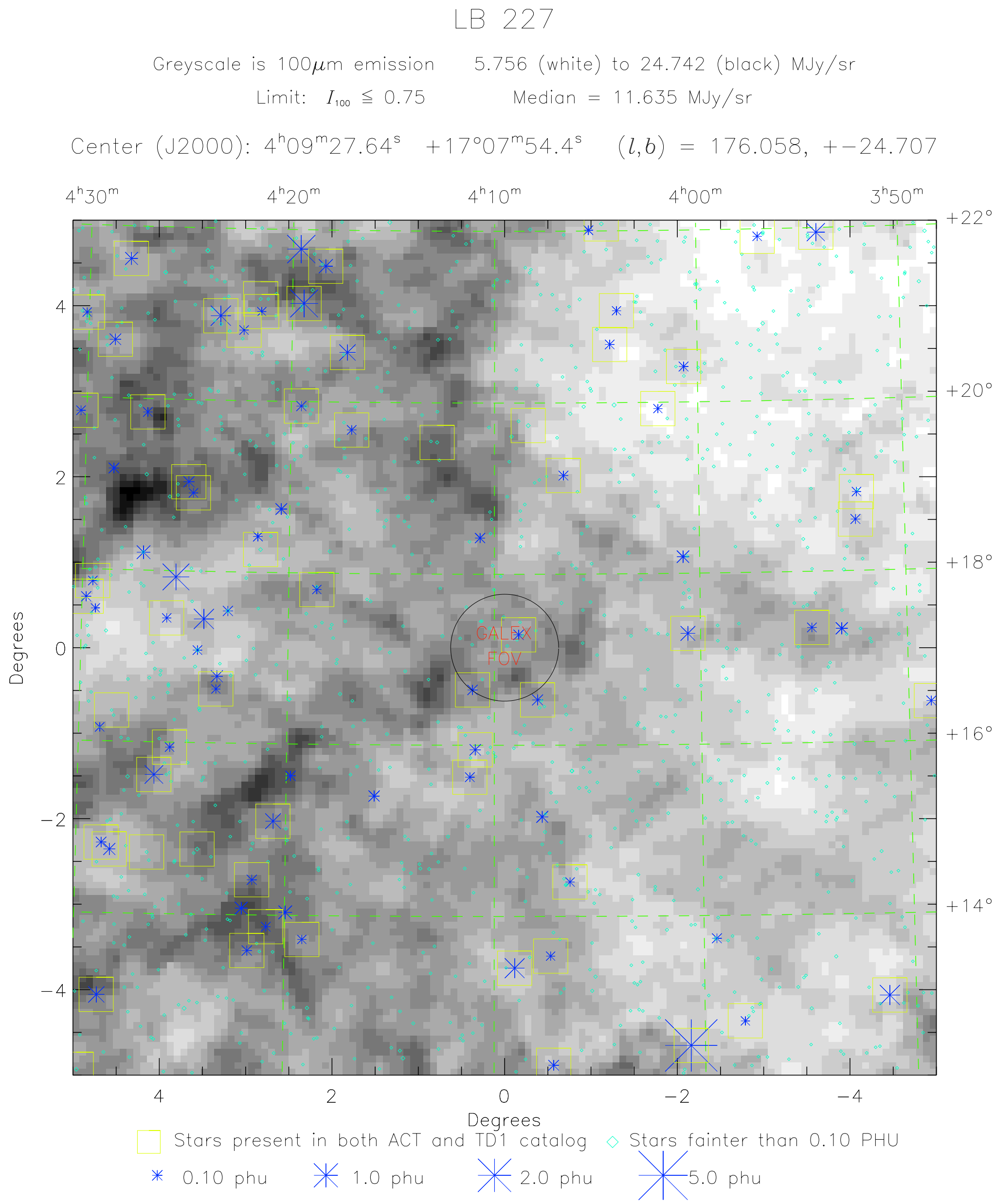

GD 50
f_λ
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

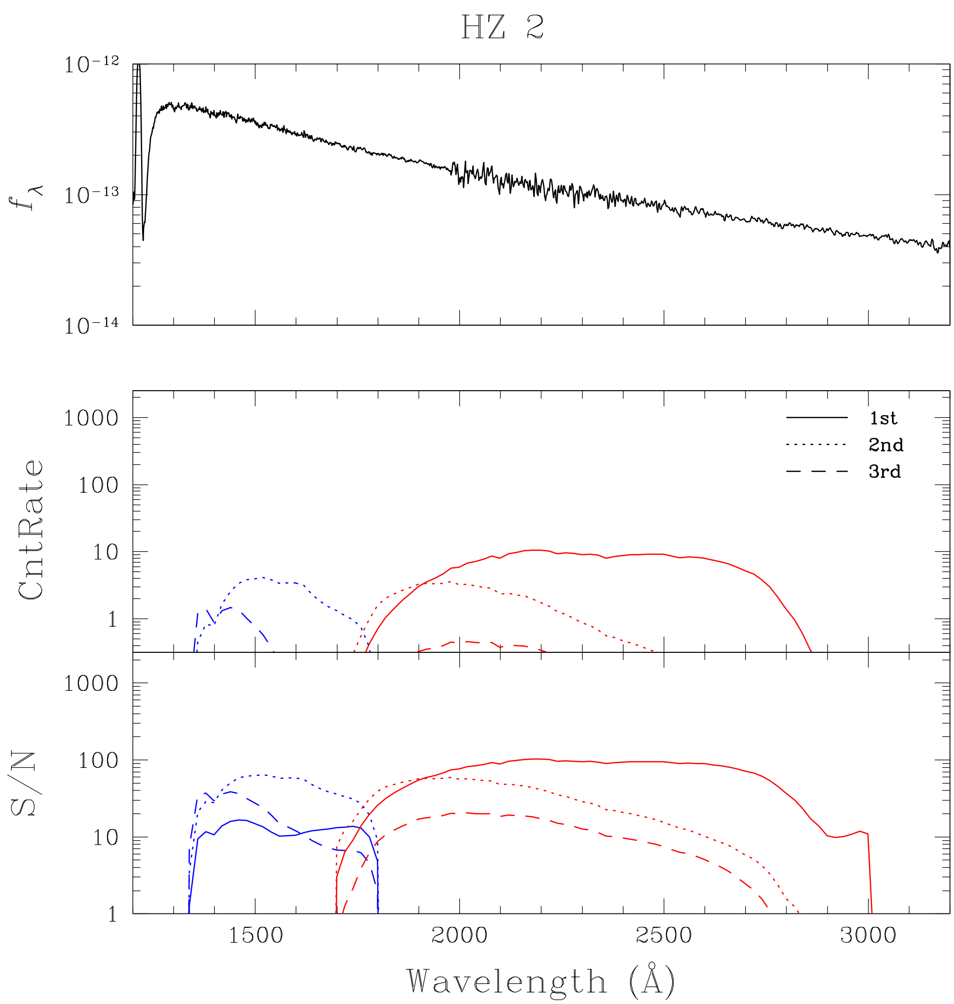

GD 50
Greyscale is 100μm emission 1.520 (white) to 21.848 (black) MJy/sr
Limit: $I_{100} \leqq 0.75$ Median = 5.372 MJy/sr
Center (J2000) 3h48m48.09s 0°58m28.5s (l,b) = 188.946, −40.104
4h00m
3h50m
3h40m
3h30m
+4°
+2°
+0°
−2°
−4°
Degrees
GALEX FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

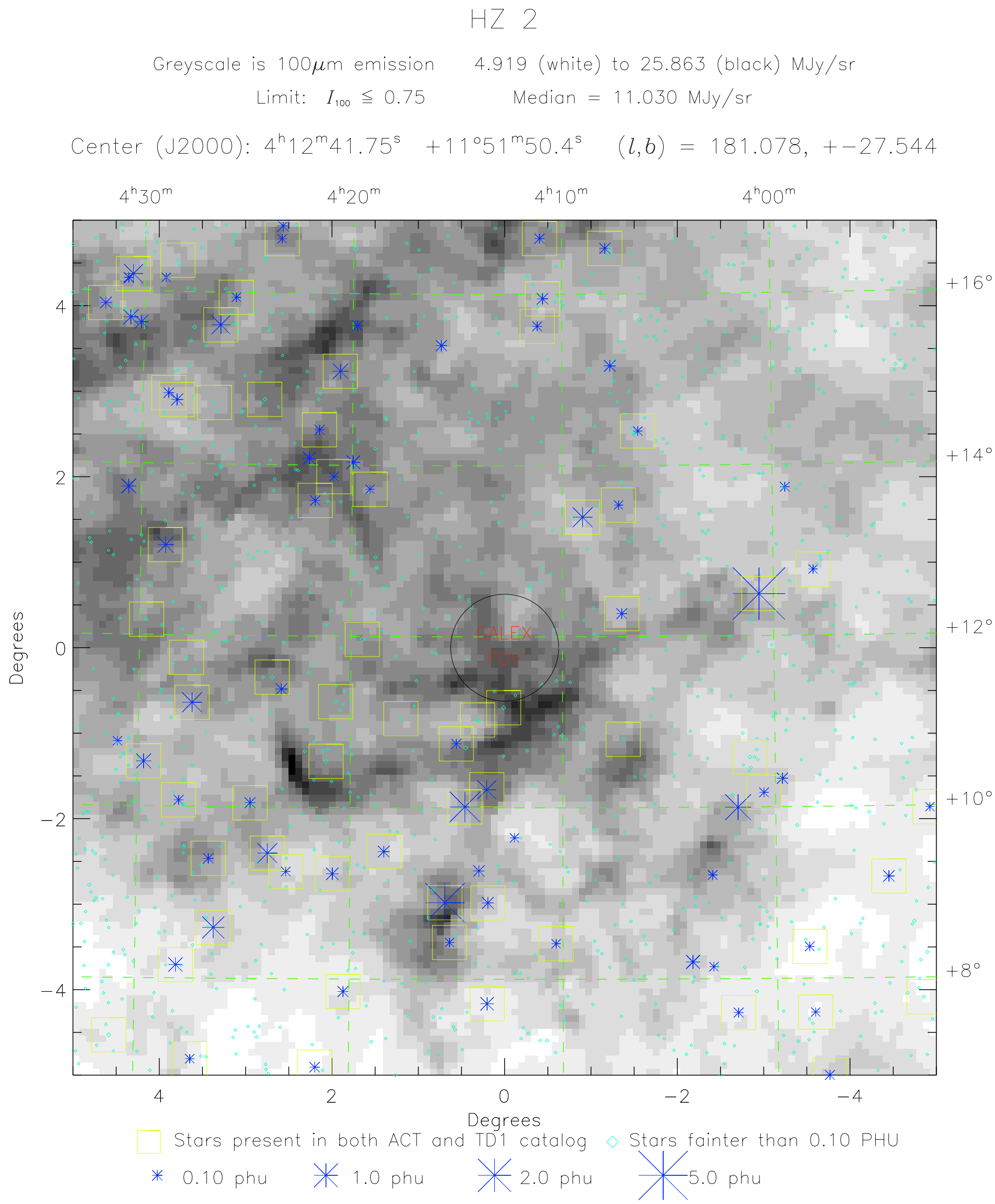

HZ 4
f_λ
10^{-13}
10^{-14}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

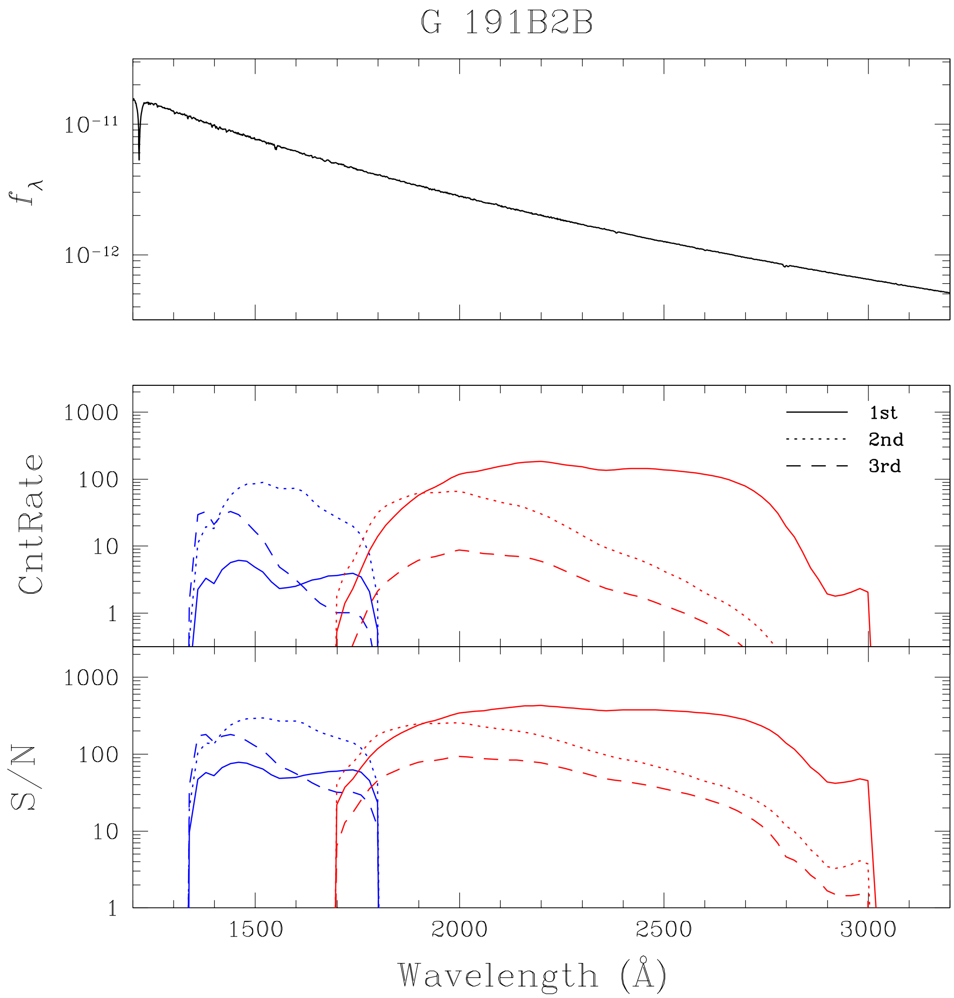

HZ 4
Greyscale is 100μm emission 4.919 (white) to 22.388 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 9.470 MJy/sr
Center (J2000): 3h55m20.83s +9°47m18.5s (l,b) = 179.738, +-32.138
4h10m
4h00m
3h50m
3h40m
+14°
+12°
+10°
+8°
+6°
GALEX
FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

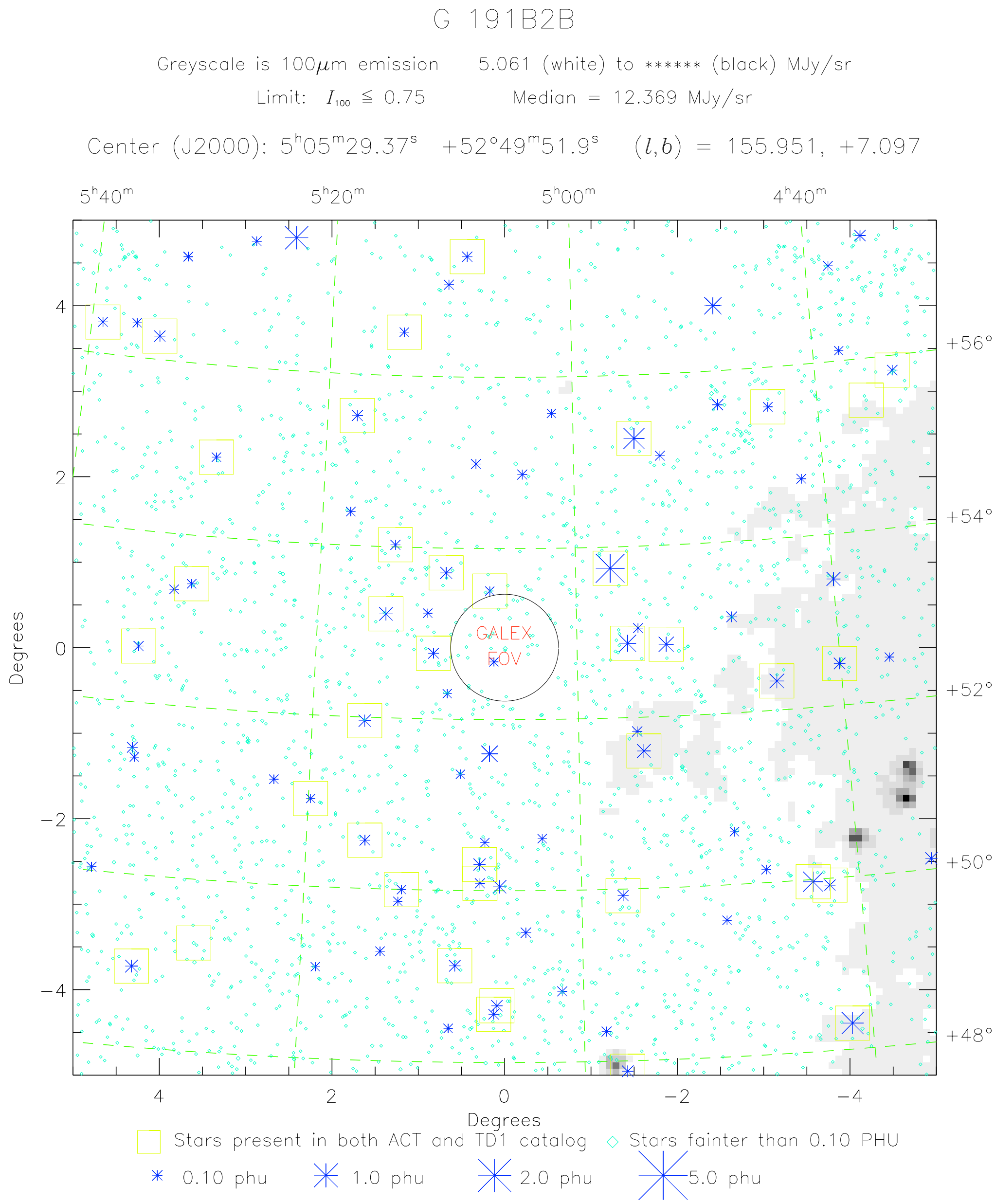

LB 227
f_λ
10^{-13}
10^{-14}
10^{-15}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)


LB 227
Greyscale is 100μm emission 5.756 (white) to 24.742 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 11.635 MJy/sr
Center (J2000): 4h09m27.64s +17°07m54.4s (l,b) = 176.058, +-24.707
4h30m
4h20m
4h10m
4h00m
3h50m
+22°
+20°
+18°
+16°
+14°
Degrees
Degrees
GALEX FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

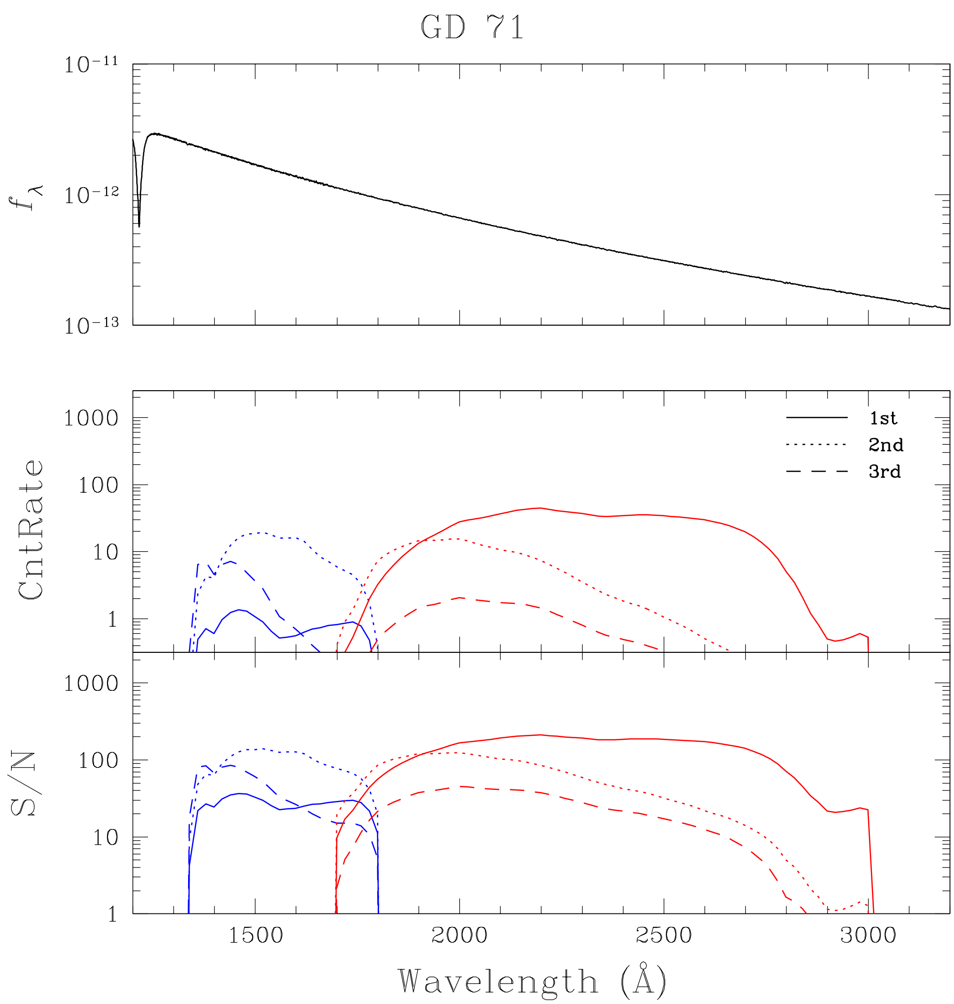

HZ 2
f_λ
10^{-12}
10^{-13}
10^{-14}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

