LVL: The Local Volume Legacy survey
Data Products Delivery – DR3
User's Guide
February 28th, 2009

1. Introduction

This document describes the third delivery (DR3) of the high level data products of the Cy4 Spitzer legacy project LVL (Local Volume Legacy; P.I.; R.C. Kennicutt; Deputy-P.I.: J.C. Lee) to the Spitzer Science Center/IRSA. DR3 is part of a plan to deliver all LVL data products over a total period of ~1.5-2 years (dependent on observing schedules) with a typical 5 months cadence.

LVL consists of a sample of 258 galaxies, which are being mapped with both IRAC (4 bands) and MIPS (3 bands). In addition, ancillary data products consisting of images in the narrow-band Hα line emission and broad-band R (from the ground) and the UV continuum (2 bands) from GALEX are also available for most of the sample, and are being delivered as part of the LVL project.

By the end of the project (expected around the end of 2009), the LVL project will have delivered to the community: IRAC and MIPS mosaics for 256 galaxies (see below), GALEX images for 251 galaxies, and optical (Hα and R) images for 170 galaxies. The final data products will also include recalibrated (through the S18 pipeline) mosaics for any archival IRAC data in the LVL sample, and MIPS mosaics corrected for the effects of non-linearity and negative streaking.

The LVL public website is currently hosted at:
http://www.ast.cam.ac.uk/research/lvls/

2. Content of the Third Data Delivery

2.1 Sample and Summary of Data Products

The LVL sample contains 258 galaxies, representing an approximately volume-complete survey of galaxies within the 11 Mpc Local Volume. Of these, a fraction is already available in the Spitzer Archive (57 for MIPS and 78 for IRAC); the archival images will be re-processed by our team to provide a common product together with the rest of the LVL sample. Of the galaxies with archival Spitzer images, 33 are from the SINGS (the Spitzer Infrared Nearby Galaxies Survey; one of the original Spitzer Legacy programs) project. Later this year, we will complete delivery of 256 of the galaxies in the LVL sample. The two remaining galaxies, the Magellanic Clouds (SMC and LMC), are already being observed and delivered as part of other Spitzer Legacy Programs, SAGE (P.I.: Meixner) and SAGE-SMC (P.I.: Gordon).

DR3 contains 31 galaxies, all of which are new LVL IRAC observations and mostly new MIPS observations (a few archival). For these galaxies, complete datasets in the IRAC and MIPS bands are being delivered. The list of galaxies in the current delivery is given in Table 1, at the end of the document. The DR3 galaxies add to the 136 DR2 galaxies (Table 2, also at the end of the document), for a total of 167 LVL galaxies delivered with complete IRAC and MIPS datasets. When including the 13 galaxies (in 12 pointings, see Table 3 at the end of the document) already delivered in DR1 with complete IRAC, MIPS, optical, and UV maps, this represents about 70% of the LVL sample.

Similarly to DR2, for the DR3 galaxies the following datasets are being delivered: IRAC mosaics (4 bands, centered at 3.6, 4.5, 5.8, and 8.0 μm) and MIPS mosaics (3 bands, centered at 24, 70, and 160 μm). For the 13 galaxies in DR1, in addition to the IRAC and MIPS mosaics, also GALEX images (2 bands: FUV, centered at ~ 0.1516 μm, and NUV, centered at ~0.2267 μm), and optical images (narrow—band centered at the wavelength of Hα+[NII] emission and scaled broad—band R) were delivered. Summaries of the data products are given below, and details on the data processing are provided in the following sections.

2.1.1 IRAC Mosaics

For each galaxy, 4 mosaics (together with their associated coverage map, see below), one for each of the four IRAC bands are delivered as single-extension FITS files. The size of the mosaics is between 2xD_{25} and 2.5xD_{25}, depending on the galaxy. The pixel scale of the mosaics is 0.75 arcsec, and the flux units are MJy sr^{-1}, the latter obtained directly from the BCD's images header. The mosaics have FITS-compliant WCS headers, are background-subtracted, and have standard orientation, with North up, East left.
The coverage maps each contain effective exposure times calculated on a pixel-by-pixel basis. These maps are in units of seconds and named using the standard IRAC convention with an additional identifier concatenated to the end (e.g.-ngc0672_irac1.cov.fits). The coverage maps are especially important in cases where archival data was used, and the image layout may differ from the standard LVL observing strategy.

2.1.2 MIPS Mosaics

For each galaxy, 6 mosaics, two for each of the MIPS bands (one mosaic is cropped to the region around the galaxy to a size of about 2xD_{25}, the other contains the full image) are delivered as single-extension FITS files. The pixel scale of the MIPS mosaics is wavelength-dependent: 1.5 arcsec at 24 μm, 4.5 arcsec at 70 μm, and 9.0 arcsec at 160 μm. The flux units are MJy sr^{-1}. The mosaics have a fixed background removed, and have orientation North up, East left. Similarly to IRAC, weight maps are delivered as well; however, unlike the IRAC coverage maps, the values of the pixels in the MIPS weight maps store the number of images stacked at that point in the map.

Sections 2.1.3 and 2.1.4 below are relevant for DR1 galaxies:

2.1.3 GALEX UV Images

GALEX ultraviolet imaging for the LVL galaxies has been/is being obtained through the 11 Mpc Hα UV Galaxy Survey (11HUGS) Cycle 1 (P.I.: R.C. Kennicutt) and Cycle 4 (P.I.: J.C. Lee) programs, through a Cycle 3 ACS Nearby Galaxies Treasury Survey program (P.I.: E. Skillman), as well as from the GALEX PI-programs Nearby Galaxies Survey (NGS), Medium-deep Imaging Survey (MIS), and All-sky Imaging Survey (AIS), plus a handful of Guest Investigators' (GI) archival data. The combined programs will provide UV data for 249 of the 258 galaxies in the LVL sample. The remaining 9 galaxies cannot be observed due to bright-object avoidance constraints.

For each galaxy, 4 intensity images, two for each GALEX band (FUV at ~1516 A and NUV at ~2267 A; one image per band containing the full GALEX field-of-view, 1.2 degrees, and the other cropped to a size of $4xD_{25}$), is being delivered, with 5 arcsec resolution. The pixel scale of the images is 1.5".

In addition to the intensity maps (calibrated in units of counts/sec/pix), the high-resolution response maps (needed to calculate photon noise) are being delivered. The two GALEX images are calibrated, registered to a common frame, and have standard WCS headers in FITS-compliant format. The images will have standard orientation, North up East left.

2.1.4 Optical Images/Mosaics

Optical imaging data in the standard R broad-band filter and in narrow-band filters at the wavelength of the Hα+[NII] emission have been obtained for most of the LVL galaxies (described in Lee 2006, PhD thesis; Kennicutt et al. 2008, ApJS 178, 247). The delivery includes: emission-line-only images (*_HA_SUB.fits), and scaled R-band images (*_CONT.fits).

The images are registered to a common frame, have standard astrometric solutions, and are flux calibrated. The images have been rotated to standard orientation (North up, East left).

All optical data are single extension FITS files. Photometric and astrometric keywords are stored in the FITS headers and the images have standard WCS headers in FITS-compliant format.

2.2 File Name Convention

For each galaxy, multiple datasets are delivered, with the following filename convention:

- *IRAC mosaics and weight maps*: ngcXXXX_irac#.fits, ngcXXX_irac#.cov.fits (with #=1,2,3,4; e.g., ngc1800_irac1.fits, ngc1800_irac1.cov.fits)

- *MIPS mosaics and weight maps*: ngcXXXX_mips#_[crop,image]_v@.fits, ngcXXXX_mips#_[crop,image]_v@_wt.fits (with #=24,70,160 and v@=version number; e.g., ngc1800_mips24_crop_v2-0.fits, ngc1800_mips24_crop_v2-0_wt.fits)
- *GALEX images*: ngcXXXX_galex_#_[int,rrhr]_[crop,image].fits (with #=FUV,NUV, e.g., ngc1800_galex_FUV_int_crop.fits; [int,rhrr] refers to the intensity or the high-resolution response maps, respectively).
- *Optical images/mosaics*: ngcXXXX_#_dr1.fits (with #=CONT,HA_SUB, e.g., ngc1800_HA_SUB_dr1.fits)

3. IRAC Data Products and Post-BCD Processing

3.1 Introduction

The LVL IRAC images are created from multiple Spitzer images in either a mosaic or single field dither pattern. The fundamental data used for these are the Version 16 , 17, and 18 (as available) Basic Calibrated Data (BCD) images produced by the Spitzer Science Center (SSC). These data have already undergone a number of processing steps including conversion from engineering to scientific units, flat fielding and bias subtraction. The LVL IRAC pipeline further processes these data to deal with a number of issues including frame geometric distortion and rotation, cosmic rays, frame alignment, and bias drift. Frames are finally combined using the drizzle algorithm to maximize resolution from the individual sub-sampled images. The major observation and processing steps are detailed below.

3.2 Data Products

The IRAC data products contained in this delivery are single-extension FITS files, two files for each IRAC band for each galaxy: science mosaics (*_irac1.fits, *_irac2.fits, etc.) and coverage maps (*_irac1.cov.fits, *_irac2.cov.fits, etc.). The science images are calibrated in MJy sr^{-1}, and have pixel sizes of 0.75 arcsec. The coverage maps contain the information on the integration time in seconds at each pixel; the pixel size of the coverage maps is the same as the science mosaics..

Astrometry is stored using FITS standard WCS coordinate keywords. The flux scale is stored in the BUNIT keyword. A boolean keyword BACK_SUB indicates if sky subtraction has occurred, and, if true, the sky value is stored under the keyword BACKGRND; BCKNOISE provides the standard deviation in the sky.

A note about sky subtraction: only constant level backgrounds have been subtracted from the images. Spatially variable backgrounds have not been removed.

3.3 Observational Strategy

Observations were carried out following the same strategy used for the SINGS IRAC campaign (Kennicutt et al. 2003, PASP 115, 928). All individual frames are 30 seconds in duration and are taken in HDR mode; an additional 1.2 second exposure is taken at each pointing to allow for recovery of data in the case of pixel saturation during the main observation (see Sec 3.4 for description of saturation recovery procedure). These observations can be divided into two categories: single field of view or mapped observations. Galaxies fitting within a single 5' IRAC field of view are imaged in two separate AORs, each consisting of four dithered frames, yielding eight 30 second exposures for each target. Galaxies larger than the IRAC field of view are taken in a mosaic pattern, offsetting the field of view by ~50% for each frame. This pattern is observed twice in two individual AORs, yielding a final mosaic where the central region has coverage in eight 30 second exposures, while a border around the outermost parts of the mosaic has coverage in four 30 second exposures. LVL IRAC images have 240 second (8 x 30) coverage over the cores of our maps, except in a number of cases where additional frames were incorporated to increase this final coverage. These deeper mosaics are identified in Sec 3.7.