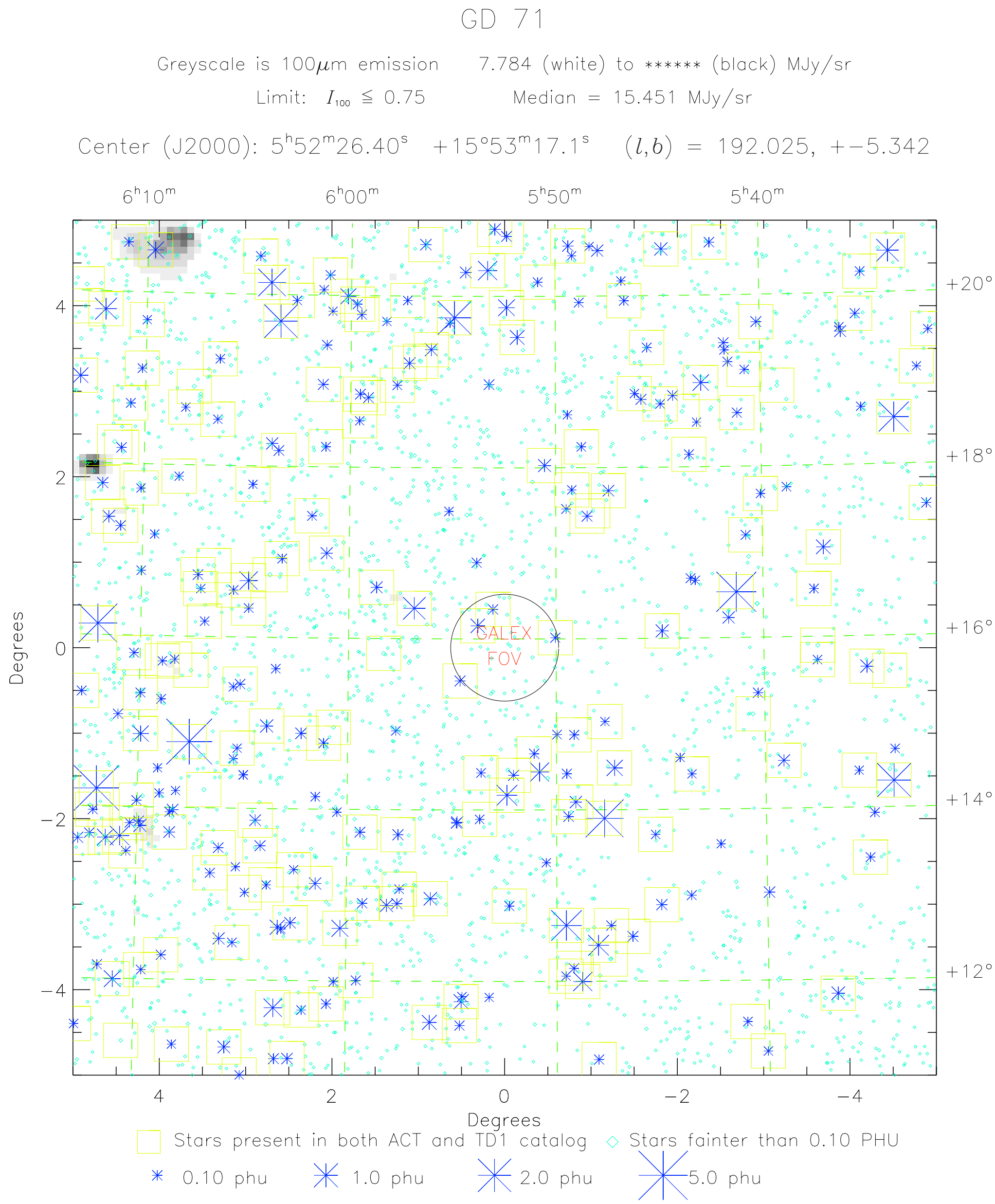

HZ 2
Greyscale is 100μm emission 4.919 (white) to 25.863 (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 11.030 MJy/sr
Center (J2000): 4h12m41.75s +11°51m50.4s (l,b) = 181.078, +-27.544
4h30m
4h20m
4h10m
4h00m
+16°
+14°
+12°
+10°
+8°
Degrees
GALEX
FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

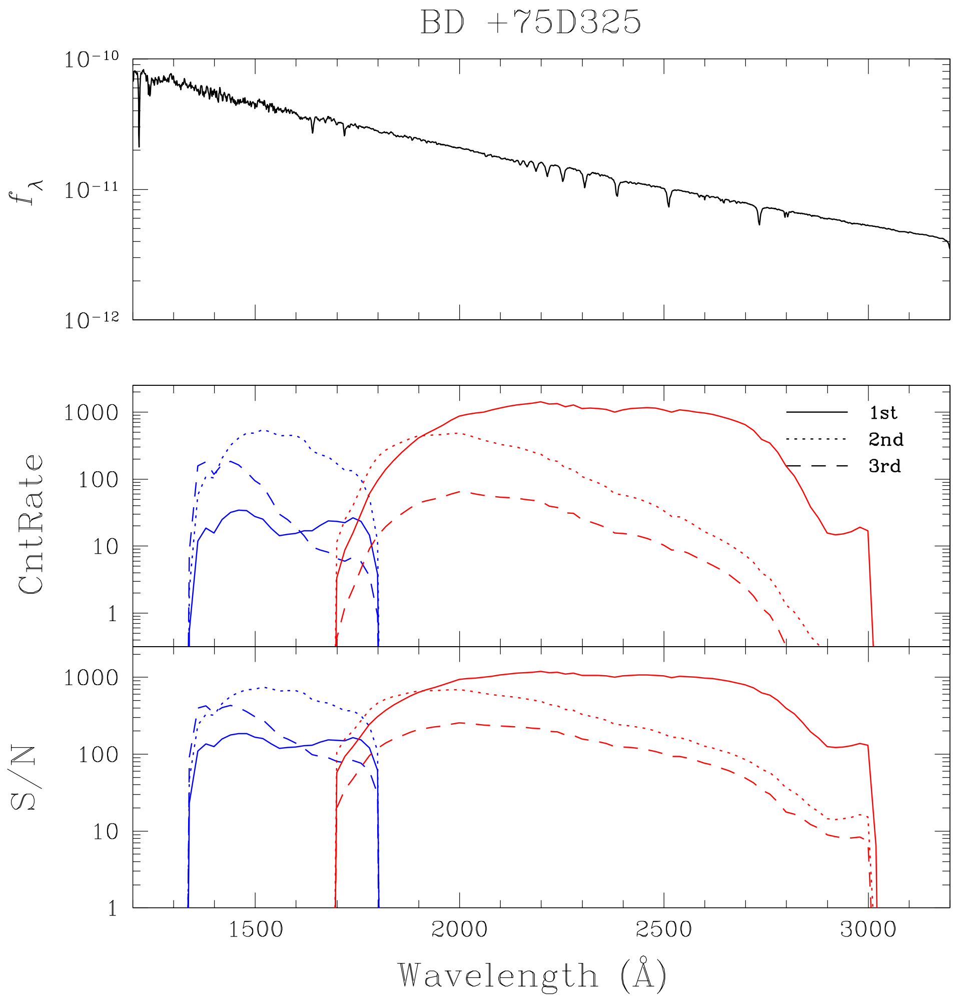

G 191B2B
10^{-11}
f_λ
10^{-12}
1000
100
10
1
CntRate
1st
2nd
3rd
S/N
1500
2000
2500
3000
Wavelength (Å)

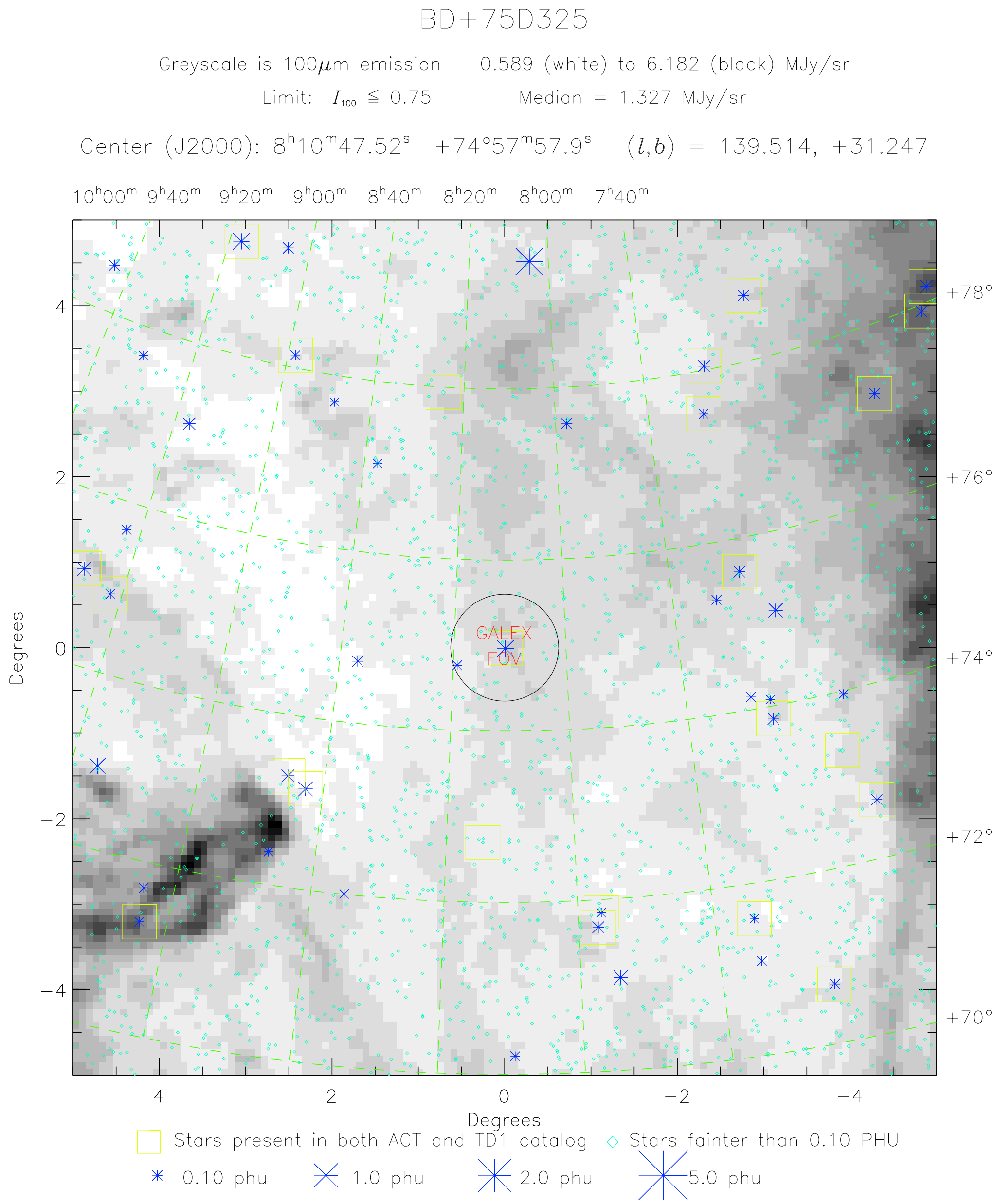


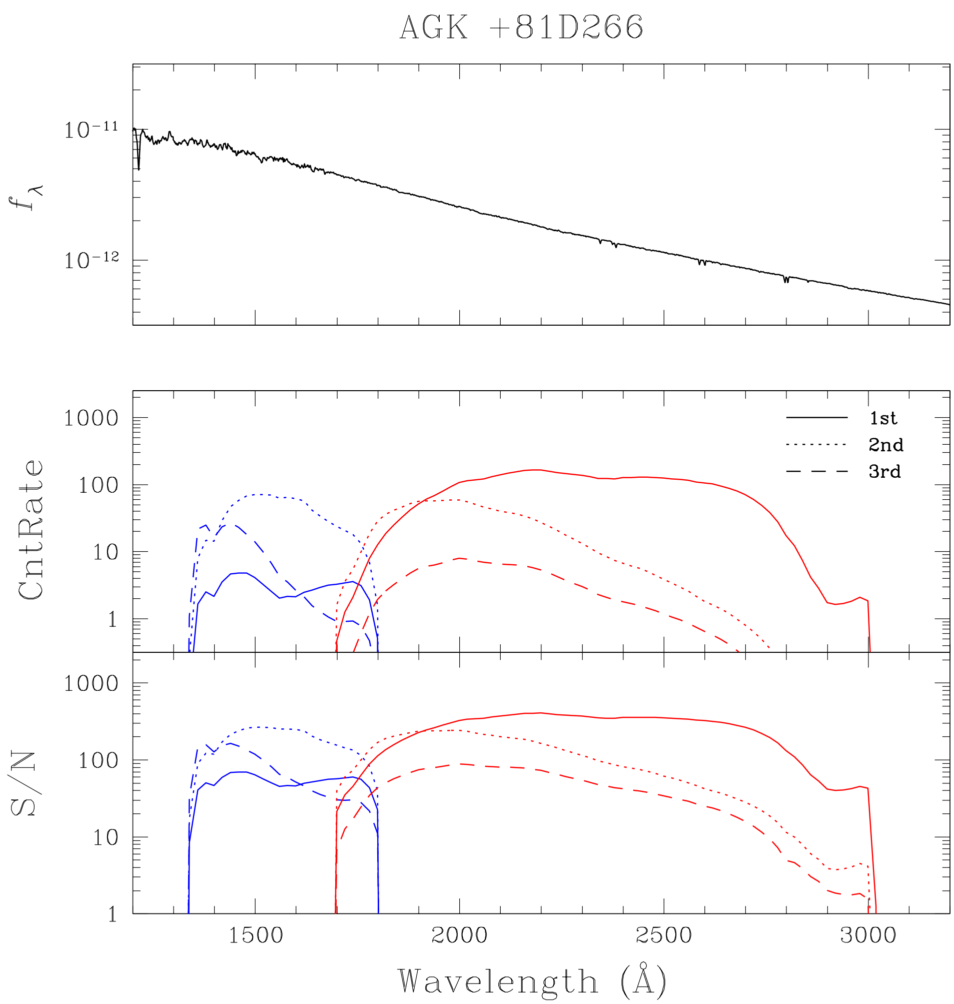
G 191B2B
Greyscale is 100μm emission 5.061 (white) to ****** (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 12.369 MJy/sr
Center (J2000): 5h05m29.37s +52°49m51.9s (l,b) = 155.951, +7.097
5h40m
5h20m
5h00m
4h40m
+56°
+54°
+52°
+50°
+48°
GALEX
FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

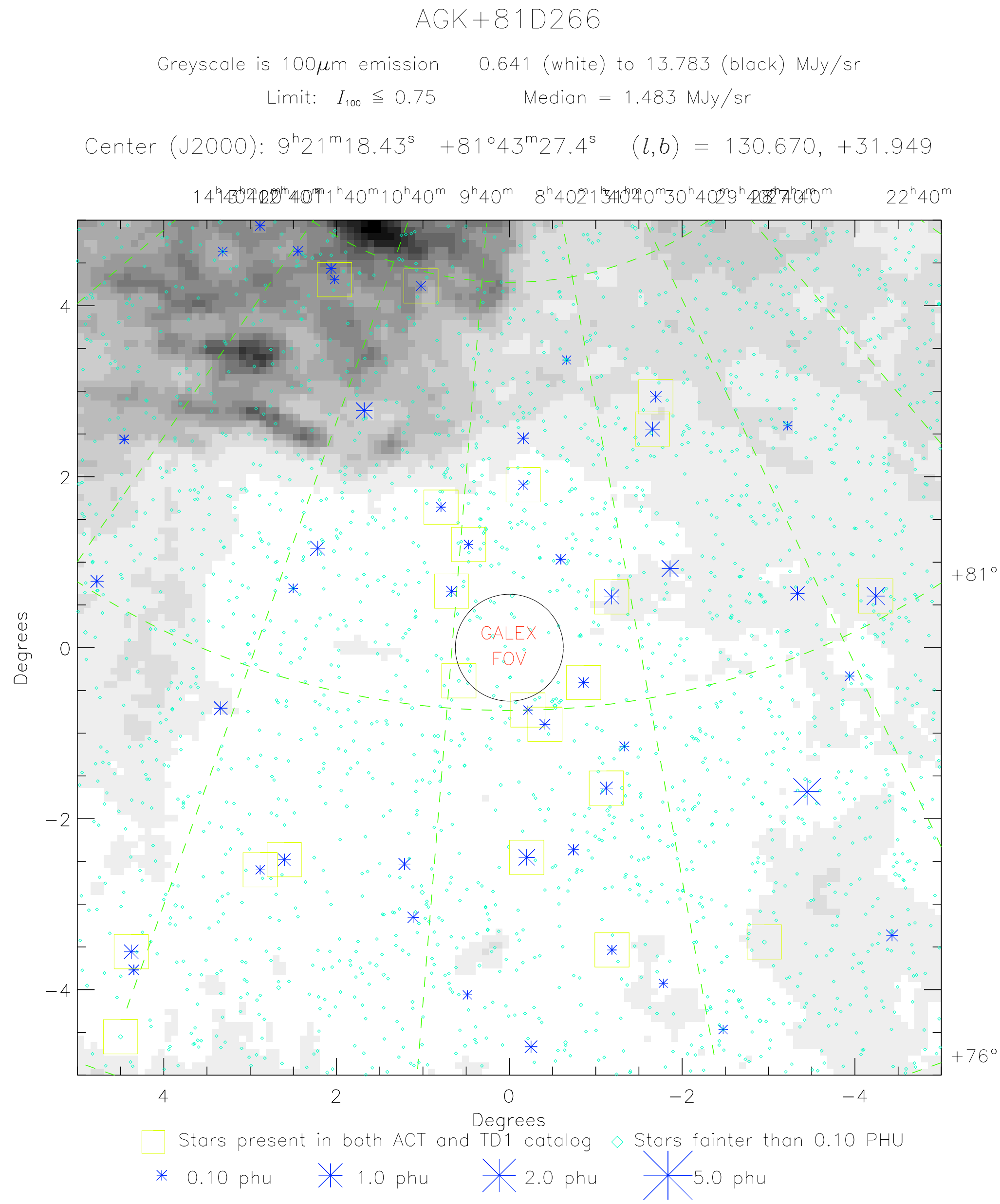

GD 71
f_λ
10^{-11}
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

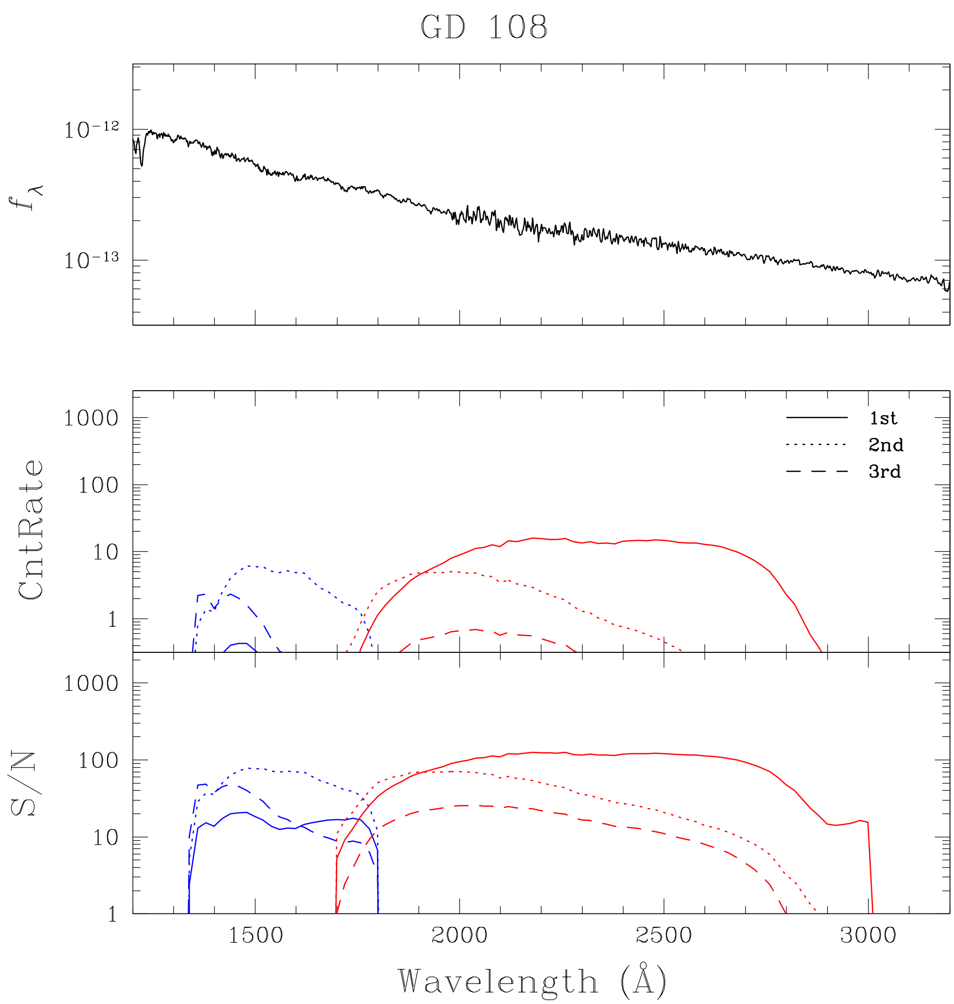

GD 71
Greyscale is 100μm emission 7.784 (white) to ****** (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 15.451 MJy/sr
Center (J2000): 5h52m26.40s +15°53m17.1s (l,b) = 192.025, +-5.342
6h10m
6h00m
5h50m
5h40m
+20°
+18°
+16°
+14°
+12°
GALEX
FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