3.4 Image Processing

The steps performed by the LVL IRAC pipeline are the following:

a. Geometric Distortion and Image Rotation

BCD images contain geometric distortions caused by IRAC's off-axis location in the Spitzer focal plane. These are corrected for utilizing MOPEX. Frames are rotated to the standard North-up, East-left.

b. Bias Structure

There is residual bias structure in many IRAC channel 3 frames due to the "first-frame effect". For galaxies that fit within the IRAC FOV, all BCD frames are binned according to the gradient across the frame, as measured in 12 columns near left and right edges. The median (source-free) gradient profile within each bin is used to correct for the gradient in each frame. A similar routine is followed for each extended (mosaicked) galaxy, but the binning and correcting is only based on data for that particular galaxy.

c. Bias Drift

IRAC images are subject to full frame DC bias drift with time. To correct for this, the LVL IRAC pipeline employs the MOPEX script overlap.pl to level the individual frame backgrounds. This offset is assumed to be due to the bias drift.

d. Cosmic Rays

Cosmic ray removal is accomplished using a dual outlier detection scheme within MOPEX: "radhits" are identified by their spatial appearance (smaller than PSF area, high counts) and confirmed using temporal filtering (looking for features that appear in less than a majority of the individual frames).

e. Saturated Pixel Recovery

In cases where exceptionally bright target sources (foreground stars are left uncorrected) saturated or entered the non-linear regime of the detector during the 30 sec exposure, additional 1.2 sec high dynamic range (HDR) images are used to allow for data recovery. Pixels affected by these issues, typically in the channel 3 and 4 frames, are flagged by MOPEX during processing. Correction begins by creating a mosaic of the 1.2 sec exposures interpolated onto the same pixel grid as the original mosaic. A difference image is then created from the two mosaics and any residual, systematic difference in the background sky levels is removed. Pixels in the difference image valued at 1 MJy/sr or higher are flagged (routinely regions of ~400 pixels) and these pixels in the long integration mosaic are replaced by their counterparts in the short integration mosaic. Mosaics that undergo this recovery procedure are identified in Sec 3.7.

f. Background Subtraction

Background levels are determined from a Gaussian fit to the histogram of the pixel levels in regions free of any sources. The peak of the Gaussian is adopted as the constant sky level for the mosaic, subtracted from the mosaic, and stored in the keyword BACKGRND.

The user is cautioned that in some cases, a constant sky level is only an approximation of the actual value. Variations across the mosaic may occur in some cases, especially in IRAC Band 4.

g. Drizzle Interpolation and Pixel Scale

The final mosaic of the corrected BCD frames is constructed using the MOPEX mosaic.pl script. Drizzle interpolation (drop factor of 0.75) is employed to determine the pixel values on a final grid of 0.75 arcsec/pixel, which is chosen to yield fully-sampled images with maximal resolution. The reference pixel for the WCS header keywords of the final mosaic is selected to be at the center of the galaxy. Blank pixels in the final mosaic images are set to NaN (not a number). The final drizzle step combines BCD frames from two different AORs, removing asteroids in the process.

3.5 Known Problems and Image Artifacts

Users are cautioned to be aware of standard IRAC detector artifacts that may be present in the LVL data, even though our observing and data processing strategies are designed to attempt to minimize these artifacts. These are detailed extensively in the IRAC Data Handbook, and include: persistent images in channels 1 and 4, diffuse stray light, stray light from point sources, muxbleed, column pulldown and banding, remaining full-frame bias and ghost images.

3.6 Important Note on Photometric Calibration

The units of the LVL IRAC mosaics are the same as the original BCDs delivered by the SSC. IRAC calibrations are performed using a 12" radius aperture on stars, and the units of MJy/sr of the mosaics refer to this specific aperture.
The user should be cautioned that when performing aperture photometry, aperture corrections need to be applied even for relatively large apertures (see the IRAC Data Handbook, section 5.5); the calibration for point sources is different from that of extended sources (http://ssc.spitzer.caltech.edu/irac/calib/extcal/).

3.7 Notes on Individual Galaxies

BK03N & UGC05336: Additional frames were added to original mosaics to produce deeper final images. Please consult coverage maps as depth varies across the final mosaic. In addition, the proximity of M81 causes variable backgrounds in the Band 4 mosaics.

CGCG217018, ESO245G005, ESO486G021, FM20001, KKH086, MRK475 & NGC7064: Muxbleed and banding effects occur on or near target galaxy.

DDO078: A bright foreground star partially obscures target galaxy.

ArpsLoop, ESO321G014, HS98117 & LEDA166101: Band 4 has a variable background.

ESO410G005: An extremely bright foreground star just out of the field of view causes strong latent images that remain uncorrected in the final mosaics.

ESO540G030 & IC1574: Band 1 images have residual artifacts due to latent correction.

F8D1: Bands 1-4 have variable backgrounds.

KK98208: A bright star off the edge of the frame causes an uncorrected stray light artifact in Band 2.

KKH037: Stray light mask causes low-coverage patch of pixels in southern corner of Band 1 image.

NGC0045: A bright foreground star lies projected on top of target galaxy.

NGC0672, NGC1510, & UGC01249: Additional frames were added to original mosaics to produce deeper final images. Please consult coverage maps as depth varies across the final mosaics.

NGC1311 & NGC4068: Persistent latent artifacts remain in Bands 1 and 2.

NGC1744: Band 1 and 3 images have residual image artifacts, due to bright, saturated foreground stars on frame.

NGC1800 & MCG-05-13-044: Both galaxies included in same IRAC mosaic. Four separate AORs were combined to produce 480 sec integration (twice normal depth) final images.

NGC2903, NGC3628, & NGC5236: Galaxy nuclei suffered from saturation issues, and were corrected by means described in Section 3.4.

NGC4096: Two persistent latent artifacts (just west of galaxy) remain in Band 1.

UGCA320: Persistence banding artifacts remain in Band 3.

UGC08760: Persistent stray light artifacts remain in Bands 1 and 2.

UGC07242: A bright foreground star fully obscures target galaxy.

4. MIPS Imaging Data Products and Post-BCD Processing

4.1 Introduction

The LVL MIPS mosaics are created from multiple Spitzer images obtained in scan-mapping mode, and fully processed with the MIPS Data Analysis Tool (MIPS DAT, Gordon et al. 2005, PASP, 117, 503). The LVL observing strategy is nearly identical to that of the SINGS MIPS observations (Kennicutt et al. 2003, PASP, 115, 928). The major observation and processing steps are detailed below. The images are calibrated using the latest calibration factors computed by the instrument team and the SSC (Engelbracht et al. 2007, Gordon et al. 2007, and Stansberry et al. 2007 at 24, 70, and 160 μm, respectively).

4.2 Data Products

The LVL MIPS data products are single-extension FITS files, four files for each MIPS band: the full scan map (*_mips#_image_v2-0.fits), an image cropped to the region around the galaxy (*_mips#_crop_v2-0.fits), and the weight map associated with each image. The images are calibrated in MJy sr^{-1}, and have pixel size 1.5, 4.5 and 9.0 arcsec for the 24 μm, 70 μm, and 160 μm mosaics, respectively. The pixel sizes of the MIPS mosaics have been chosen to sample adequately the point spread function and at the same time be an approximate integer multiple of the IRAC mosaics' pixel scale (approximately 0.75 arcsec, see section 3). Constant backgrounds have been subtracted from the data as part of the data processing. Spatially variable backgrounds, such as cirrus structure, have not been removed.

All original fits header information has been retained. The headers' content has been re-arranged so that basic information on the observations, the target, and coordinates, and the pixel sizes appears first in the listing. Among the relevant keywords: the mosaics' astrometry is stored in the standard FITS WCS keywords; the flux units are stored in ZUNITS; and the background subtraction and its value are stored in the keywords BACK_SUB (performed=T, not performed=F) and BACKGRND (value), respectively. All other information, which includes details on the observations and the data processing, is located after these basic keywords.

4.3 Observational Strategy

The new LVL MIPS observations were obtained using the scan-mapping mode in two separate visits to the galaxy. Separate visits allow asteroids to be recognized and provide observations at orientations up to a few degrees apart to ease removal of detector artifacts. As a result of redundancy inherent in the scan-mapping mode, each pixel in the core map area was effectively observed at least 40, 20, and 4 times at 24, 70, and 160 microns, respectively, resulting in integration times per pixel of at least 160 s, 80 s, and 16 s, respectively. The exact depth of any observation can be found in the weight maps discussed in section 2.1.2.

4.4 Post-BCD Image Processing

The MIPS data were processed using the MIPS DAT versions 3.10 along with additional customized processing software. The processing steps are as follows.

For the 70 and 160 μm data, a linear fit is applied to the ramps (the counts accumulated in each pixel during the non-destructive readouts), and slopes are derived. This step also removes cosmic rays and readout jumps and applies an electronic nonlinearity correction.

The initial processing of the 24 μm data is different from the 70 and 160 μm data, as slopes are already fit to the 24 μm data on the spacecraft. Thus, the 24 μm images are processed through a droop correction (that removes an excess signal in each pixel that is proportional to the signal in the entire array), correction for non-linearity in the ramps, and dark current subtraction.

Telescope optical signatures and time-dependent responsivity variations in the detector elements are removed from the data, in the following way:

For the 24 μm images, flatfielding is performed in two steps. First, scan mirror position dependent flatfields are applied to the data (to correct dark spots caused by particulate matter on the scan mirror that shift in position from frame to frame). These flatfields are created from a superflat with a superimposed spot map that is shifted to match the spots in the individual scan legs. Next, scan mirror position independent flats are created from off-target data in the data from each AOR; these flatfields are applied to the data to remove any residuals left by the scan-mirror-dependent flats. Additionally, a readout offset correction is applied between the flatfielding steps to correct variations across the columns in the images. Latent images in the 24 μm data (from bright sources and bright cosmic ray hits) are masked out after the flatfielding. The "jailbar" pattern caused by bright sources is corrected, and an additive correction is applied to images with a DC level which is offset by a significant amount from their neighbors (which can happen when the droop correction is underestimated for images containing a saturating source). Following this, the background is subtracted from the individual frames of data. This is done by finding the background levels as a function of time for each individual scan leg while excluding the target and other bright sources, then fitting a third order polynomial to the background values. The function is then used to calculate the background for each frame, and this background is subtracted. Finally, the low-level (~0.2%) scan-mirror-position-dependent scattered light is subtracted from each image.

The stimflash frames taken by the telescope are used for responsivity corrections of the 70 and 160 μm arrays. Next, the dark current is subtracted, and illumination corrections are applied to the data. Following this, short-term variations in the images caused by drift are subtracted. This last step also subtracts the background from the data. At 70 μm we mask pixels for about 20 images that have been subjected to high fluxes. The effect of this is most obvious in NGC3077, which is very bright.

A preliminary mosaic is made with the resolution set to the native pixel resolution of the MIPS detectors. During this mosaicking process, the individual frames of data are rewritten. A statistical analysis is performed on all pixels that overlap, and pixels that deviate at the 3σ level are masked out in the rewritten frames. This step effectively filters out cosmic rays and other transient phenomena.

In all three bands, asteroids are identified by comparing different epochs (or different scan legs, for those archival scan maps that have been obtained only once) and masked from further processing.

Final mosaics are made from the individual frames. Data from both AORs are mosaicked together.

After the mosaics are created, the images are multiplied by a final calibration factor that converts the MIPS units into MJy sr^{-1}. The factors are the following (keyword JANSCALE in the image headers):
24 μm: 0.0454 MJy sr^{-1} $MIPS\_units^{-1}$
70 μm: 702 MJy sr^{-1} $MIPS\_units^{-1}$
160 μm: 41.7 MJy sr^{-1} $MIPS\_units^{-1}$

The cropped mosaics in this delivery have been sized to include all of the galaxies' optical disks and any nearby galaxy or extended structure. The cropped images also include a minimum of 40" space between the edge of the optical disk and the edge of the image, so that sufficient information for measuring the background is provided.