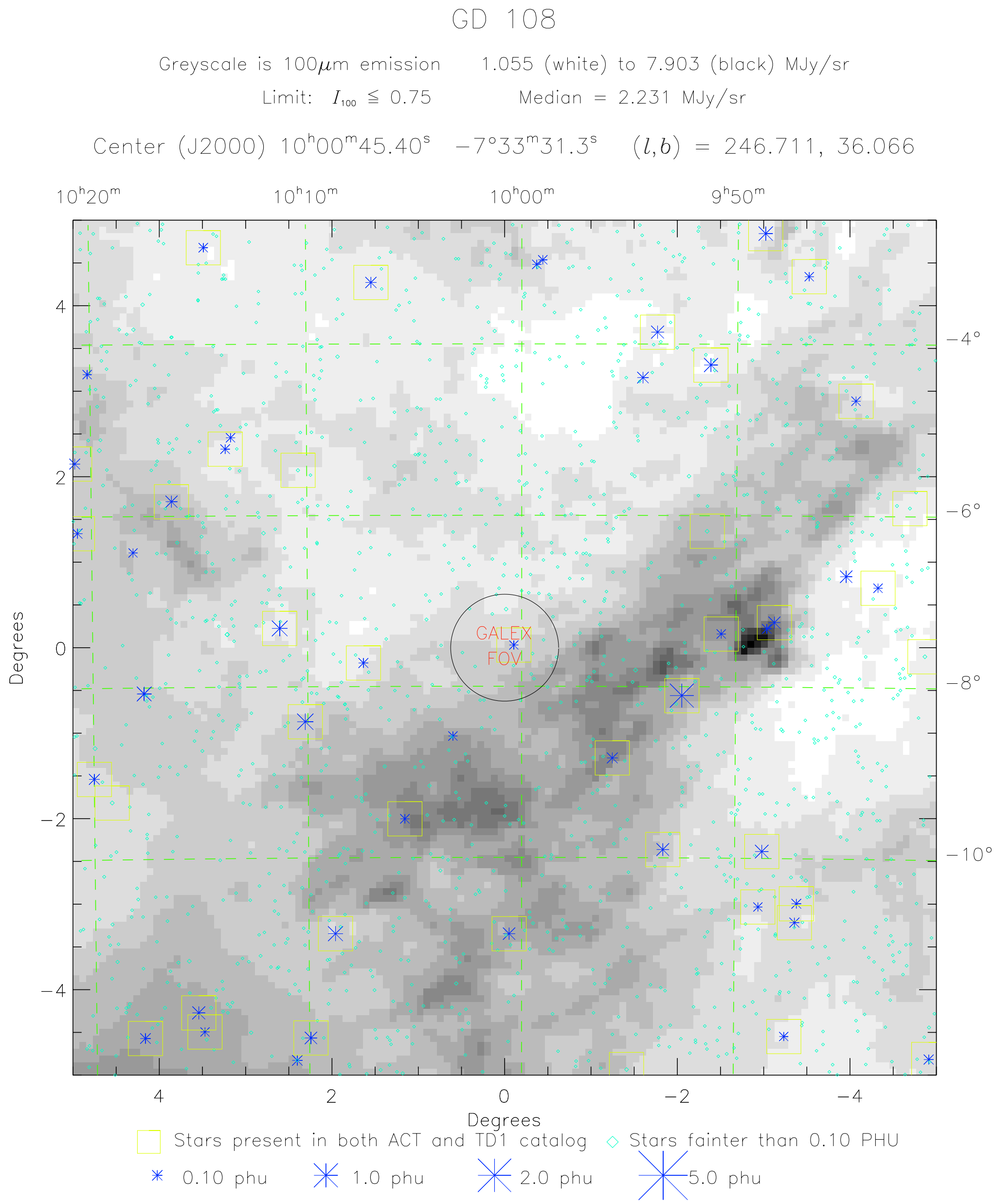

BD +75D325
f_λ
10^{-10}
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

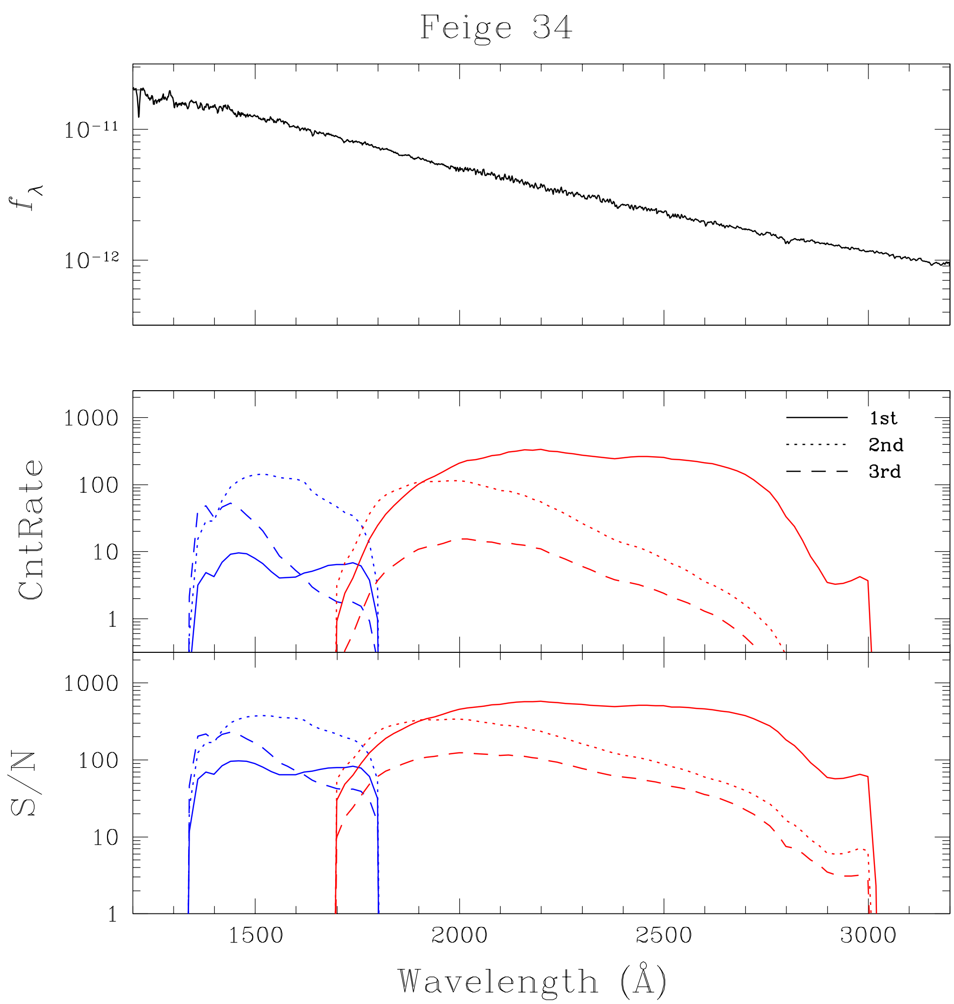

BD+75D325
Greyscale is 100μm emission 0.589 (white) to 6.182 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.327 MJy/sr
Center (J2000): 8h10m47.52s +74°57m57.9s (l,b) = 139.514, +31.247
10h00m 9h40m 9h20m 9h00m 8h40m 8h20m 8h00m 7h40m
+78°
+76°
+74°
+72°
+70°
4
2
0
−2
−4
Degrees
GALEX FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

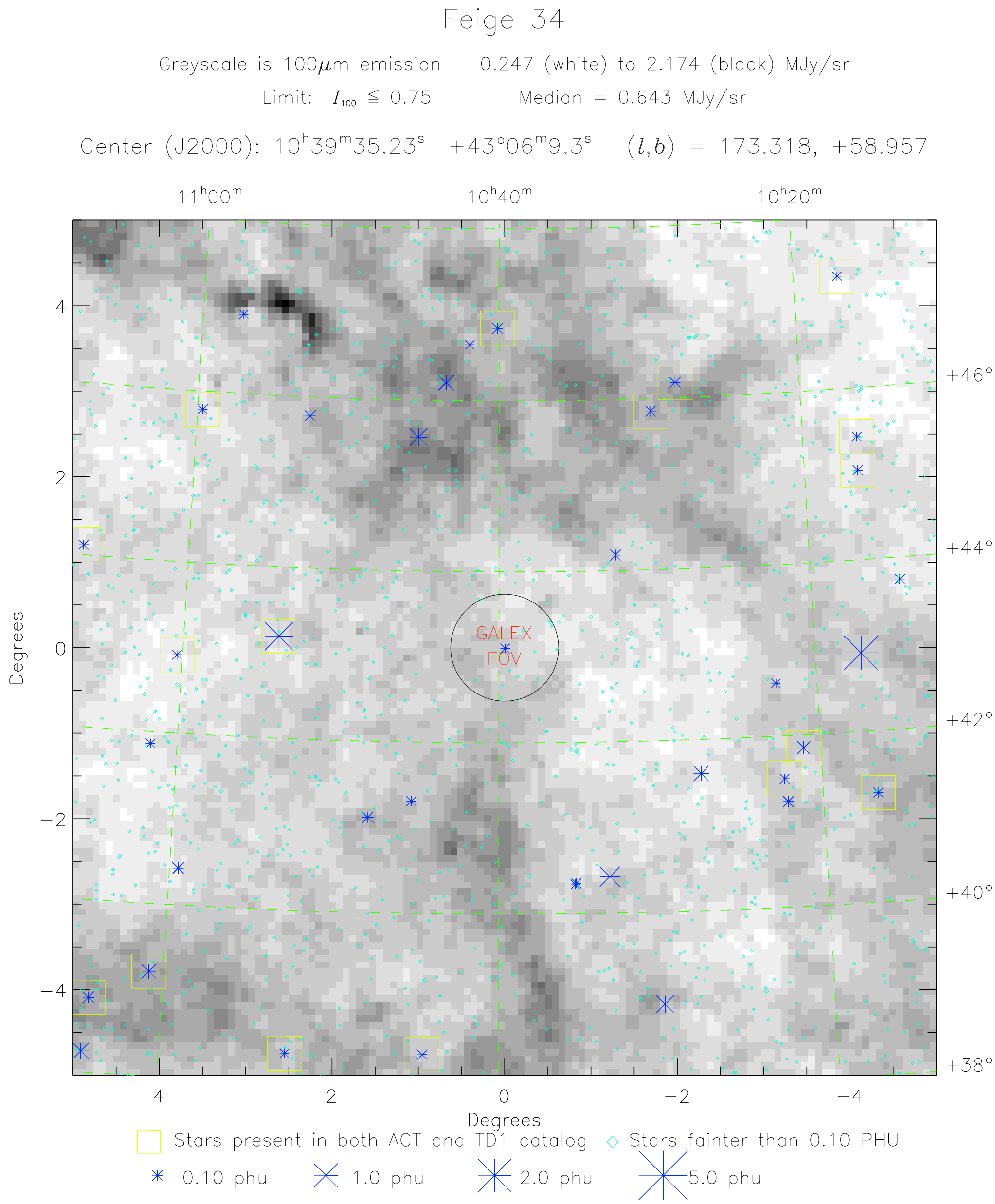

AGK +81D266
f_λ
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

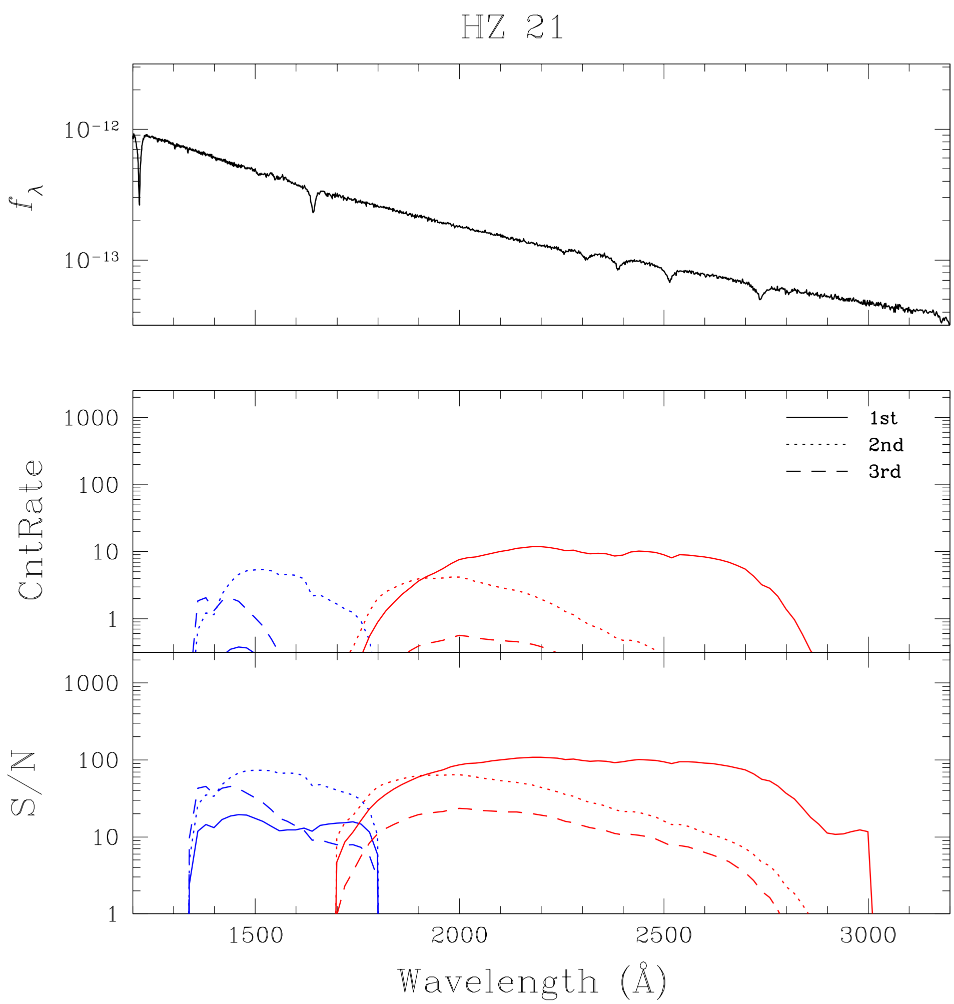

AGK+81D266
Greyscale is 100μm emission 0.641 (white) to 13.783 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.483 MJy/sr
Center (J2000): 9h21m18.43s +81°43m27.4s (l,b) = 130.670, +31.949
22h40m
+81°
+76°
GALEX FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

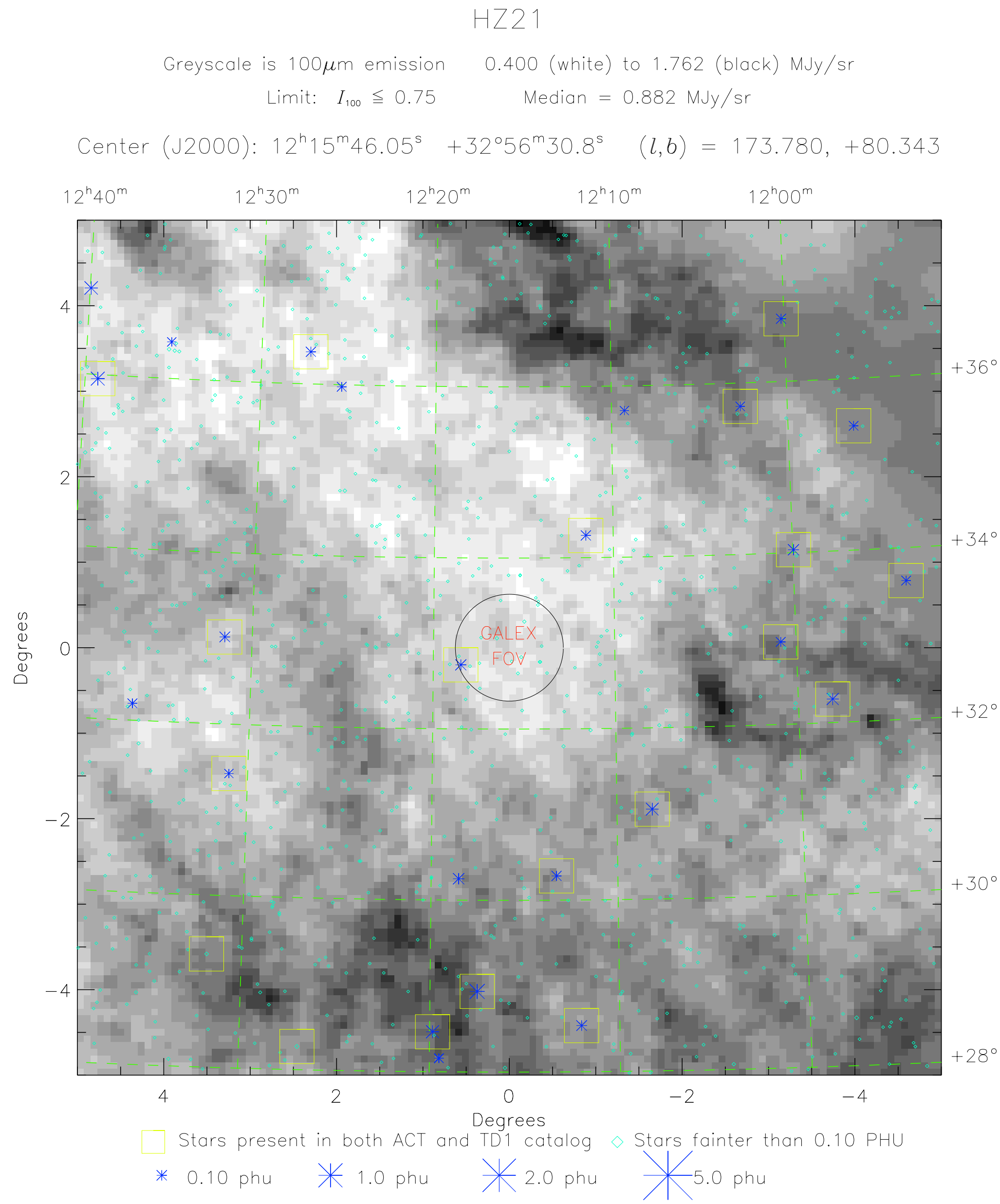

GD 108
f_λ
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1500
2000
2500
3000
Wavelength (Å)