4.5 Special Cases, Known Problems and Uncertainties

Streaking in the 70 μm data (DR1 and DR2 data)

Bright sources in the 70 μm data produce negative latent images that are manifested as negative streaks in the data. Sometimes positive streaks on the opposite side of the bright sources from the negative streaks are also apparent. These positive streaks are regions where, partly because of the negative latent images, the background is under-subtracted. Work is underway to correct the negative streaking, which should also lead to a reduction of the positive streaking.

The galaxies most obviously affected by this problem are NGC5236, NGC3628, NGC2903, NGC0625, and NGC4605.

Non-linearity Effects in the 70 μm data

The MIPS 70 μm array is affected by nonlinearity at high count rates. This effect becomes significant in point sources at 3 Jy, where measured counts are ~10% too low, and the effect becomes larger for brighter sources (Gordon et al. 2007). Since the effect is to depress counts on the brightest pixels, it can be alleviated in unresolved sources by performing photometry via PSF fitting, which delays the onset until ~10 Jy.

However, PSF fitting is generally not applicable to extended targets like the LVL galaxies. In the case of compact sources, the 70 μm nonlinearity decreases the global fluxes of any source brighter than about 3 Jy. Furthermore, it is likely that the nonlinearity acts to depress the response of any pixel viewing a high flux density, so the user is cautioned that the 70 μm profiles of galaxies with high central surface brightnesses (above ~66 MJy/sr) may have been flattened somewhat by this effect. However, global fluxes of extended sources, with significant contributions from low-surface brightness regions, are not affected significantly.
The galaxies affected by 70 μm nonlinearity are NGC2683 and NGC3077 in DR3.
In DR2, they are: NGC5236, NGC3628, NGC2903, NGC0625, NGC4605, ISZ399, NGC1313, NGC1487, NGC3239, NGC4096, NGC4656, and NGC3432.

A correction for the nonlinearity is under development, but has not yet been implemented at the time of this writing.

Artifacts near Bright Sources in the 24 μm data

In some cases, bright sources in the 24 μm data trigger a strong "jailbar" effect and a droop effect visible as a step function in the background. Corrections for these effects have been applied to the data, but a residual offset is still present on the array rows most heavily saturated by the target, which results in a streak perpendicular to the scan direction (i.e., the long axis of the "image" mosaics) and through the center of the bright source.

Photometric Uncertainties

Currently the estimated calibration uncertainties for MIPS extended object photometry are 2%, 5%, and 9% for the 24, 70, and 160 μm data, respectively. The uncertainty figure for the 70 μm images refers only to sources unaffected by the non—linearity discussed above. The user is advised that aperture corrections, background noise, and color corrections will add to the uncertainty (e.g., Dale et al. 2007, ApJ, 655, 863).

5. GALEX Data Products and Pipeline Processing

THIS SECTION IS RELEVANT FOR DR1 GALAXIES

5.1 Introduction

GALEX images in two ultraviolet bands, far-UV (FUV; λ_{eff}=1516 Å) and near-UV (NUV; λ_{eff}=2267 Å), are delivered. The majority of the LVL images have been obtained as part of the GALEX *Guest Investigator* (GI) Cycle-1 #47 (PI: R.C. Kennicutt), Cycle-3 #61 (PI: E. Skillman), and Cycle-4 #95 (PI: J. Lee) programs and the *Nearby Galaxies Survey* GALEX PI-program. A few objects were observed as part of other public GI datasets and of the *Medium-Deep Imaging Survey* GALEX PI-program.

For 9 objects (SMC, LMC, NGC3077, UGC5076, ISZ399, UGC7490, UGC8508, UGC8837, and NGC7713), GALEX data will not be available, because of Bright Objects Avoidance constraints or other limitations.

The processing steps performed by the GALEX pipeline (v6) include the generation of count maps (in sky coordinates) by the combination of the time-tagged photon positions and the satellite aspect solution, which are then divided by the respective relative response map in order to obtain the intensity images released here. More details on the GALEX data processing are given below.

5.2 Data Products

The GALEX data products delivered are single-extension FITS files. For each object we deliver full-frame intensity FUV (*-fd-int.fits) and NUV images (*nd-int.fits) along with the corresponding high-resolution response maps (*-fd-rrhr.fits, *-nd-rrhr.fits). All four images are registered to a common frame and are WCS-compliant with North up and East left. The images are 1.6ºx1.6º in size but only the central ~1.2 degrees (in diameter) are exposed. The pixel size is 1.5 arcsec in all cases. Additionally, we deliver intensity images and high-resolution response maps cropped to a size equal to 4 times the D_{25} diameter of the galaxies.

The units of the intensity images are *counts/sec/pixel* and can be converted into AB magnitudes via $m_{AB}=ZP-2.5log10(counts/sec)$, where the corresponding zero points are ZP_{FUV}=18.82 mag and ZP_{NUV}=20.08 mag. The high-resolution response map, which is the product of the response by the effective exposure time, can be used to determine the total number of detected photons (and from them the photon noise) simply via multiplication by the intensity image.

5.3 GALEX Pipeline processing

The GALEX images have been processed with the version 6 of the GALEX pipeline. The processing of the GALEX data includes three main steps: *Static Calibration, Dynamic Aspect Correction, and Generation of Data Products*. Here we briefly summarize the operations performed to complete these three steps. See Morrissey et al. (2007, ApJS 173, 682) for an extensive description of the GALEX pipeline and the calibration procedure for the GALEX intensity images.