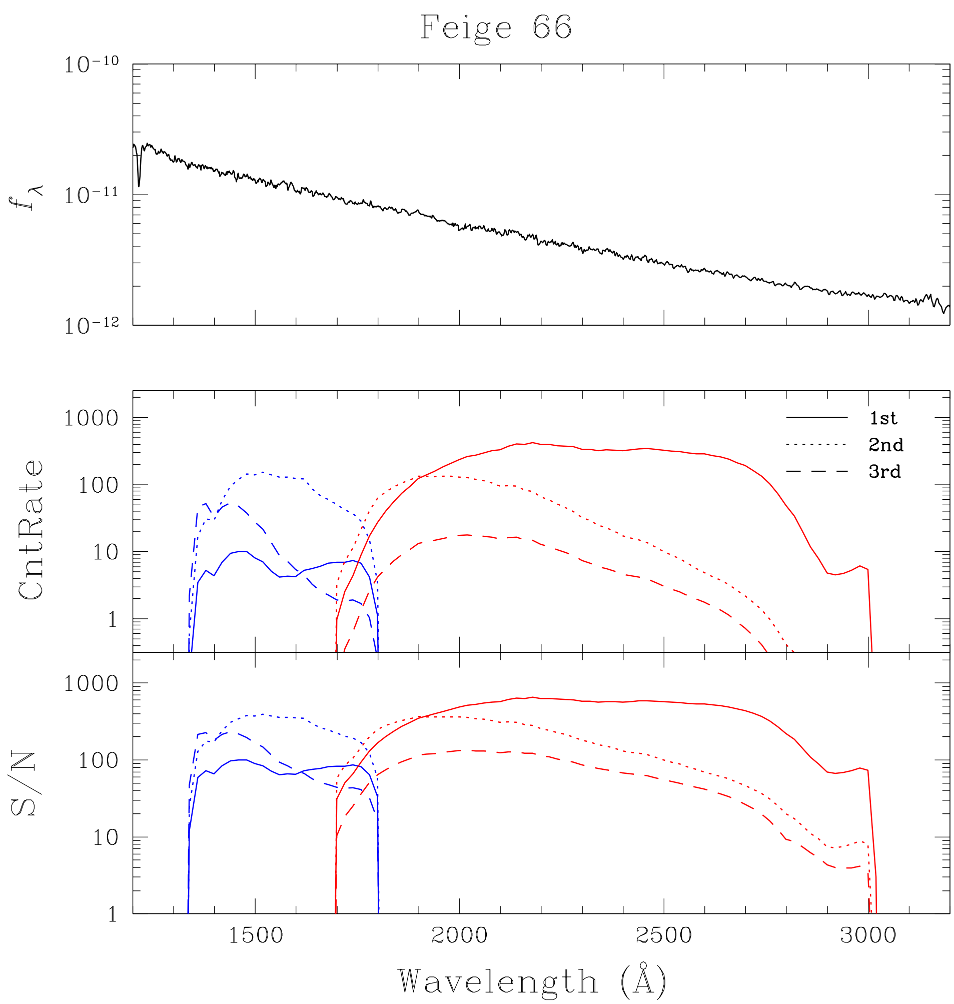

GD 108
Greyscale is 100μm emission 1.055 (white) to 7.903 (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 2.231 MJy/sr
Center (J2000) 10h00m45.40s −7°33m31.3s (l,b) = 246.711, 36.066
10h20m
10h10m
10h00m
9h50m
GALEX
FOV
Degrees
Degrees
−4°
−6°
−8°
−10°
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

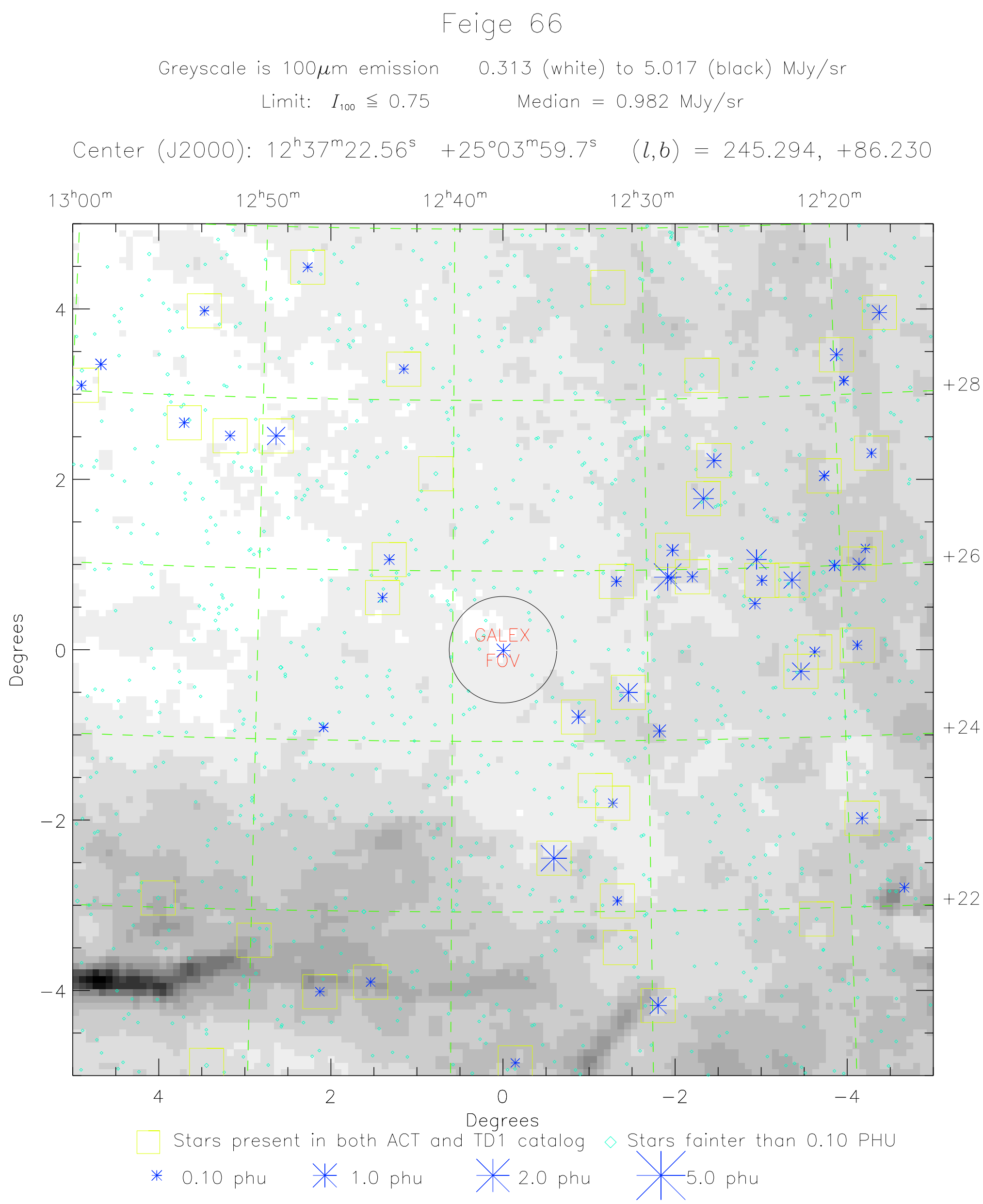

Feige 34
f_λ
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1500
2000
2500
3000
Wavelength (Å)

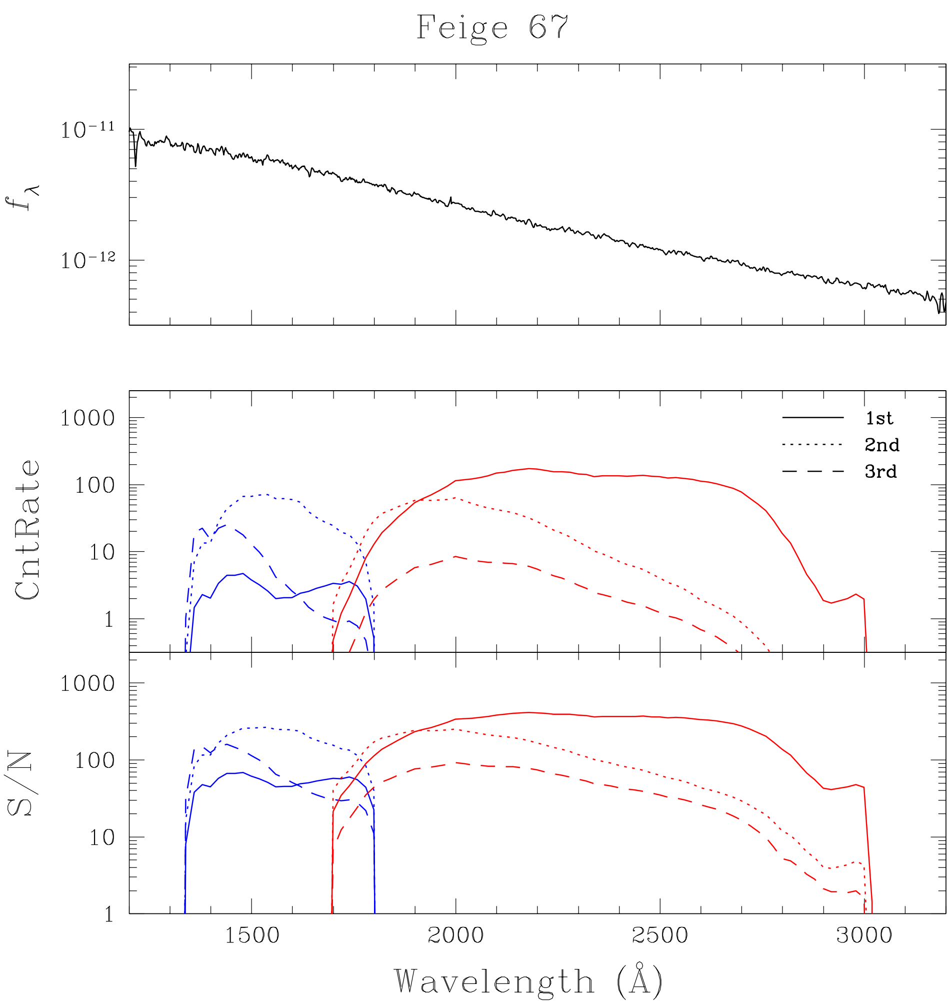

Feige 34
Greyscale is 100μm emission 0.247 (white) to 2.174 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 0.643 MJy/sr
Center (J2000): 10h39m35.23s +43°06m9.3s (l,b) = 173.318, +58.957
11h00m
10h40m
10h20m
+46°
+44°
+42°
+40°
+38°
4
2
0
−2
−4
Degrees
GALEX FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu


HZ 21
10^{-12}
f_λ
10^{-13}
1000
100
10
1
CntRate
1st
2nd
3rd
1000
100
10
1
S/N
1500
2000
2500
3000
Wavelength (Å)

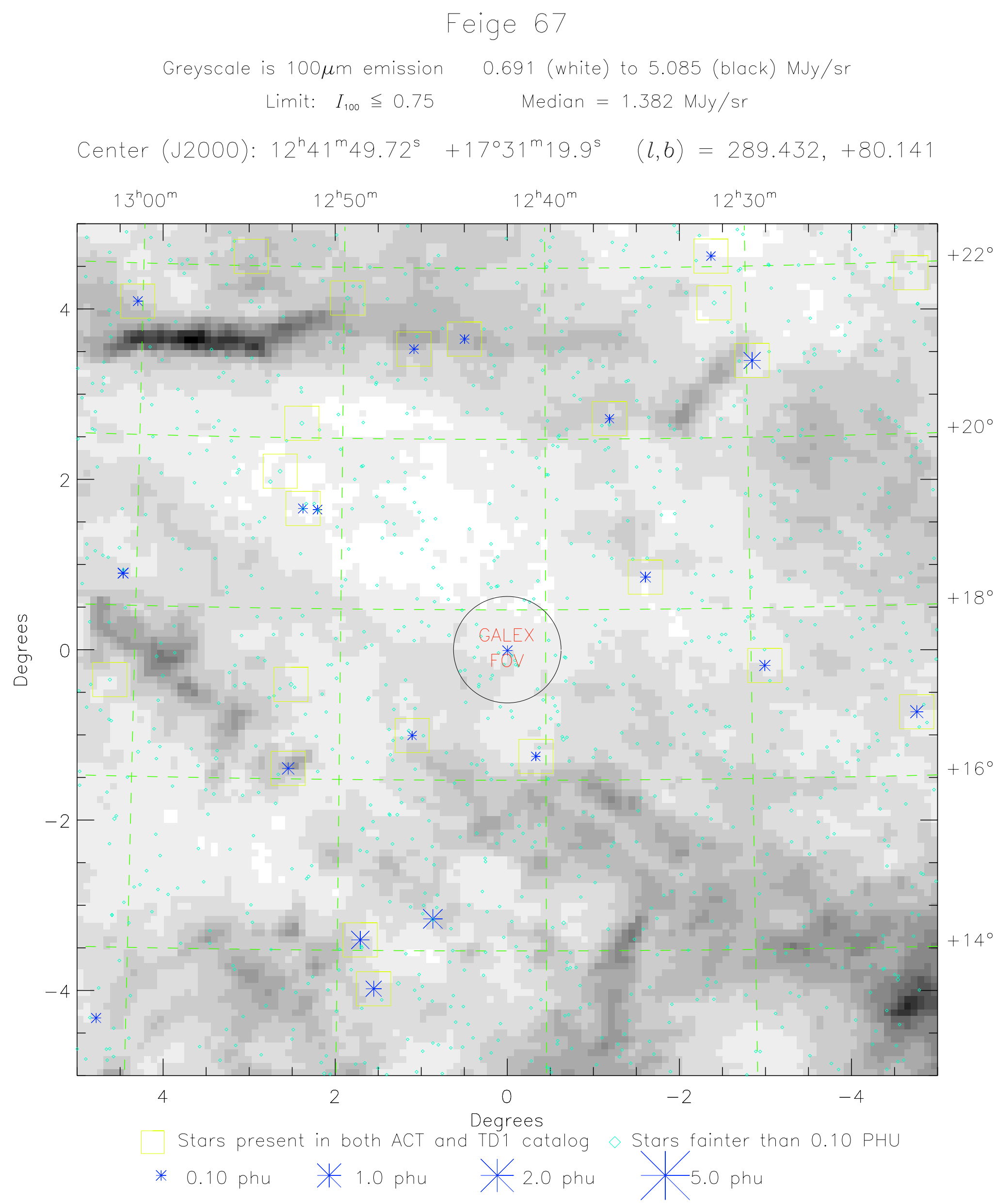

HZ21
Greyscale is 100μm emission 0.400 (white) to 1.762 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 0.882 MJy/sr
Center (J2000): 12h15m46.05s +32°56m30.8s (l,b) = 173.780, +80.343
12h40m
12h30m
12h20m
12h10m
12h00m
+36°
+34°
+32°
+30°
+28°
GALEX
FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

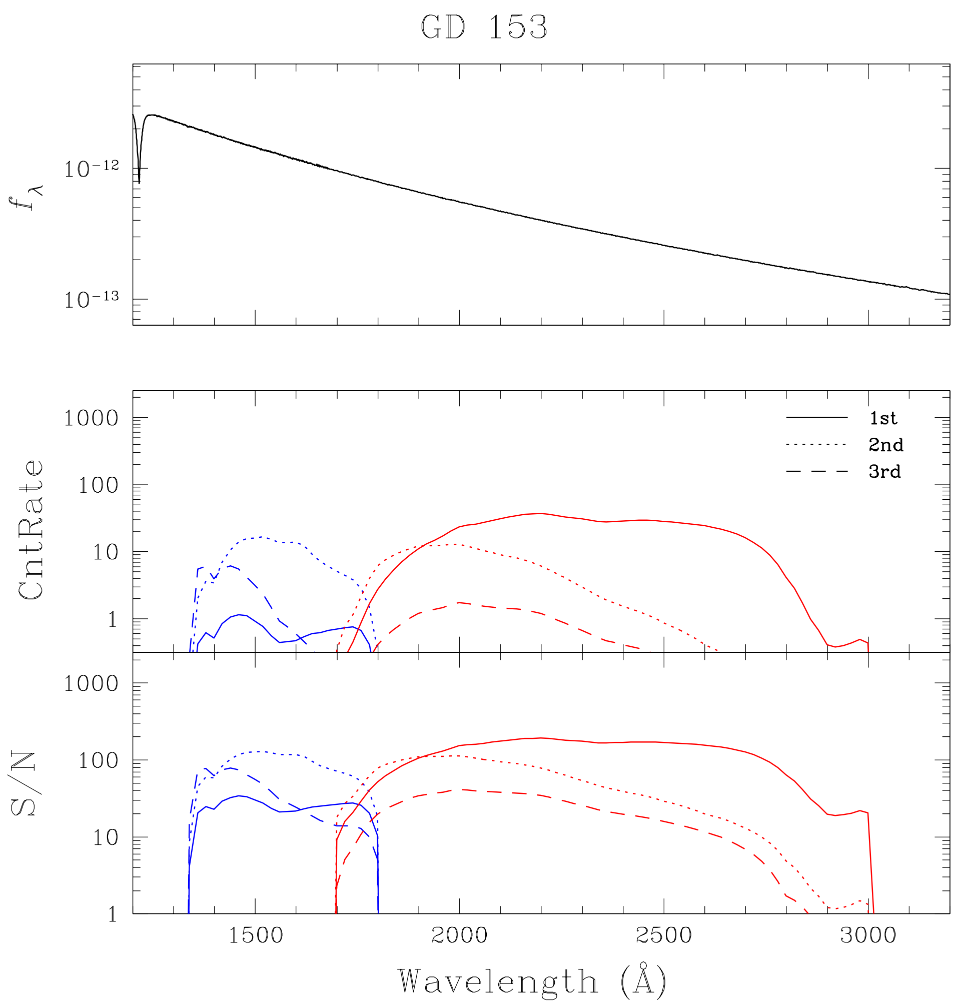

Feige 66
f_λ
10^{-10}
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

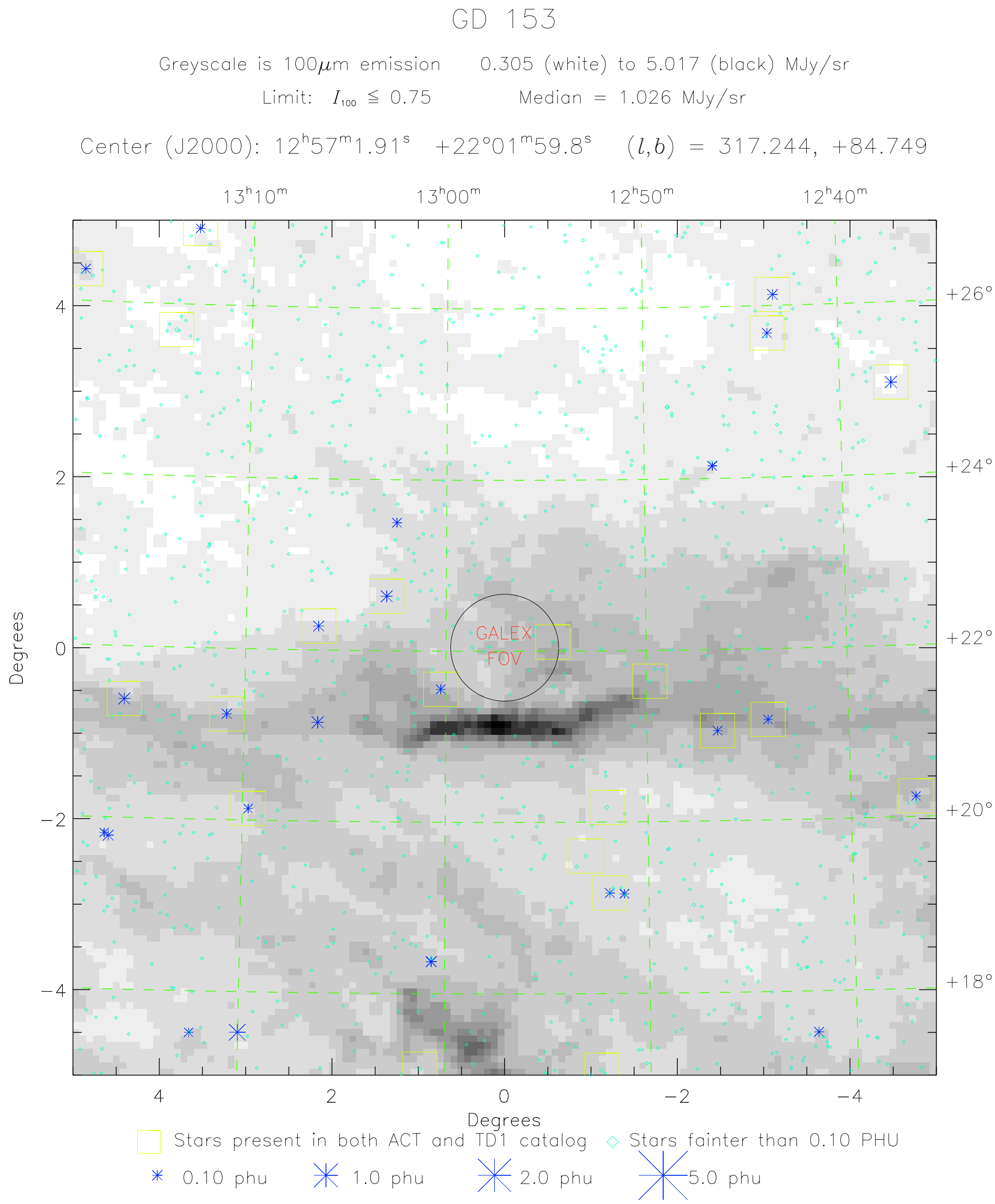

Feige 66
Greyscale is 100μm emission 0.313 (white) to 5.017 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 0.982 MJy/sr
Center (J2000): 12h37m22.56s +25°03m59.7s (l,b) = 245.294, +86.230
13h00m
12h50m
12h40m
12h30m
12h20m
+28°
+26°
+24°
+22°
GALEX FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu



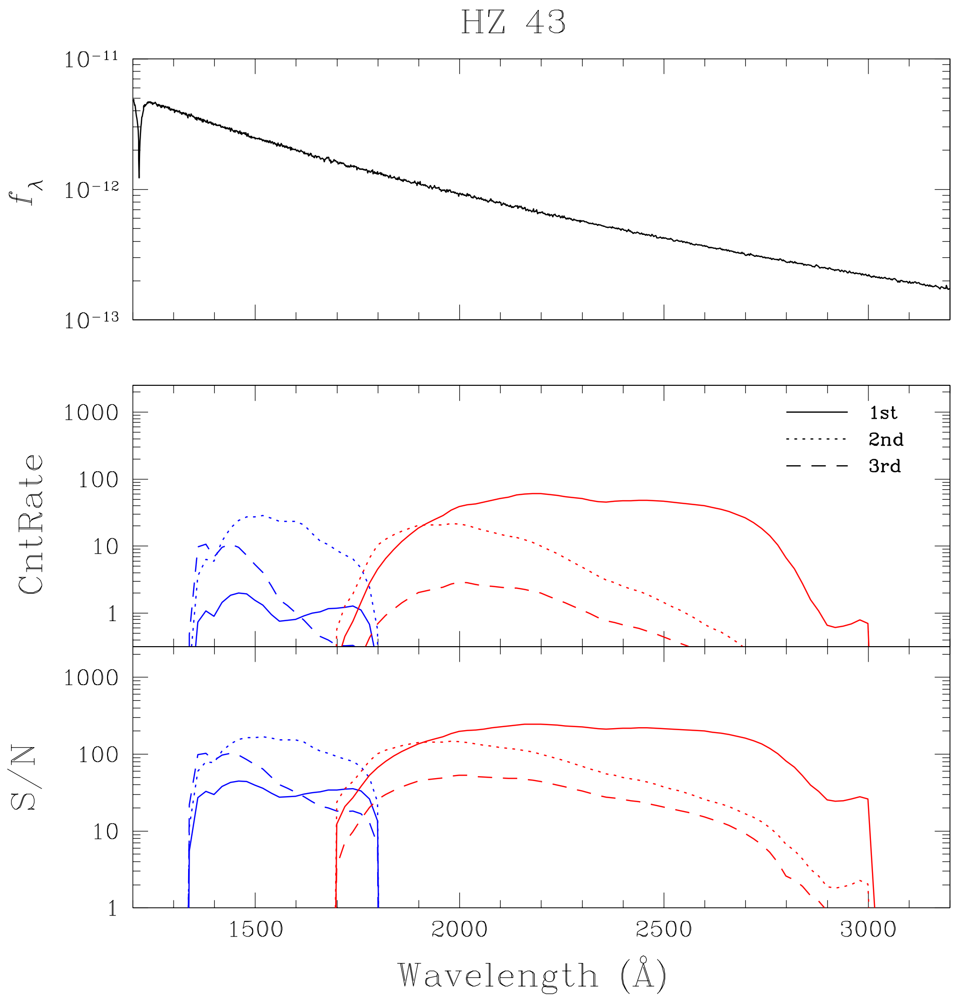
Feige 67
f_λ
10^-11
10^-12
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

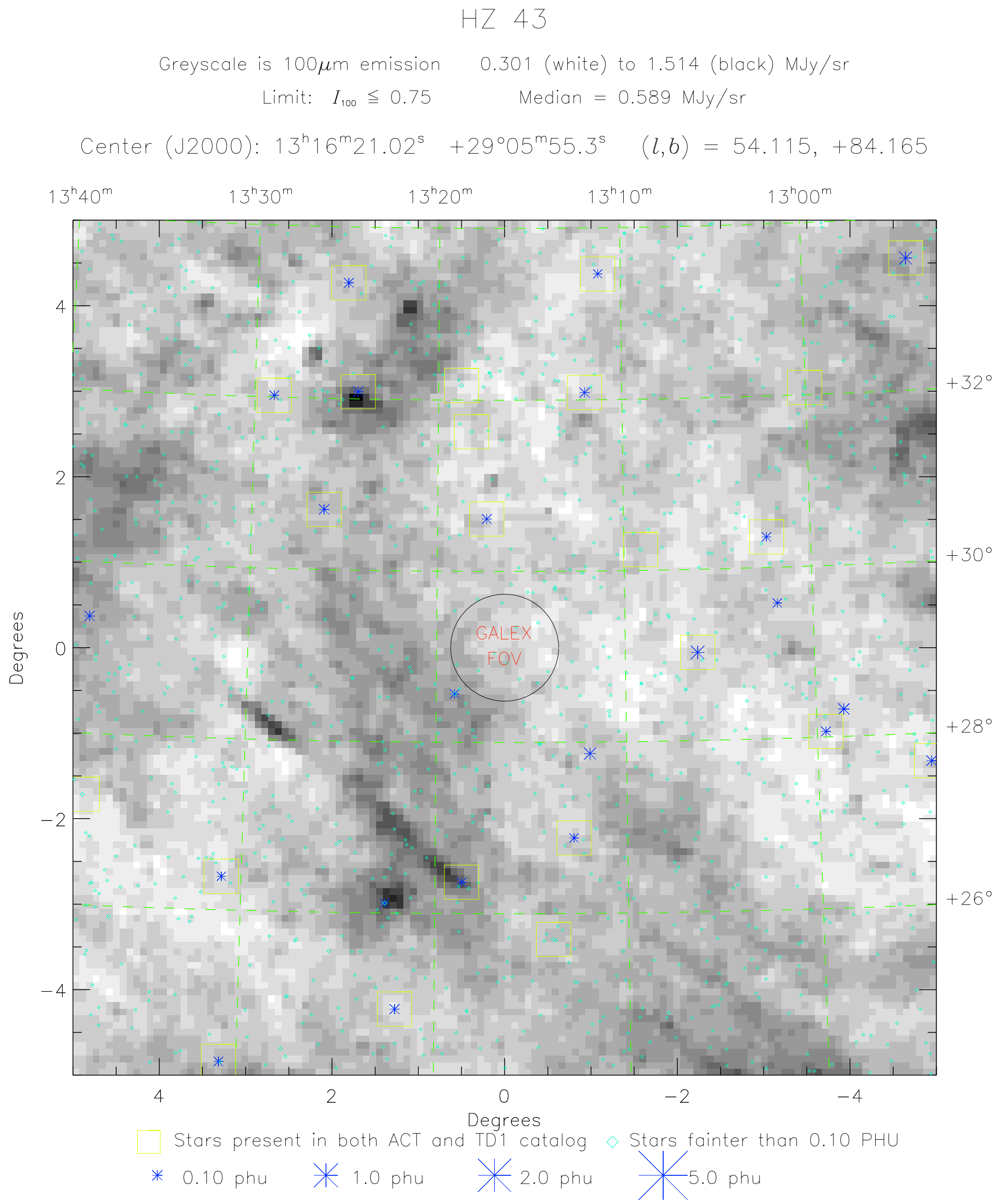

Feige 67
Greyscale is 100μm emission 0.691 (white) to 5.085 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.382 MJy/sr
Center (J2000): 12h41m49.72s +17°31m19.9s (l,b) = 289.432, +80.141
13h00m
12h50m
12h40m
12h30m
+22°
+20°
+18°
+16°
+14°
Degrees
Degrees
GALEX FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu


GD 153
f_λ
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

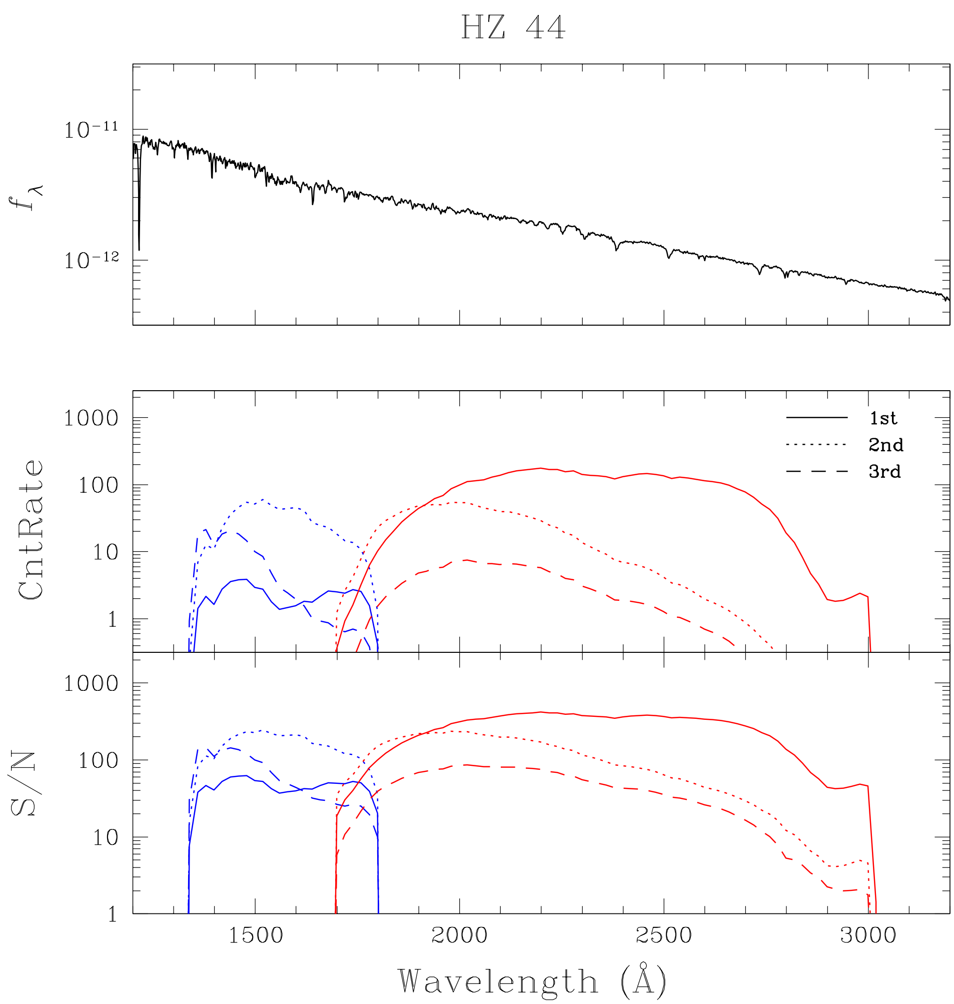


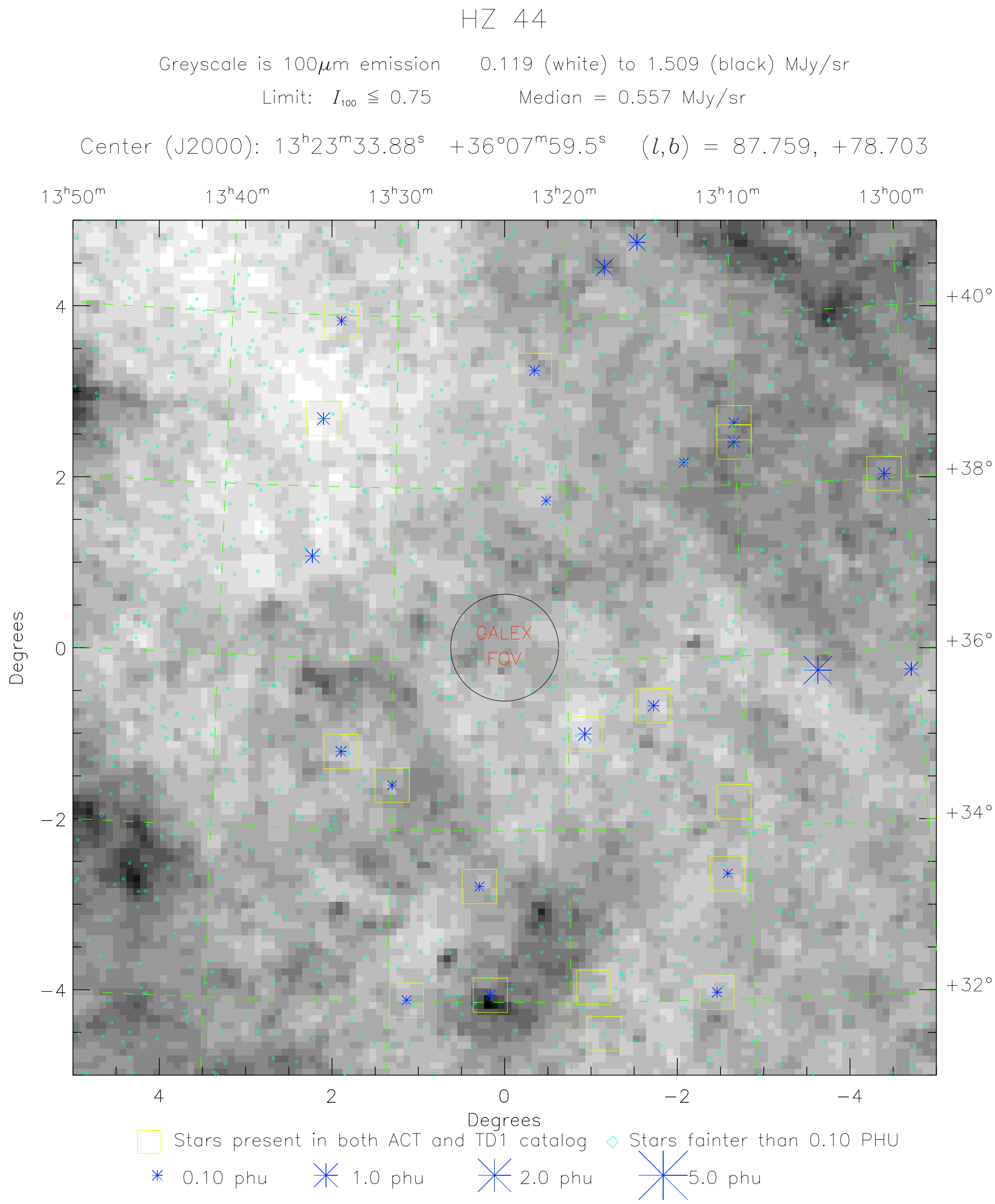
GD 153
Greyscale is 100μm emission 0.305 (white) to 5.017 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.026 MJy/sr
Center (J2000): 12h57m1.91s +22°01m59.8s (l,b) = 317.244, +84.749
13h10m
13h00m
12h50m
12h40m
+26°
+24°
+22°
+20°
+18°
4
2
0
−2
−4
Degrees
GALEX
FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