Static Calibration: In this first stage the time-tagged photon lists (which also include pulse-height information) obtained from the GALEX satellite are processed to derive accurate focal-plane positions for all photon events. This is also the stage when the GALEX pipeline identifies events that are not photon generated, such as the STIM pulses. The first operation to be performed as part of the Static Calibration is the *determination of raw positions* from the coarse-clock counters plus fine position measurements, which are essentially given by the coarse-clock phase. Once these raw positions are assembled, the following (static) corrections are applied: *centering and scaling, wiggle, walk, spatial non-linearity (distortion) at the detector edges, and hot-spot masking.*

Dynamic Aspect Correction**:** Once precise detector coordinates are computed for all photon events, the sky coordinates of these events are determined. In order to do so the GALEX pipeline reconstructs the spacecraft trajectory in the sky (in RA, Dec, and roll angle of the telescope bore-sight) during the exposure as a function of time. The GALEX pipeline makes use of the information provided by the *Attitude Control System*, which is refined by tracking the actual trajectory in the NUV detector of bright stars included in the ACT catalogue. The main objective of this procedure is to remove the spiral dither pattern of ~1 arcmin of amplitude that is applied to the satellite while carrying out the observation and that is intended to homogeneously distribute the detector fatigue.

Generation of Data Products: The corrected photon data, generated at the end of the processing steps described above, are then binned in pixels of 1.5”x1.5” in size in what is called the Count image. The Count image is then divided by the Relative Response image to obtain the Intensity image included as part of this data delivery. The High-Resolution Response map (also delivered) is simply an up-scaled (1.5 arcsec/pixel) version of the 6” Relative Response image. Note that the response images are different for the two bands.

No special post-pipeline procedures were applied to the images included in this data delivery. The full-frame GALEX images of all objects (except UGC 08833) are also available at the *Multimission Archive at STScI* (MAST) as part of the GALEX Data Release 4 (GR4). Intensity images and response maps delivered here are identical to those available at MAST.

Rotation-matrix elements (CD) were added to the image header. These keywords and the CROTA and CDELT-based astrometry keywords already included in the MAST images are redundant with respect to most software applications. In the case of the cropped images we added some extra information to the image header, which includes the position of the galaxy center in pixel coordinates of the cropped image (XCENTER, YCENTER) and the dimensions of the cropped image (NDIMX,NDIMY).

5.4 Known problems and GALEX specifics

The GALEX images show some artifacts that the potential user of these data should be aware of. The most common ones are due to reflections of bright field stars in the dichroic beam splitter or in the window of the NUV detector (associated either to the window itself of to its beveled exterior surface). These latter artifacts are only found in the NUV images. Reflections due to the dichroic usually appear as oblique circles in both the FUV and NUV bands. Reflections in the NUV window are wide circular rings where the shade of the secondary-mirror spider can often be seen. On the other hand, the reflections on the beveled exterior surface of the NUV window of bright stars located just outside the GALEX field of view appear as elongated trails near the edge of the NUV image and perpendicular to it. In rare occasions these trails are accompanied by a (sometimes circular, sometimes bow-shaped) interior ghost that can be seen far inside the field of view. In Section 5.5 we list the most obvious artifacts found in the images included in this data delivery. More details on these artifacts are found in the "GALEX Pipeline Data Guide" at the GALEX GI website (**http://galexgi.gsfc.nasa.gov/docs/galex/Documents/**).

Another peculiarity of the GALEX data is the extremely low background of the images. The typical backgrounds in GALEX fields at high Galactic latitudes are ~10^3 and 10^4 photons s^{-1} $arcsec^{-2}$ in the FUV and NUV bands, respectively. Thus, for an average exposure time of 1,500 seconds we expect roughly 1 (10) counts/pixel in the FUV (NUV). Such low values result in highly non—Gaussian distributions for the sky background, especially in the FUV. Because of this peculiarity we warn against the use of certain estimators of the average background, such as the mode. Should the flux measurements be based on *mean* values (e.g. average surface brightness), the same estimator (i.e., the *mean*) should be used to compute the sky background as well.

5.5 Notes on individual galaxies

NGC1522: Ghosts from bright field stars to the W and SW. Ghosts from the window of the NUV detector (circular) appear only in the NUV image. Ghosts from the dichroic beam splitter (oblique) appear both in the FUV and NUV images. FUV hot spot to the SE.

NGC1744: Extremely faint (interior) ghost from NUV window bevel reflection located 10-arcmin south of the galaxy.

UGCA319 & UGCA320: Ghost from bright field star to the E. Ghosts associated to the NUV detector window and the dichroic are both seen. Faint edge ghost due to a NUV-window bevel reflection.

UGC08320: Ghost from the window of the NUV detector 10-armin north of the field center.

UGC08331: Ghost from bright field star to the NW. Ghosts associated to the NUV-detector window and the dichroic are both seen. Extremely faint (interior) ghost from NUV window bevel reflection NW of the galaxy.

UGC08760: PSF deteriorates slightly to the very north edge of the GALEX full frame.

UGC08833: Ghost from bright field star to the SW. Ghosts associated to the NUV detector window and the dichroic are both seen. Extremely faint (interior) ghost from NUV window bevel reflection SE of the field center. The intensity images and response maps of this object were not publicly released as part of the GALEX Data Release 4. Nevertheless, the pipeline version and the products generated are the same as those in the GALEX DR4**.**

NGC5068: Ghosts from bright field stars to the E and NE. Ghosts associated to the NUV-detector window and the dichroic are both seen. Scattered FUV light (most likely from Galactic cirrus) is seen across the field.

NGC5832: Ghosts from bright field stars to the E and S. Ghosts associated to the NUV-detector window and the dichroic are both seen.

6. Optical Images: Data Products and Processing

THIS SECTION IS RELEVANT FOR DR1 GALAXIES

6.1 Introduction

Optical imaging data in R broadband as well as in narrowband filters which capture the Hα and [NII]λλ6548,84 emission lines are being delivered for the 13 galaxies in this first data release. The R-band data that are provided here have been scaled to match the continuum levels in the narrowband filter, while the narrowband data have been continuum subtracted using these scaled R-band images to isolate the Hα+[NII] line emission.

These data are stored in single extension FITS files (one file for each filter), and have astrometric solutions. The narrowband data have been flux calibrated using observations of spectrophotometric stars. Calibration and astrometric keywords are stored in the FITS headers.

The scaled R-band and continuum-subtracted narrowband images are registered to a common frame. The flux scale is in units of counts, and the flux calibration keywords needed to convert the observed counts to ergs cm^{-2} s^{-1} are RESPONSE, the unit response, and TRANSMISS, the effective transmission of the narrowband filter.

6.2 Observations

The narrowband Hα+[NII] and R-band imaging data in this delivery have been obtained as part of the precursor 11 Mpc Hα Survey. Full details on the observations, data processing, flux calibration and measurements are provided in (Lee 2006, Kennicutt et al. 2008).

Imaging was obtained over a five year period between 2001-2005 using CCD direct imagers on the Steward Observatory Bok 2.3m telescope on Kitt Peak, the Lennon 1.8m Vatican Advanced Technology Telescope (VATT) on Mt. Graham, AZ, and the 0.9m telescope at the Cerro Tololo Interamerican Observatory (CTIO). Below, we reproduce Table 2 from Kennicutt et al. (2008), which summarizes the main properties of the observational set-ups used.

At the Bok 2.3m, the narrowband imaging was obtained using a custom 88 mm Andover 3-cavity interference filter with a high peak transmission of 90%. When combined with the 94% quantum efficiency of the 2K Loral CCD detector this produced a high system throughput that allowed us to achieve relatively deep flux and surface brightness limits ($\sim 2\times10^{-16}$ ergs/cm^{-2}/s and $\sim 4\times10^{-18}$ ergs/cm^{-2}/s/$arcsec^{-2}$ respectively) in exposure times of 1000 sec. In order to remove the stellar continuum flux in these images, we also observed the same fields with a Kron-Cousins R filter, with standard integration times of 200 sec.

Most of the observations on the VATT telescope were made using the same narrowband Hα filter. For a few objects, a matching filter centered at 6600 A was used.

Longer total integration times of 1800 sec (narrowband) and 360 sec (R) were used to compensate for the smaller telescope aperture and the somewhat lower quantum efficiency of the CCD detector, and yielded the same signal/noise limits as the Bok observations to within 10%.

Southern galaxies that were not reachable from the Arizona telescopes were observed with the Cassegrain Focus CCD Imager (CFCCD) on the CTIO 0.9 m telescope. Data were obtained during 3 observing runs in 2001-2002. A 75 A bandpass Hα interference filter from CTIO was used for the observations. Because of the much smaller telescope aperture it was not practical to achieve the depth of the Bok and VATT observations, so exposure times were chosen (2700 sec narrowband, 300-600 sec broadband) to achieve approximately one third of the effective exposure time. The smaller aperture of this instrument was offset by the wide field of view of the CFCCD camera (13.5 arcmin on the side), which allowed many of the largest galaxies in the project to be imaged efficiently.

All of the images provided in this first data release have been observed under photometric conditions. Spectrophotometric stars from the catalogs of Massey et al. (1988), Oke et al. (1990), and Hamuy et al. (1992, 1994) were observed to flux calibrate the narrowband images.

Telescope	Detector	CCD Scale	Continuum Filter (CWL/FWHM)	Line Filter(s) (CWL/FWHM)	Exposure Times (line/continuum)
Bok 2.3m	Loral 2K x 2K	0."43/pix	6451A/1473A	6585A/66A "658"	1000s/200s
VATT 1.8m	Loral 2K x 2K	0."40/pix	6338A/1186A	6585A/66A "658" 6600A/69A "660"	1800s/360s
CTIO 0.9m	Tek 2K x 2K	0."79/pix	6425A/1500A	6563A/75A "65" 6600A/75A "66"	2700s/360s

6.3 Data Processing

Data reduction followed standard procedures using IRAF. Bias subtraction, flat-fielding, and cosmic ray removal using the JCRREJ2 package (Rhoads 2000) were performed. Net emission-line images were produced by subtracting a scaled R image from the narrowband image, after aligning the two using foreground stars. The value used to scale the R-band image is stored in the SCALE_R header keyword. Astrometric solutions (with rms deviations typically less than 0."5) were derived for the R images using the USNO-A2 catalog, and the same solution is assumed for the corresponding narrowband image. WCS keywords (FITS standard) stored in the image headers.

6.4 Data Characteristics

The LVL DR1 optical images are in units of counts (COUNTS, stored in the UNITS keyword). For the narrow-band images, the keyword FILTER records the name of the filter used for the observations as indicated in the table above. Original header information from the facility is preserved and information on the subsequent processing, astrometry and flux calibration information has been added. For convenience, a few keywords have also been added which repeat information already contained in the original headers but were recorded under different facility-dependent keywords. These are CCDSCALE, the pixel scale of the image, CCD noise, the readnoise of the detector, and FILTER. The effective airmass for the observations CAIRMASS has also been calculated. All images conform to the North-up/East-left convention.