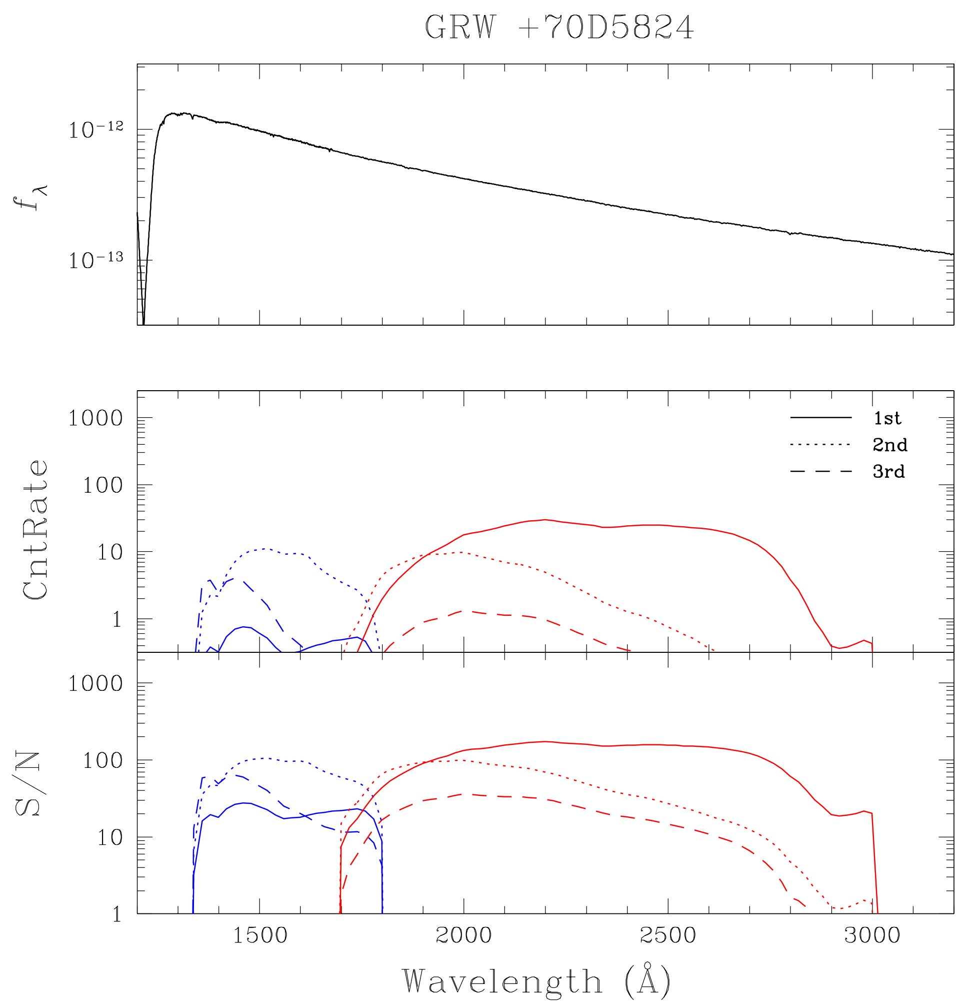

HZ 43
f_λ
10^{-11}
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

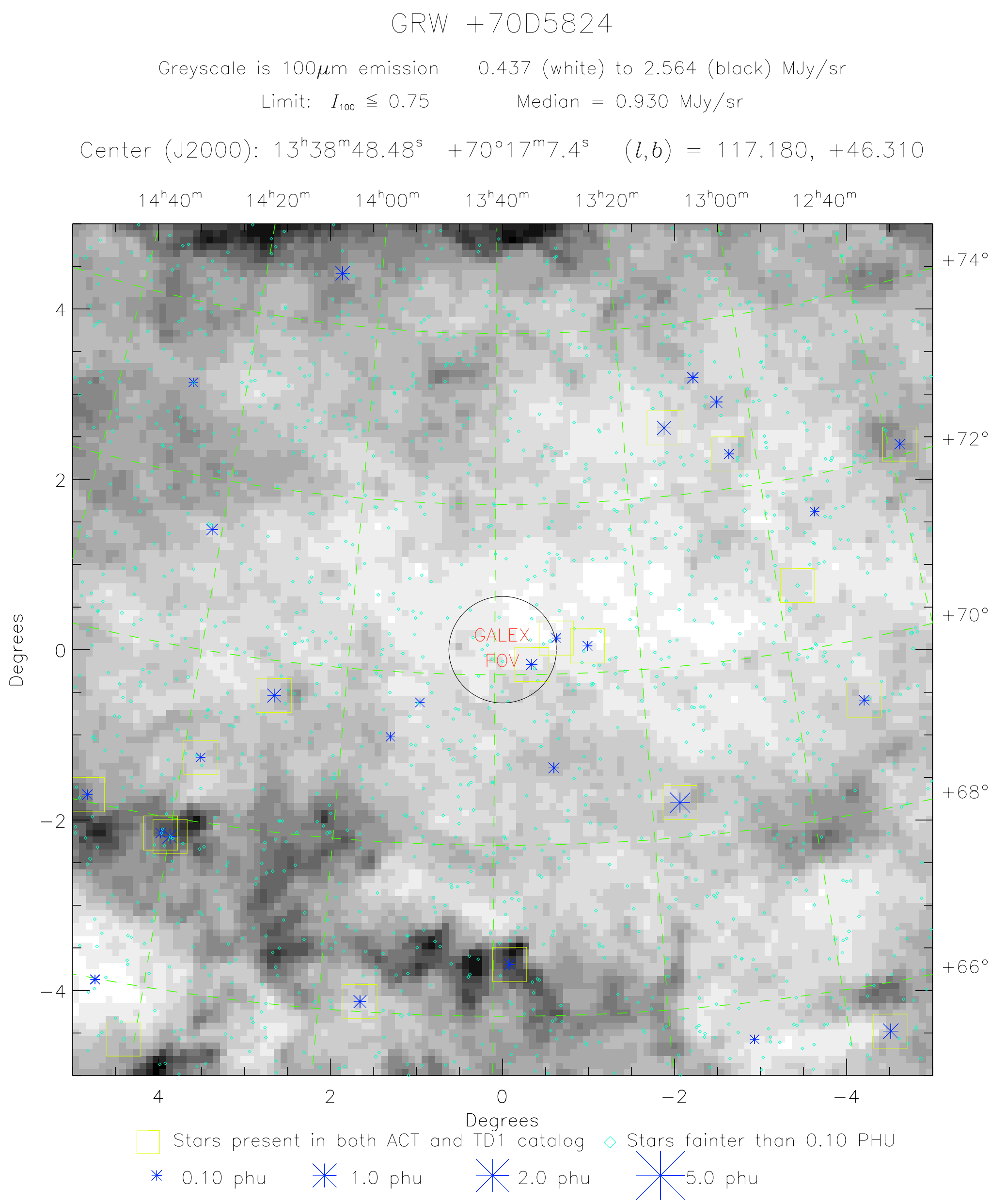


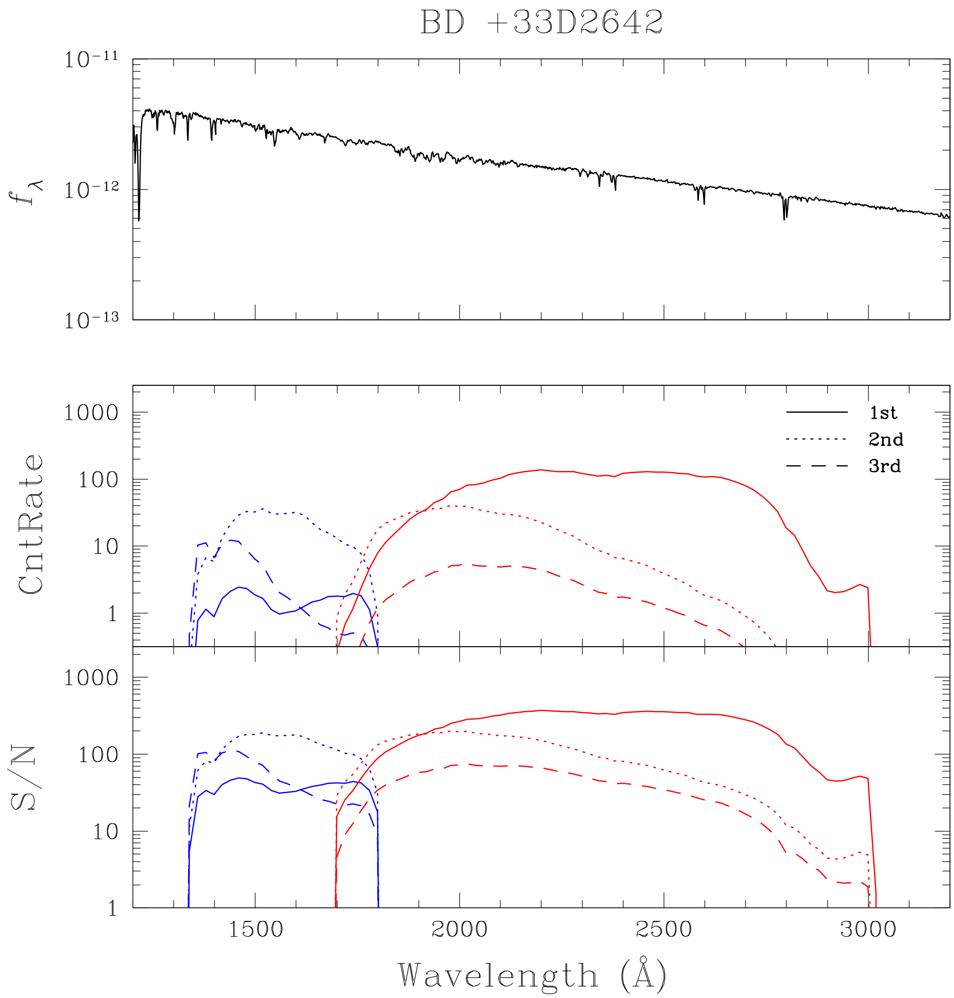
HZ 43
Greyscale is 100μm emission 0.301 (white) to 1.514 (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 0.589 MJy/sr
Center (J2000): 13h16m21.02s +29°05m55.3s (l,b) = 54.115, +84.165
13h40m
13h30m
13h20m
13h10m
13h00m
+32°
+30°
+28°
+26°
GALEX
FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

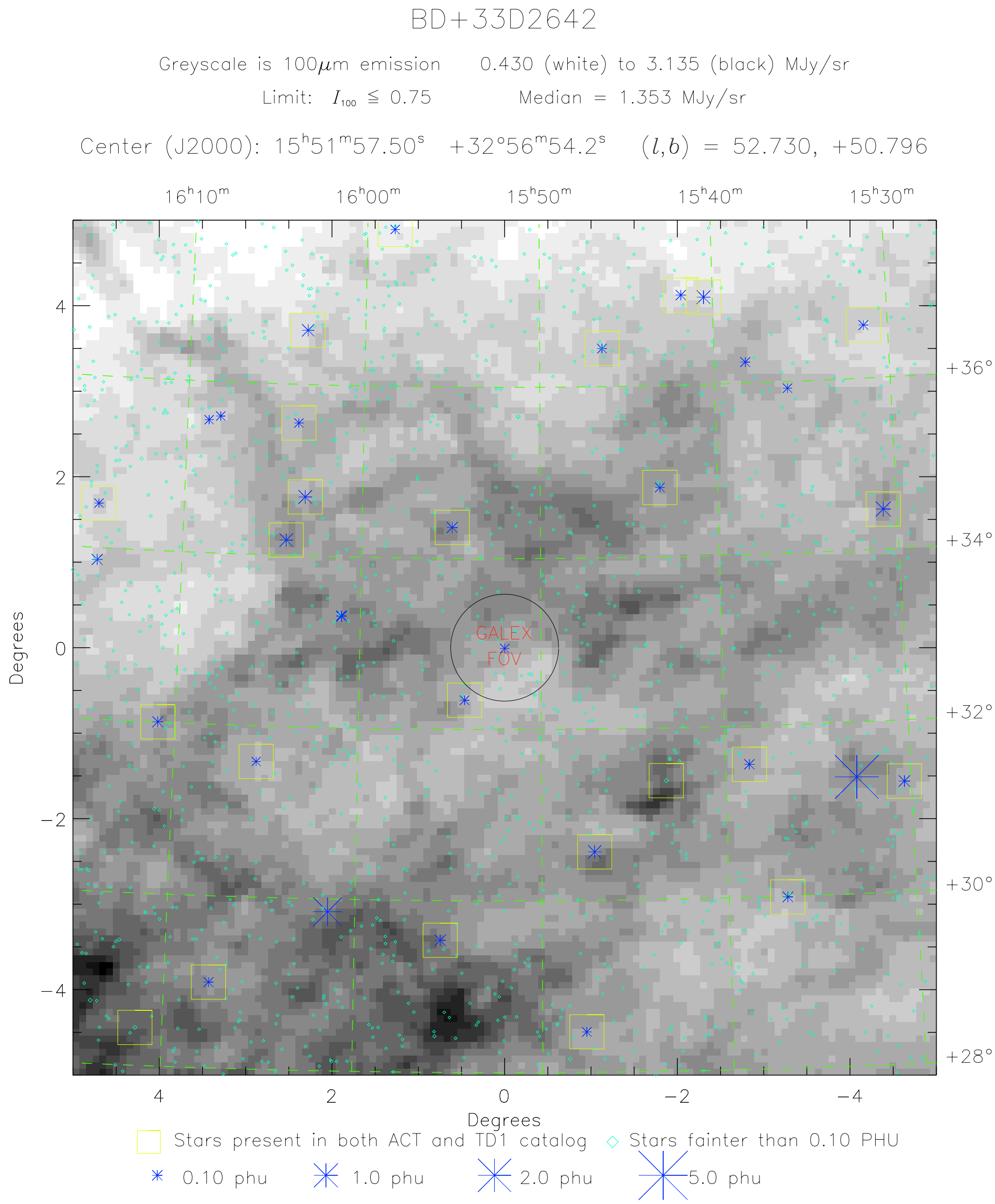

HZ 44
f_λ
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

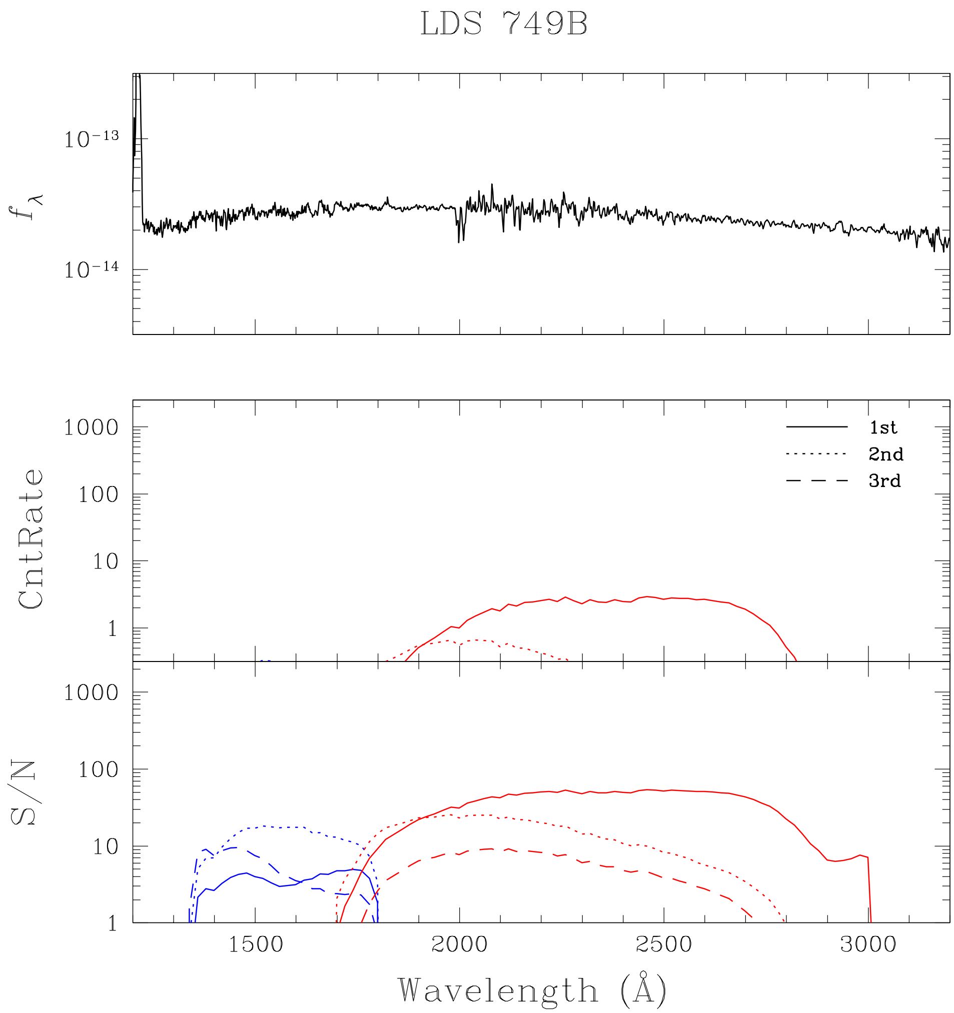

HZ 44
Greyscale is 100μm emission 0.119 (white) to 1.509 (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 0.557 MJy/sr
Center (J2000): 13h23m33.88s +36°07m59.5s (l,b) = 87.759, +78.703
13h50m
13h40m
13h30m
13h20m
13h10m
13h00m
+40°
+38°
+36°
+34°
+32°
4
2
0
−2
−4
Degrees
GALEX
FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

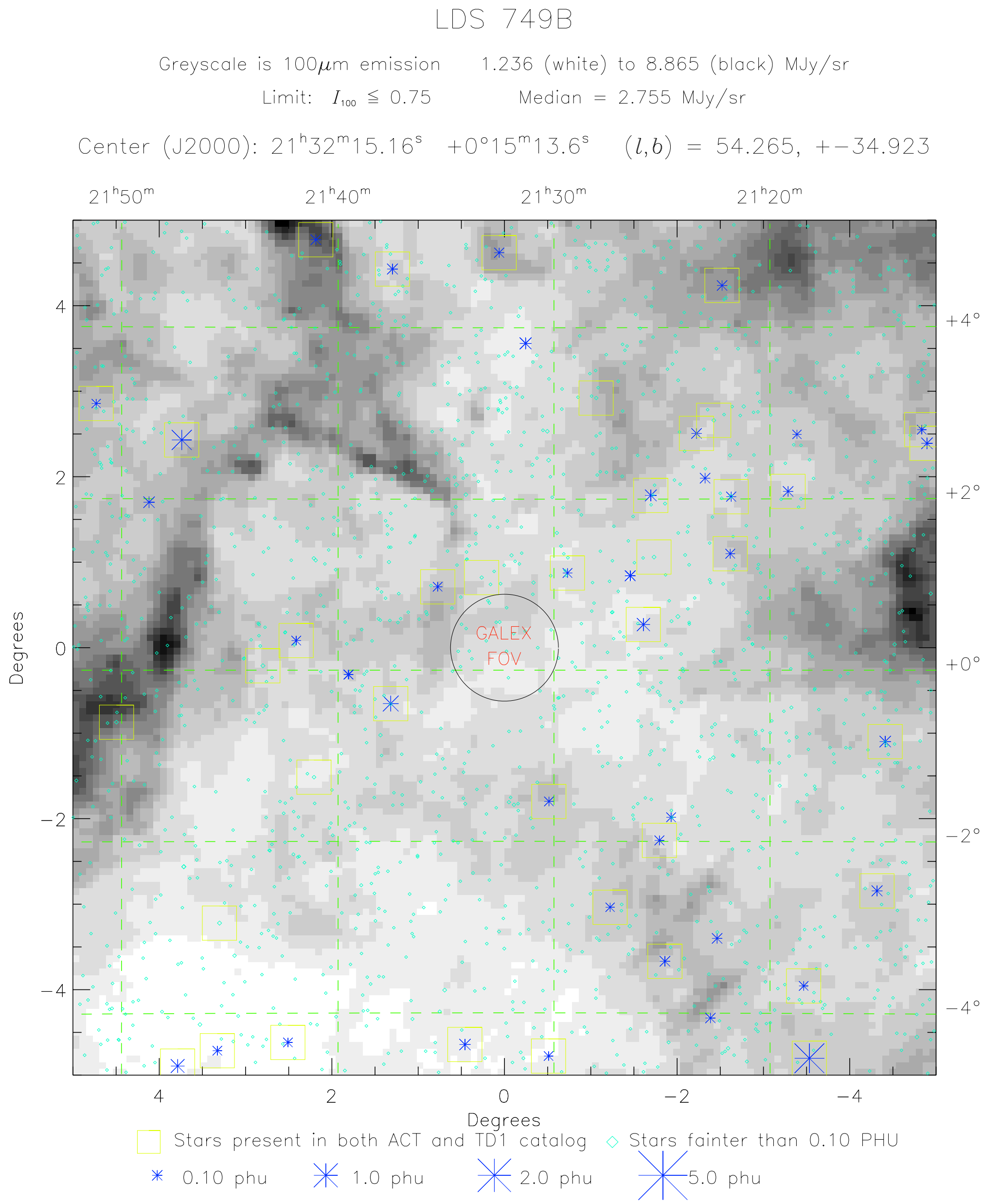

GRW +70D5824
f_λ
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

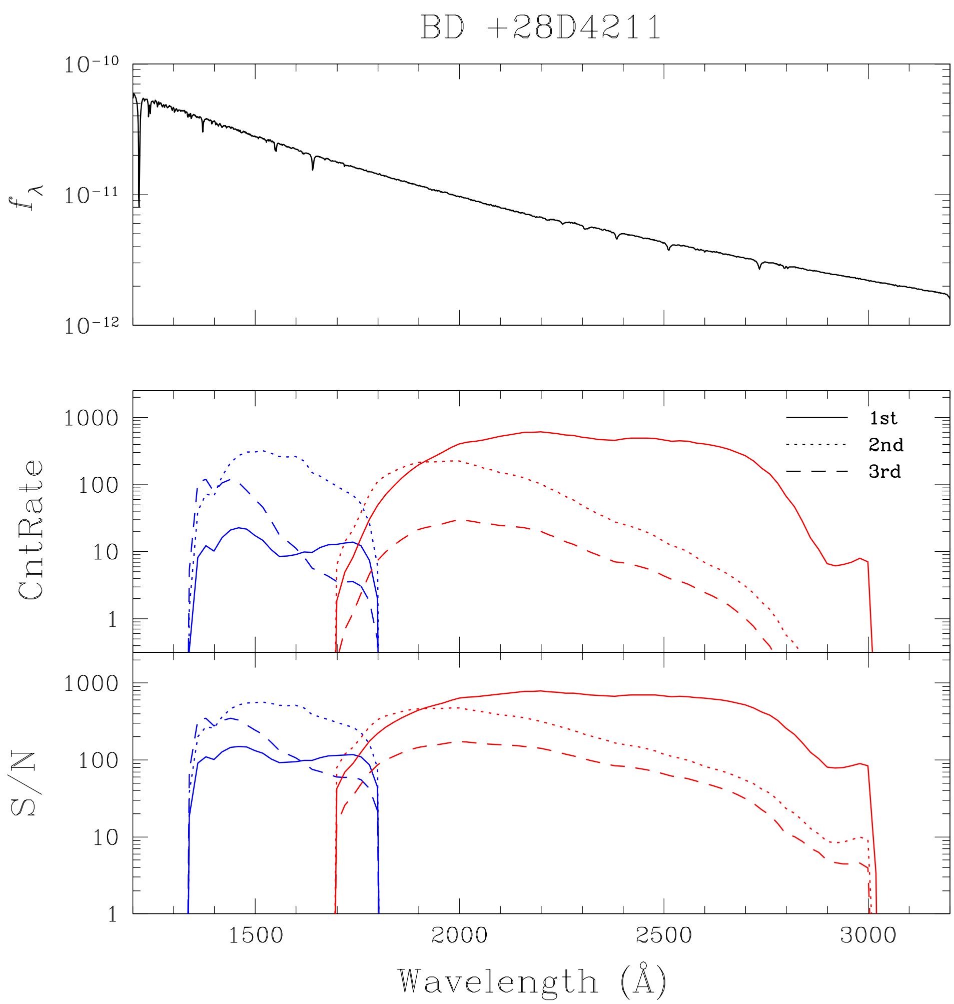

GRW +70D5824
Greyscale is 100μm emission 0.437 (white) to 2.564 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 0.930 MJy/sr
Center (J2000): 13h38m48.48s +70°17m7.4s (l,b) = 117.180, +46.310
14h40m 14h20m 14h00m 13h40m 13h20m 13h00m 12h40m
+74° +72° +70° +68° +66°
4 2 0 −2 −4
Degrees
GALEX
FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