The narrowband images (*_HA_SUB.fits) have been continuum-subtracted and contain emission from Hα, as well as [NII]$\lambda\lambda$ 6548,6584A. The scaled R-band images used to perform the subtractions (*_CONT.fits) are also provided. Users can recover the uunsubtracted continuum image by adding the *_HA_SUB.fits and the *_CONT.fits images together. The unscaled R-band image can be recovered by using the SCALE_R keyword value in the headers, to multiply *_CONT.fits image. The LVL DR1 imaging is **not** background-subtracted.

Photometric zeropoint uncertainties are less than ±2%, as determined from the consistency of the standard star photometry. Uncertainties in the flat-fielding are generally ±1-4%. There is a median uncertainty of ~10% in the determination of the continuum level, with a range of ±5% (for bright spirals with large continuum dominated regions) to ±15-20% (for galaxies with the weakest continua or those with strong diffuse Hα emission). This results in a total median error of 12% for the integrated Hα+[NII] fluxes as reported in Kennicutt et al. (2008). (For a more detailed discussion of uncertainties see Kennicutt et al. 2008, section 3.6).

For studies seeking to examine the fluxes in a spatially-resolved manner (e.g., for determination of Hα surface brightness profiles), extra care must be taken to account for additional systematic uncertainties which may arise from spatial variations in the continuum level (that are not tracked by the broad R band filter) and the [NII]/Hα ratio. Such issues will be most relevant to galaxies with large color and abundance gradients.

6.5 Conversion from count-rates to fluxes/magnitudes

To calculate emission-line fluxes in erg s^{-1} cm^{-2}, the RESPONSE, the unit response, TRANSMISS, the effective filter transmission, keywords are required:

$$F(H\alpha+[NII])\ [erg\ s^{-1}\ cm^{-2}] = RESPONSE/TRANSMISS * (measured\ counts/T\_EXP)$$

The effective filter transmission is calculated by accounting for the presence of both Hα and the [NII] doublet in the filter bandpass, and the variation of the [NII]/ Hα among galaxies (Kennicutt et al. 2008, Appendix A2). Globally averaged [NII]/ Hα ratio values are provided in Kennicutt et al. 2008 Table 3, and can be used to correct the integrated fluxes for contamination by the [NII] lines.

6.6 Notes on individual galaxies:

NGC1522, NGC1744, NGC1800: slight gradient in the R-band background. For NGC1522 there is a slight background also in the Hα+[NII] image.

Table 1: List of Galaxies in Current Delivery (DR3). IRAC and MIPS higher-level data only are delivered in DR3.

UGC0521	UGC0685	UGC0695	UGC0891	UGC1056
UGC01104	UGC01176	ESO245-G007	ESO486-G021	UGC4426
NGC2683	UGC4704	UGC4787	UGC5076	ArpsLoop
UGC5364	UGC5373	NGC3109	NGC3077	AM1001-270
UGCA281	UGC8091	IC4247	KK98208	ESO444-G084
NGC5264	MRK475	IC4951	DDO210	UGCA438
UGC12613				

Table 2: List of Galaxies in Previous Delivery (DR2). IRAC and MIPS higher-level data only were delivered in DR2.

BK03N	BK05N	BK06N	CGCG035007	CGCG217018
DDO078	ESO115G021	ESO119G016	ESO149G003	ESO154G023
ESO158G003	ESO245G005	ESO294G010	ESO321G014	ESO347G017
ESO410G005	ESO483G013	ESO540G030	ESO540G032	F8D1
FM20001	HS98117	IC0559	IC1574	IC1959
IC2049	IC5256	IC5332	IKN	ISZ399
KDG061	KDG073	KK98230	KKH037	KKH057
KKH086	KKH098	LEDA166101	MCG-03-34-002	NGC0045
NGC0059	NGC0247	NGC0300	NGC0625	NGC0672
NGC0784	NGC1311	NGC1313	NGC1487	NGC1510
NGC1796	NGC2552	NGC2903	NGC3239	NGC3274
NGC3299	NGC3432	NGC3510	NGC3623	NGC3628
NGC3741	NGC4020	NGC4068	NGC4080	NGC4096
NGC4163	NGC4190	NGC4248	NGC4288	NGC4395
NGC4455	NGC4605	NGC4656	NGC4707	NGC5236
NGC5238	NGC5477	NGC5949	NGC7064	NGC7713
SCULPTOR-DE1	UGC1249	UGC2716	UGC4998	UGC5272
UGC5288	UGC5336	UGC5428	UGC5442	UGC5456
UGC5672	UGC5692	UGC5764	UGC5797	UGC5829
UGC5889	UGC5918	UGC6457	UGC6782	UGC6817
UGC6900	UGC7242	UGC7267	UGC7408	UGC7490
UGC7559	UGC7577	UGC7599	UGC7605	UGC7608
UGC7639	UGC7690	UGC7698	UGC7699	UGC7719
UGC7774	UGC7866	UGC7916	UGC7949	UGC7950
UGC8188	UGC8245	UGC8313	UGC8508	UGC8638
UGC8837	UGC9240	UGC9405	UGC9992	UGCA015
UGCA106	UGCA133	UGCA193	UGCA276	UGCA319
UGCA442				

Table 3: List of Galaxies in the First Delivery (DR1). Full datasets (IRAC, MIPS, GALEX, and optical) were delivered for these galaxies.

Name	Morphology	Reason for Selection
NGC1522	S0:pec	Morphology
NGC1744	SBd	Large angular diam., high inclination
NGC1800+MCG-05-13-044	IBm+N/A	Strong star formation; outflows?
UGCA320	IB(s)m	CenA Group dwarf
UGC8320	IBm	Diffuse Galaxy
UGC8331	IAm	Morphology
UGC8651	Im	Morphology
UGC8760	SABdm	Highly inclined
UGC8833	Im	Intense star formation
NGC5068	SBd	Morphology
NGC5229	SBd?	Highly inclined
NGC5832	SBb	Morphology