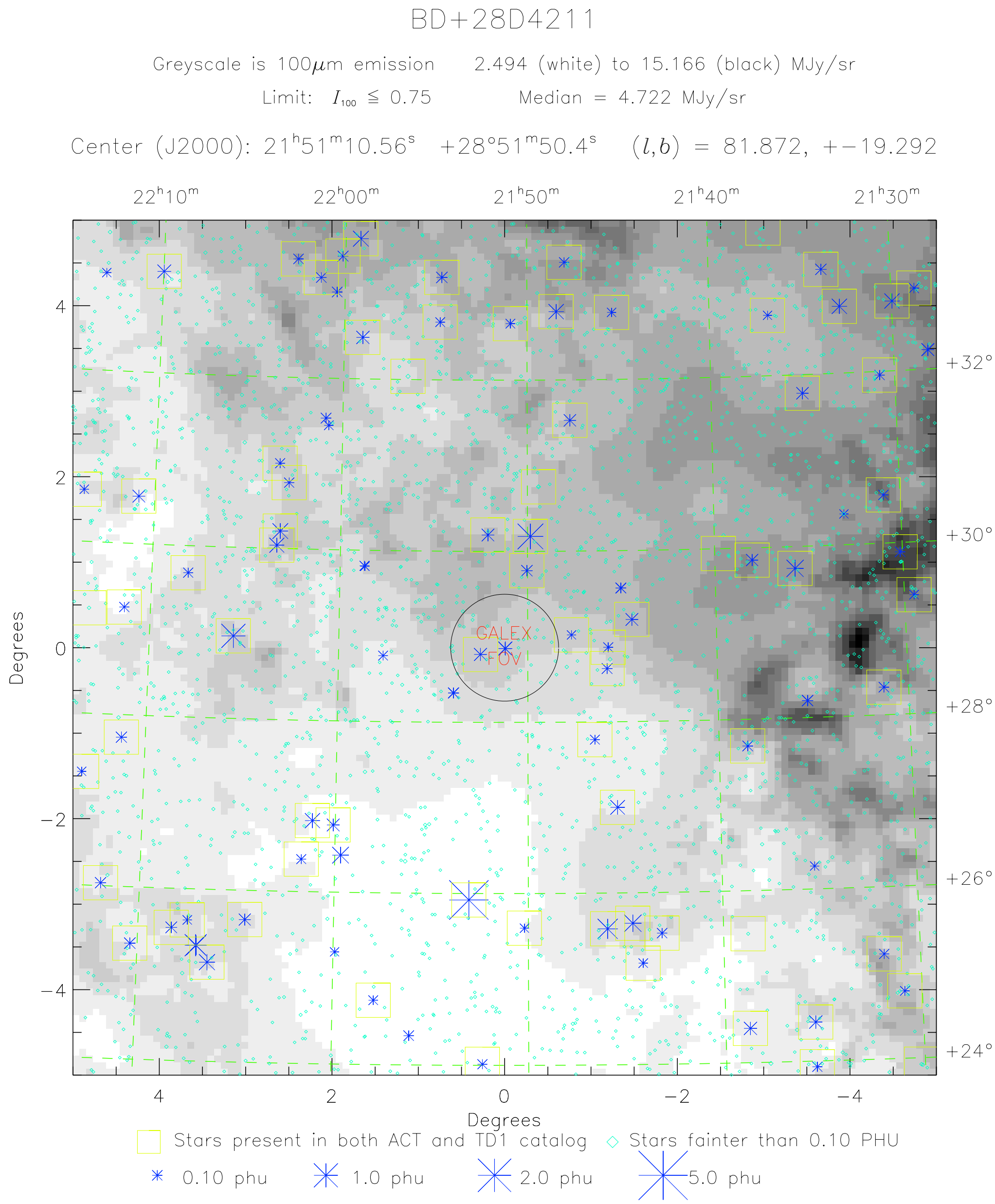

BD +33D2642
f_λ
10^{-11}
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)


BD+33D2642
Greyscale is 100μm emission 0.430 (white) to 3.135 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.353 MJy/sr
Center (J2000): 15h51m57.50s +32°56m54.2s (l,b) = 52.730, +50.796
16h10m
16h00m
15h50m
15h40m
15h30m
+36°
+34°
+32°
+30°
+28°
Degrees
GALEX FOV
4
2
0
−2
−4
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

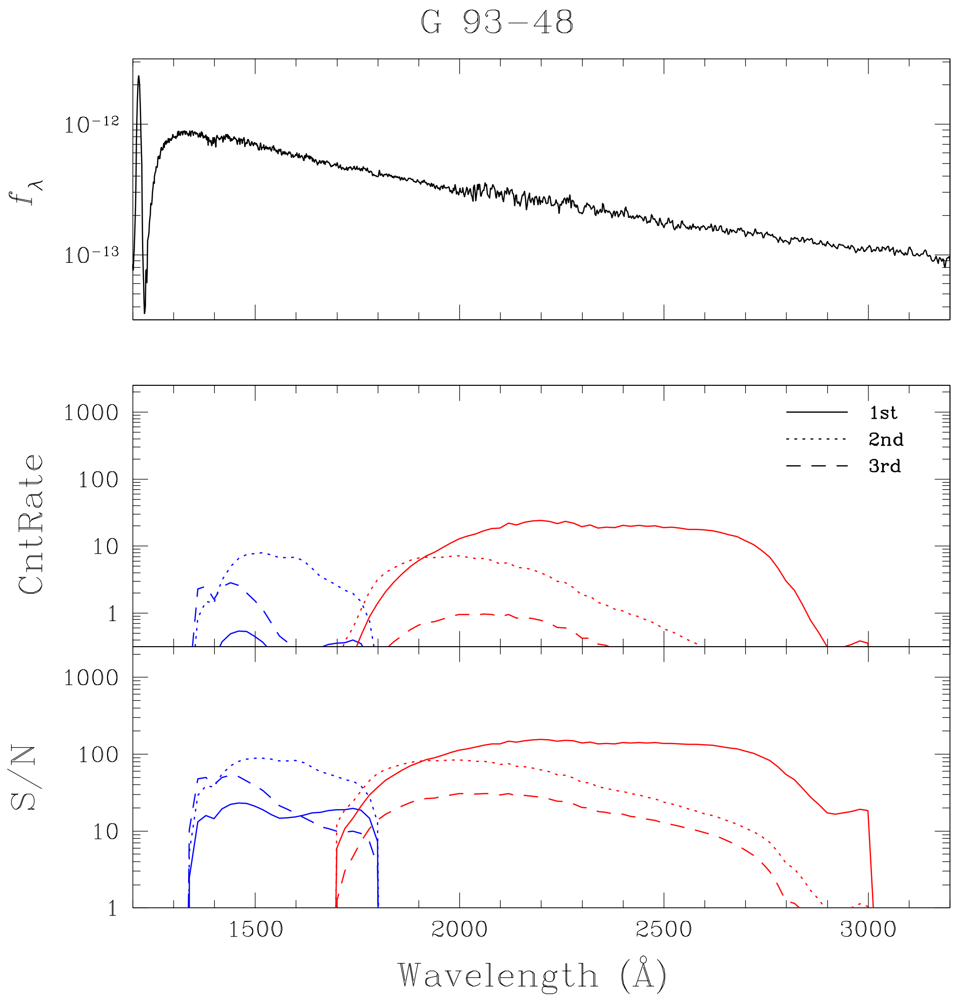

LDS 749B
f_λ
10^{-13}
10^{-14}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

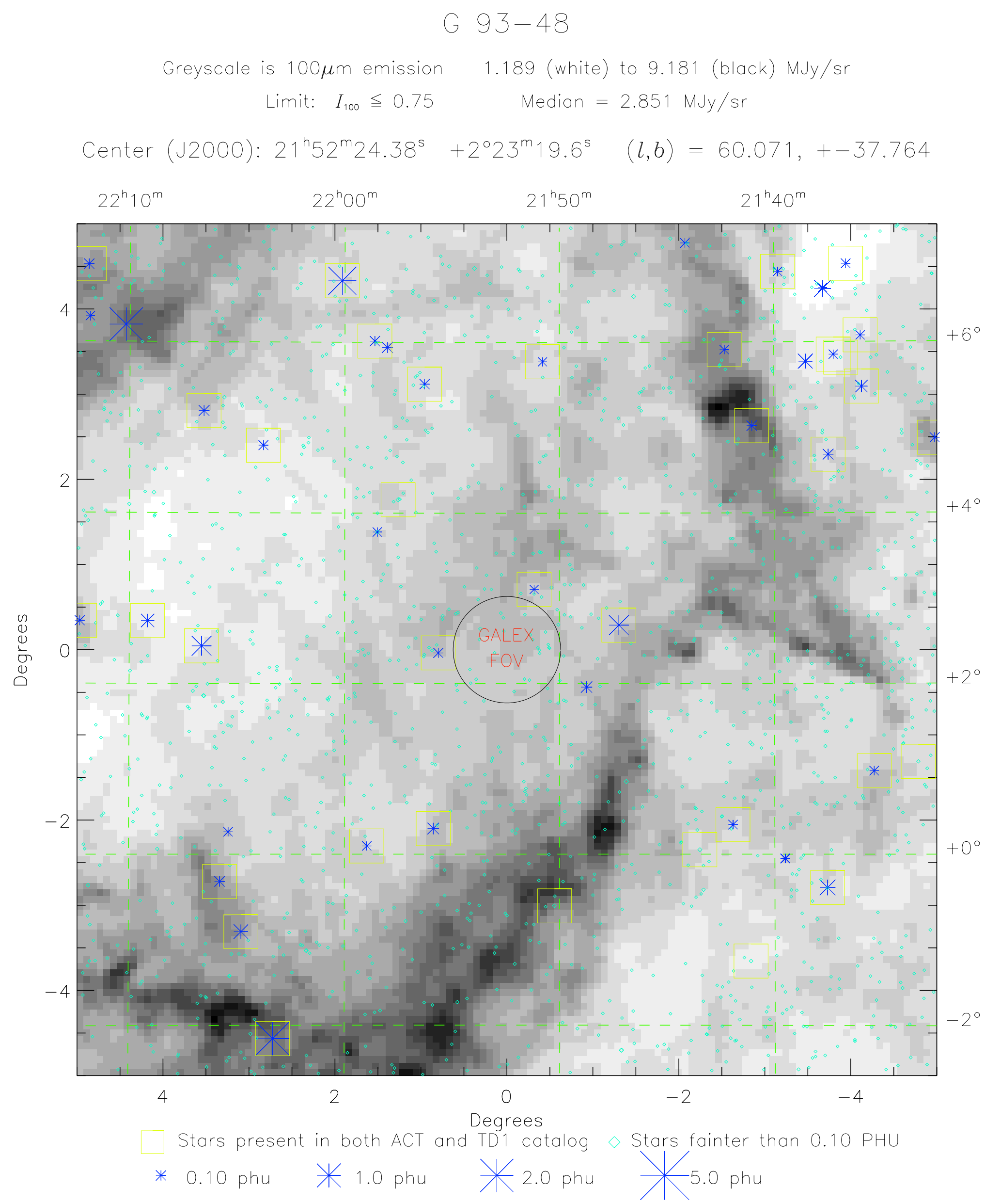

LDS 749B
Greyscale is 100μm emission 1.236 (white) to 8.865 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 2.755 MJy/sr
Center (J2000): 21h32m15.16s +0°15m13.6s (l,b) = 54.265, +-34.923
21h50m
21h40m
21h30m
21h20m
GALEX
FOV
Degrees
Degrees
4
2
0
−2
−4
+4°
+2°
+0°
−2°
−4°
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu


BD +28D4211
f_λ
10^{-10}
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

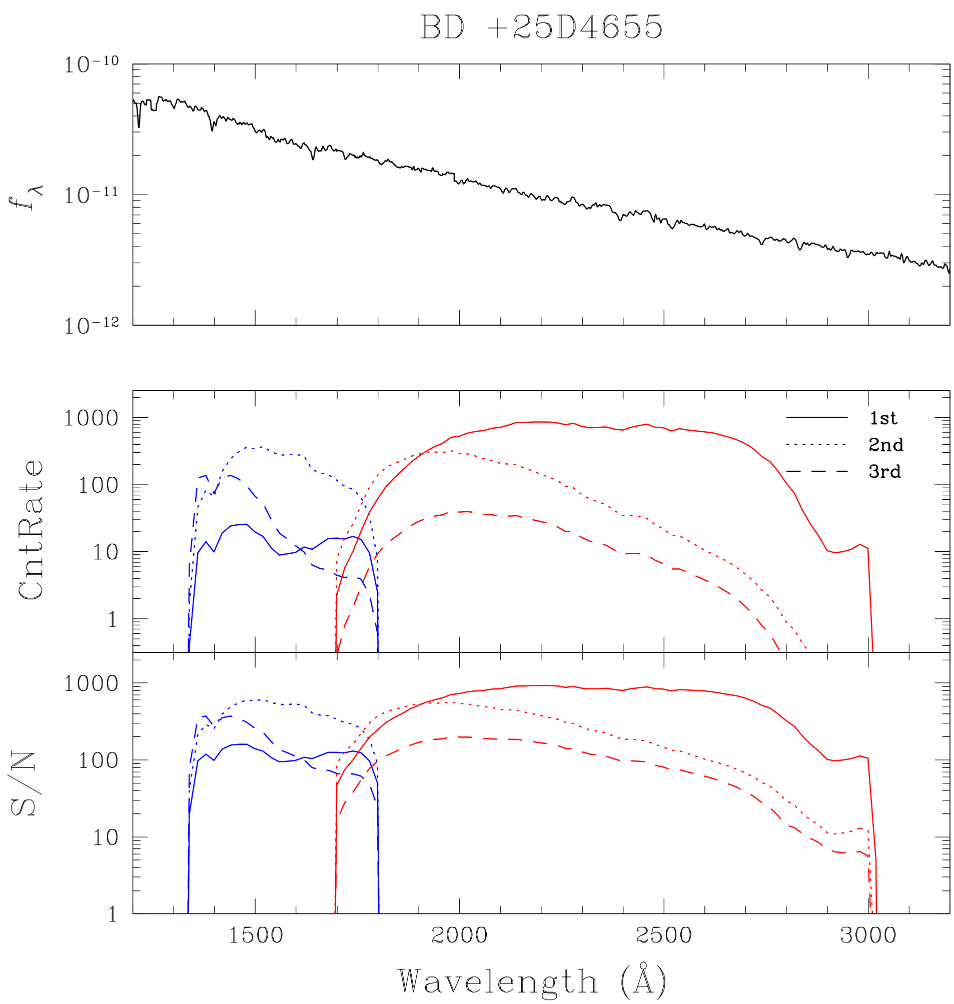


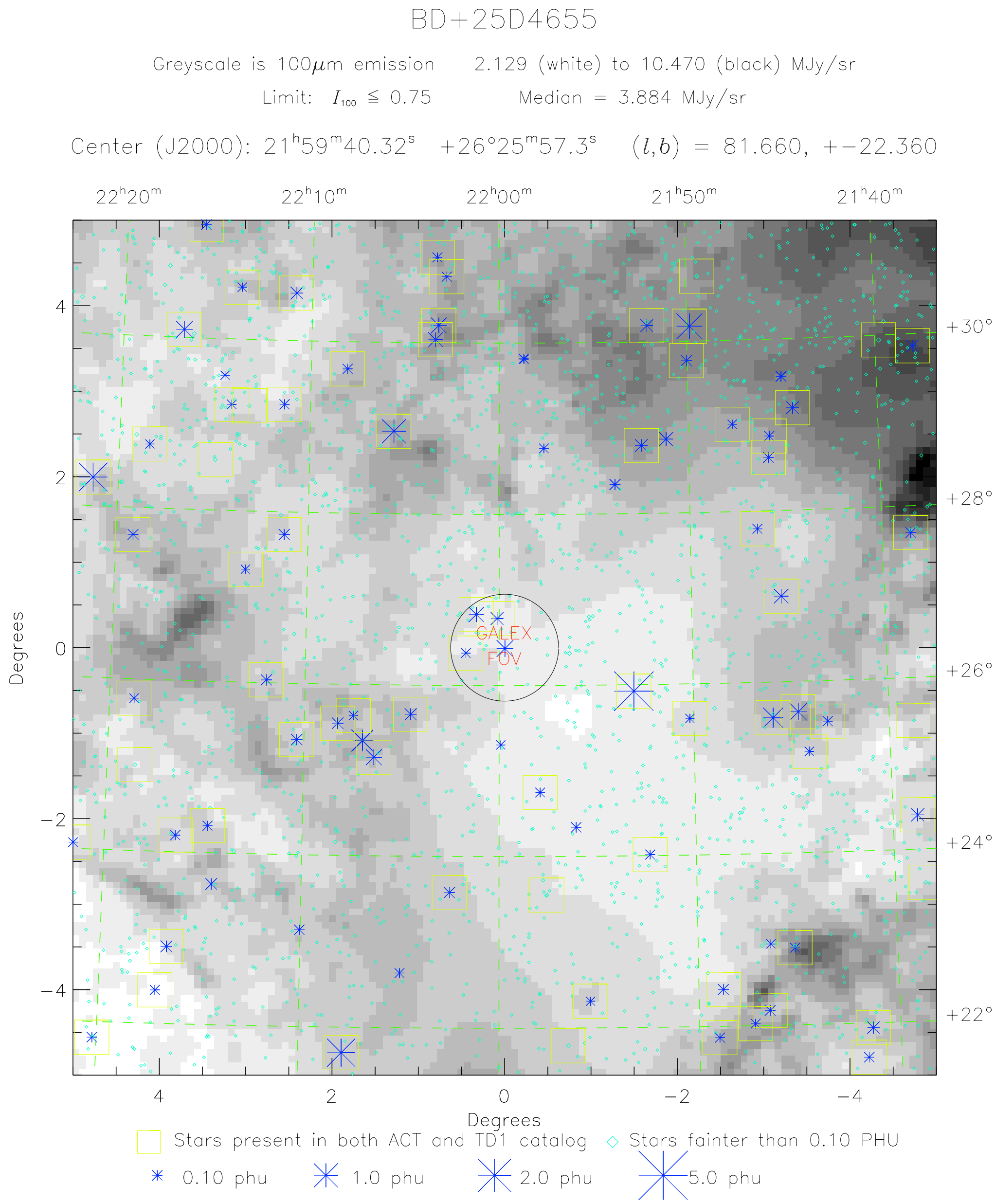
BD+28D4211
Greyscale is 100μm emission 2.494 (white) to 15.166 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 4.722 MJy/sr
Center (J2000): 21h51m10.56s +28°51m50.4s (l,b) = 81.872, +-19.292
22h10m
22h00m
21h50m
21h40m
21h30m
+32°
+30°
+28°
+26°
+24°
4
2
0
−2
−4
Degrees
GALEX
FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

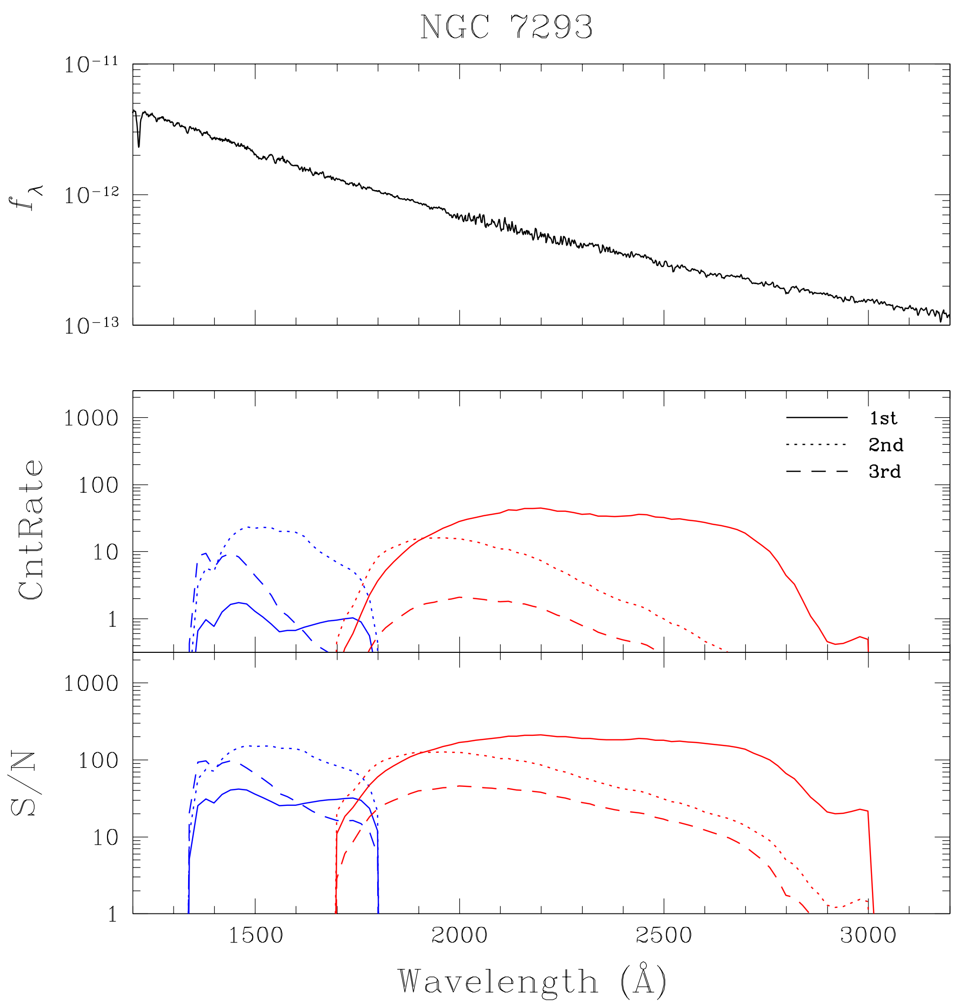

G 93−48
f_λ
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

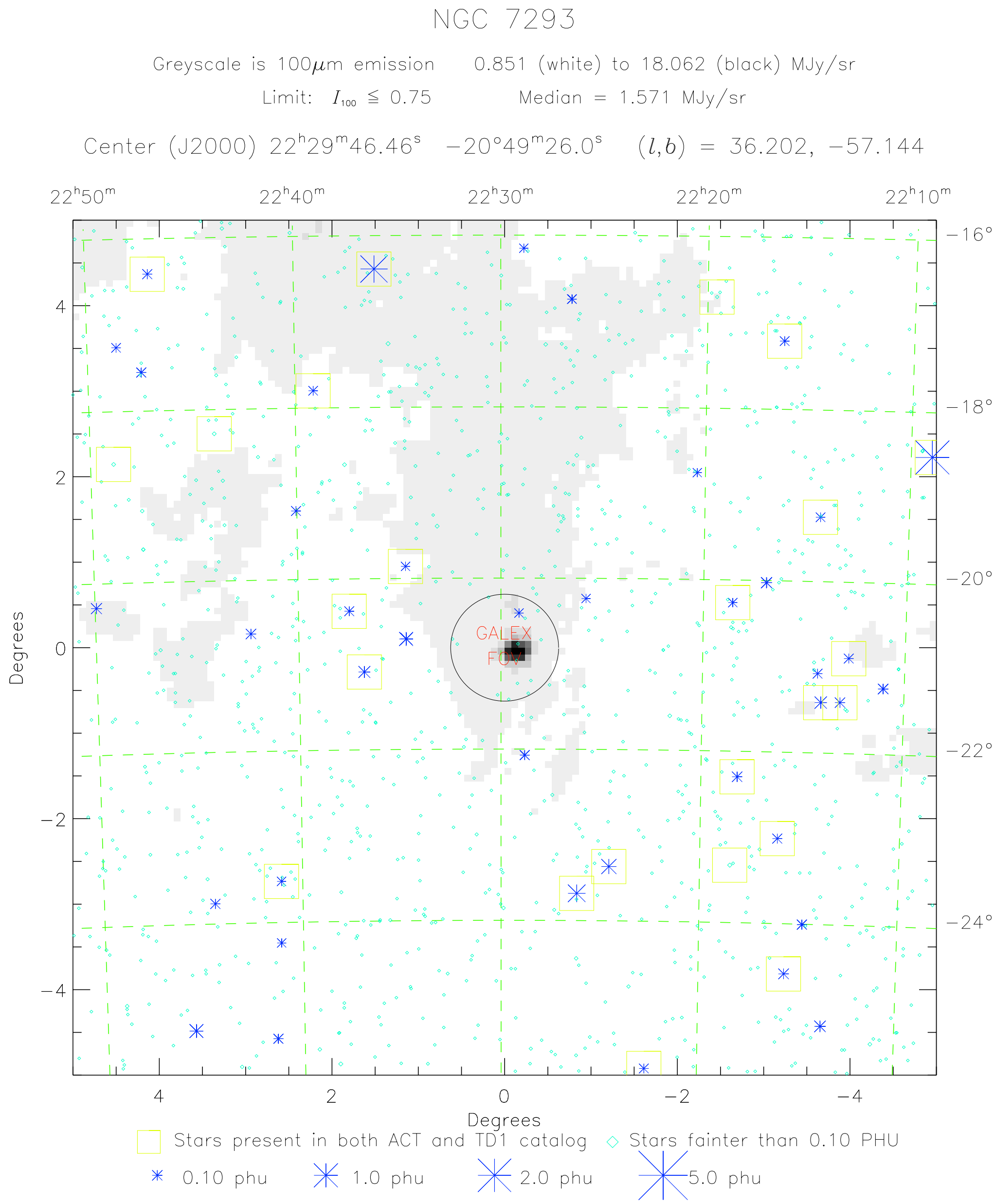


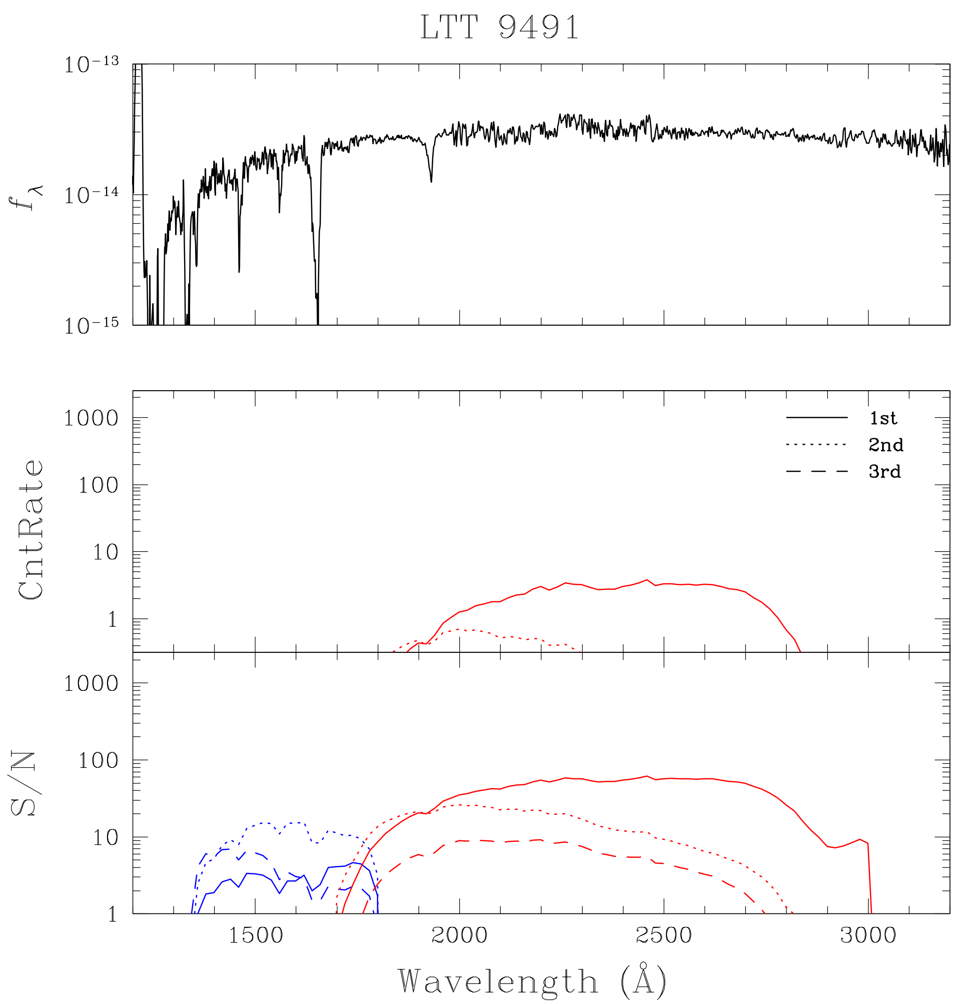
G 93−48
Greyscale is 100μm emission 1.189 (white) to 9.181 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 2.851 MJy/sr
Center (J2000): 21h52m24.38s +2°23m19.6s (l,b) = 60.071, +−37.764
22h10m
22h00m
21h50m
21h40m
GALEX FOV
Degrees
Degrees
+6°
+4°
+2°
+0°
−2°
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

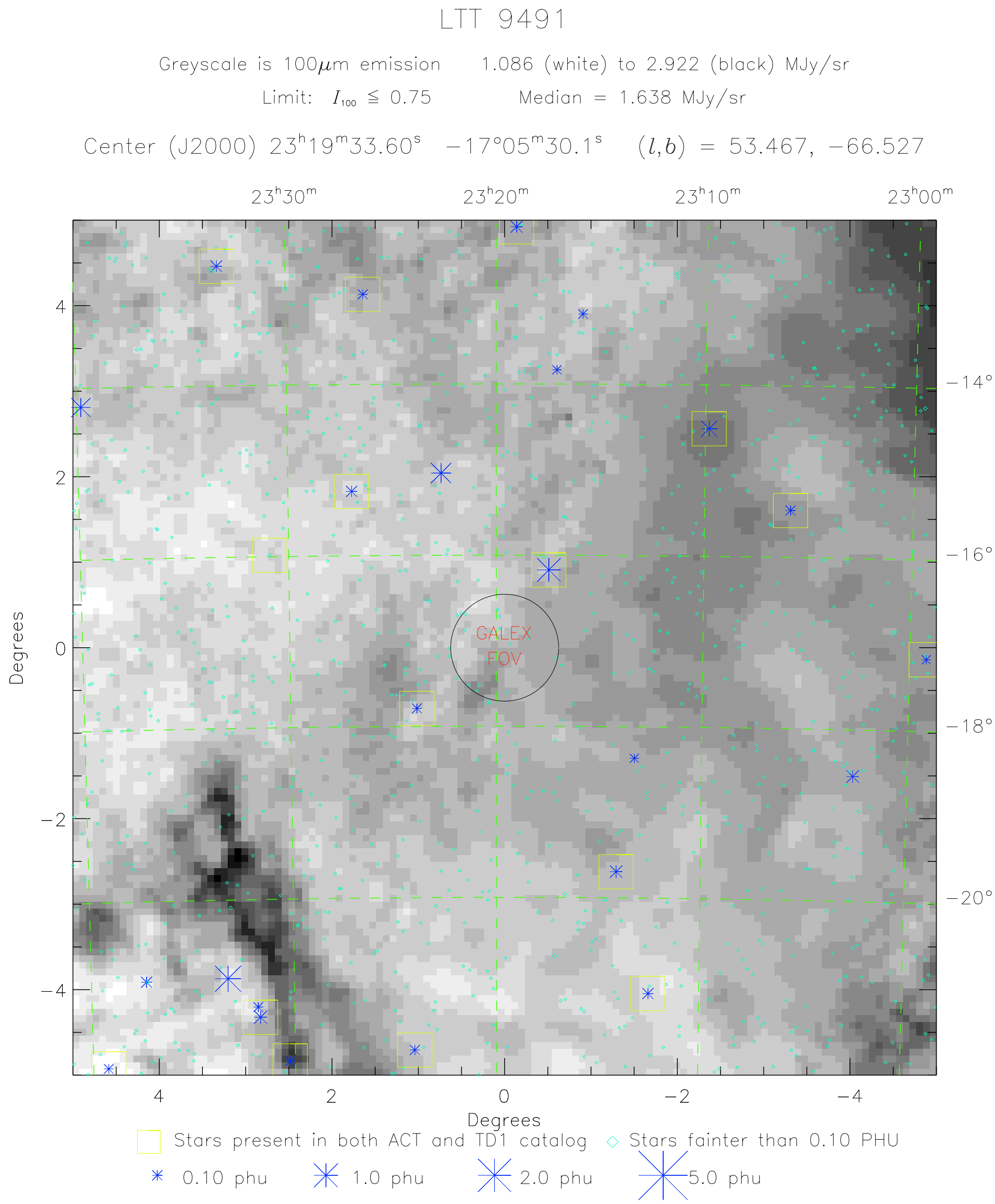

BD +25D4655
f_λ
10^{-10}
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)

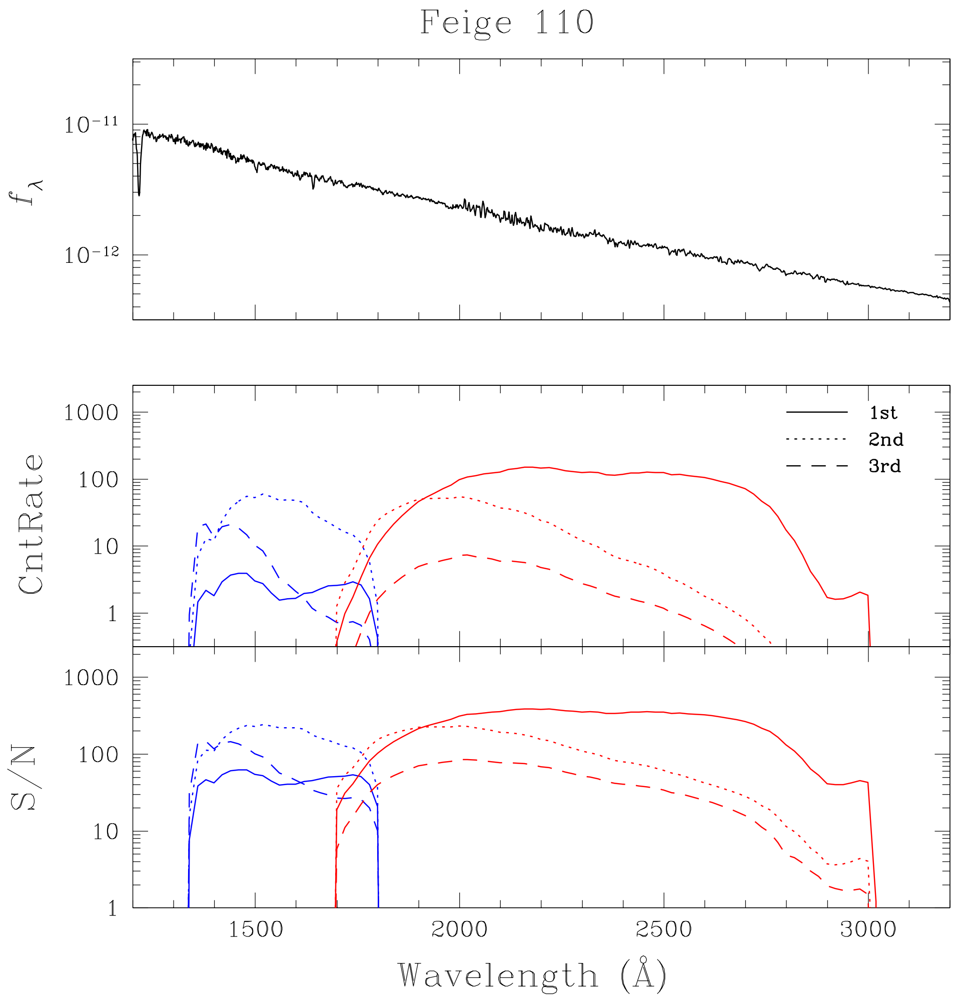

BD+25D4655
Greyscale is 100μm emission 2.129 (white) to 10.470 (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 3.884 MJy/sr
Center (J2000): 21h59m40.32s +26°25m57.3s (l,b) = 81.660, +−22.360
22h20m
22h10m
22h00m
21h50m
21h40m
+30°
+28°
+26°
+24°
+22°
GALEX
FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu

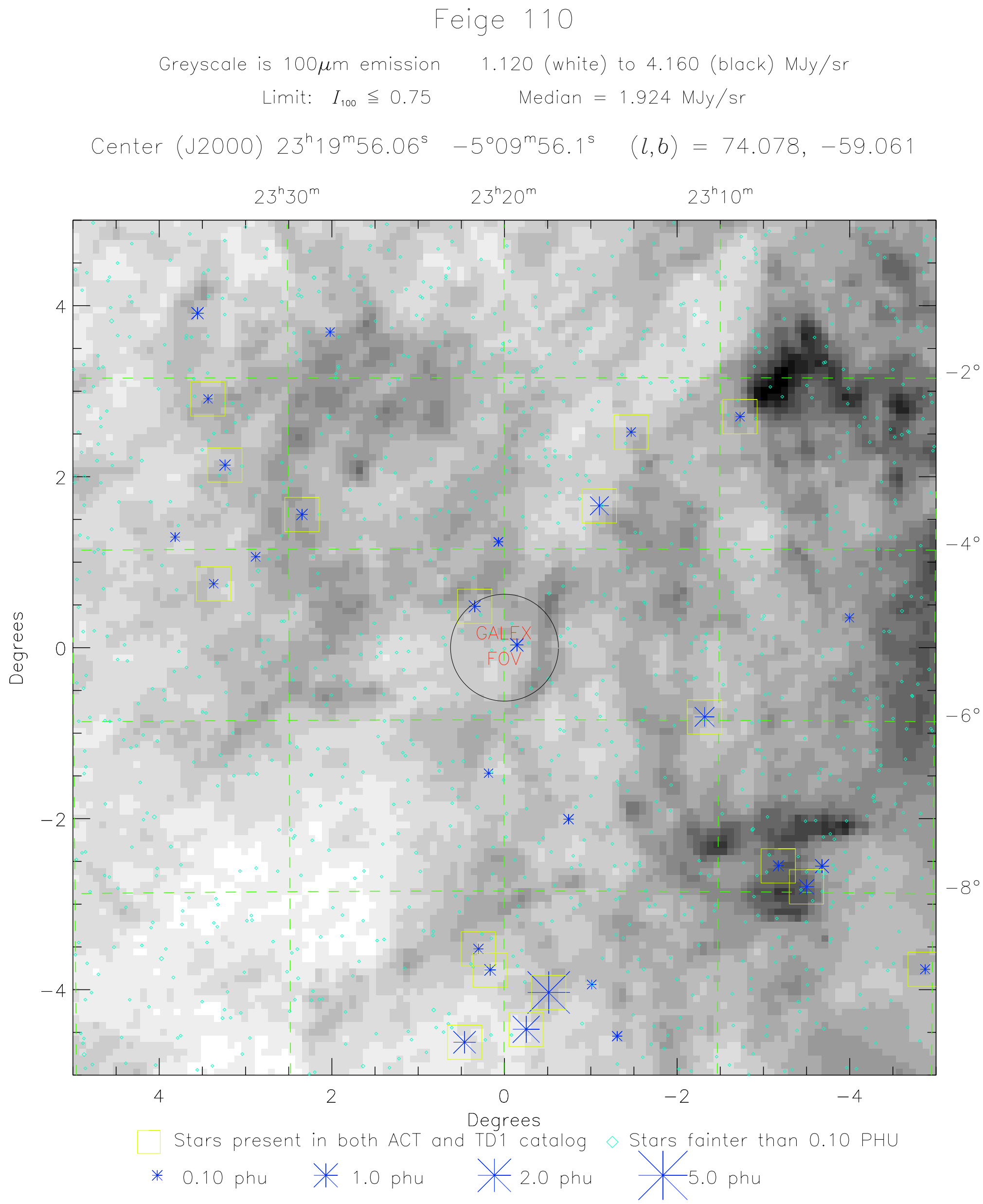

NGC 7293
f_λ
10^{-11}
10^{-12}
10^{-13}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)


NGC 7293
Greyscale is 100μm emission 0.851 (white) to 18.062 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.571 MJy/sr
Center (J2000) 22h29m46.46s −20°49m26.0s (l,b) = 36.202, −57.144
22h50m
22h40m
22h30m
22h20m
22h10m
−16°
−18°
−20°
−22°
−24°
Degrees
Degrees
GALEX
FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu


LTT 9491
f_λ
10^{-13}
10^{-14}
10^{-15}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)


LTT 9491
Greyscale is 100μm emission 1.086 (white) to 2.922 (black) MJy/sr
Limit: I_{100} ≦ 0.75 Median = 1.638 MJy/sr
Center (J2000) 23h19m33.60s −17°05m30.1s (l,b) = 53.467, −66.527
23h30m
23h20m
23h10m
23h00m
−14°
−16°
−18°
−20°
Degrees
Degrees
GALEX FOV
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu


Feige 110
f_λ
10^{-11}
10^{-12}
CntRate
1000
100
10
1
1st
2nd
3rd
S/N
1000
100
10
1
1500
2000
2500
3000
Wavelength (Å)


Feige 110
Greyscale is 100μm emission 1.120 (white) to 4.160 (black) MJy/sr
Limit: I100 ≦ 0.75 Median = 1.924 MJy/sr
Center (J2000) 23h19m56.06s −5°09m56.1s (l,b) = 74.078, −59.061
23h30m
23h20m
23h10m
GALEX FOV
Degrees
Degrees
Stars present in both ACT and TD1 catalog
Stars fainter than 0.10 PHU
0.10 phu
1.0 phu
2.0 phu
5.0 phu