

**SINGS: The Spitzer Infrared Nearby Galaxies Survey**  
**Third Data Delivery**  
**October 2005**

**USER'S GUIDE**

**1. Introduction**

This document describes the third data delivery of the Spitzer Legacy program SINGS. This delivery contains 2/3 of the total galaxies in the sample. The document is organized as follows: section 2 lists the data products contained in this delivery and their general characteristics; sections 3, 4, and 5 provide a description of the post-BCD processing for IRAC, MIPS, and IRS data, respectively; finally, section 6 briefly describes the data reduction steps of the ancillary data associated with this delivery.

For a complete description of the SINGS program, galaxy sample, and observing strategy, please refer to Kennicutt et al. 2003, PASP, 115, 928.

**2. Content of the Data Delivery**

**2.1 Third-Delivery Sample and Data Products**

The SINGS sample contains 75 galaxies, representative of a large range of properties of local normal galaxies (Kennicutt et al. 2003). Of these 75, 50 are in the present delivery, and are listed in Table 1.

**Table 1: Galaxies in the SINGS third data delivery**

Name	Name	Name	Name	Name
DDO053	NGC0628	NGC2976	NGC3938	NGC4826
DDO154	NGC1097	NGC3049	NGC4125	NGC5194
DDO165	NGC1266	NGC3184	NGC4254	NGC5408
HolmbergII	NGC1377	NGC3190	NGC4321	NGC5713
HolmbergIX	NGC1404	NGC3198	NGC4536	NGC5866
IC2574	NGC1566	NGC3265	NGC4552	NGC6822
IC4710	NGC1705	NGC3351	NGC4569	NGC7331
Mrk33	NGC2798	NGC3521	NGC4579	NGC7552
NGC0337	NGC2841	NGC3627	NGC4725	NGC7793
NGC0584	NGC2915	NGC3773	NGC4736	Tol89

### 2.1.1 IRAC Mosaics

For each galaxy, 4 mosaics, one for each of the four IRAC bands, are delivered as single-extension FITS files. The pixel scale of the mosaics is 0.75 arcsec, and the flux units are MJy sr<sup>-1</sup> (see, however, the Important Note About Photometric Calibration, section 3.7). The mosaics have standard orientation, with North up, East left.

Details of the post-BCD processing are given in Section 3.

### 2.1.2 MIPS Mosaics

For each galaxy, 3 mosaics, one for each of the MIPS bands, 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<sup>-1</sup>. The mosaics have orientation North up, East left.

Details on the post-BCD processing are given in section 4.

### 2.1.3 IRS Spectra, Maps, and Cubes

For 50 galaxies, six 2-dimensional maps of the nucleus (continuum-subtracted maps of [Ne III] 15.5 μm and [Si II] 34.8μm, complementary continuum maps at 15μm and 35μm, and maps of poly-cyclic aromatic hydrocarbon (PAH) emission at 7.6μm+8.6μm and 11.3μm) are being delivered. For each nuclear region, a single one-dimensional spectrum in all four IRS modules is also being delivered (Short-Low (SL) λ=5-15 μm, R=50-100; Long-Low (LL) λ=15-37μm, R=50-100; Short-High (SH) λ=10-20μm, R=600; and Long-High (LH) λ=20-37μm, R=600), ranging in size from 22.6"×14.8" (high resolution, SH and LH) to 50"×33" (low resolution, SL and LL). One-dimensional spectra are in ASCII (\*.tbl), while the maps are in FITS format.

For 25 of the 50 galaxies, full three-dimensional spectral cubes in FITS format for all the modules are delivered for the first time. Maps and spectra are provided for 26 extra-nuclear, optically selected regions in five galaxies (HoII, NGC0628, NGC3031, NGC5194, and NGC6946). For these, three 2-dimensional maps (PAH emission at 7.7+8.6 μm, and 11.3 μm and a continuum map at 13.5 μm) and a corresponding one-dimensional spectrum in the SH, LH and SL modules are delivered.

The units of the [NeIII] and [SiII] line maps are W m<sup>-2</sup> sr<sup>-1</sup>, while all other maps and spectra have units of MJy/sr.

Details on the data format and content, and on the post-BCD processing for the spectra are given in section 5.

### 2.1.4 Optical Images/Mosaics

Optical imaging data in the standard B, V, R, I broad-band filters and in narrow-band filters at the wavelength of the Hα+[NII] emission, plus continuum-subtracted Hα+[NII]

images, are delivered for 48 of the 50 galaxies (for NGC5408, only the continuum-subtracted H $\alpha$  and associated continuum images are available, while for NGC4569 there are no optical data available).

The images are either single pointings, or mosaics of 2 or more adjacent and partially-overlapping frames. The images are not background-subtracted.

All optical data are single extension FITS files (one file for each filter); they are flux calibrated and have astrometric solutions. Photometric and astrometric keywords are stored in the FITS headers.

The pixel scale is 0.305 arcsec (KPNO data) or 0.433 arcsec (CTIO data). The images have NE orientation, and are registered to a common frame. The flux scale is count/sec (CPS), and the relevant photometric keywords are: PHOTFLAM, to convert CPS to Jy, and ZPOINT, for the zeropoint.

More details on the optical images are given in section 6.1.

### *2.1.5 Optical One-dimensional Spectra*

One-dimensional (1D) spectra in the wavelength range 0.36-0.70  $\mu\text{m}$  are delivered for 44 of the 50 galaxies (there are no spectroscopic data available for HolmbergII, DDO154, IC4710, NGC5408, NGC6822, and NGC7552). For most galaxies, two spectra are delivered: the nuclear spectrum, and the central 20''x20'' drift-scan spectrum.

The nuclear spectra are 2.5''x2.5'' (KPNO) or 2.5''x3.0'' (CTIO) aperture extractions of the brightest few central pixels. The 20''x20'' drift-scan spectra target the central region of each galaxy, in a similar fashion to some of the IRS spectra. Both type of optical spectra are wavelength and flux calibrated. Resolution is  $\sim 8$  Angstrom, and all fluxes are corrected for foreground Galactic extinction.

Nuclear and drift scan spectra are stored in separate ASCII files (\*.txt). More details on the data and on individual galaxies are given in section 6.2.

## **2.2 File Name Convention**

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

- *IRAC mosaics*: ngcXXXX\_v5.phot.ircac#.fits (with #=1,2,3,4; e.g., ngc0337\_v5.phot.ircac1.fits)
- *MIPS mosaics*: ngcXXXX\_mips#\_crop\_v3-\*.fits (with #=24,70,160 and \*=0,1; e.g., ngc0337\_mips24\_crop\_v3-0.fits)
- *IRS Low-Res 1D spectra*: ngcXXXX\_DR3\_MD#\_nuc\_sp.tbl (MD=SL,LL; #=1,2, nuclear spectra) and ngcXXXX\_extranuc\_\$\$\_DR3\_MD#\_sp.tbl (extranuclear spectra, \$\$=number of extranuclear region)
- *IRS Low-Res 1D Estimated Background Spectra (selected sources only)*: ngcXXXX\_DR3\_SL#sky\_sp.tbl (#=1,2)

- *IRS High-Res 1D spectra*: ngcXXXX\_DR3\_MD\_nuc\_sp.tbl (MD=SH,LH, nuclear spectra) and ngcXXXX\_extranuc\_\$\$\_DR3\_MD\_sp.tbl (extranuclear spectra, \$\$=number of the extranuclear region)
- *IRS 2D Maps*: ngcXXXX\_DR3\_MD#\_line.fits and ngcXXXX\_extranuc\_\$\$\_DR3\_MD#\_line.fits (line=neIII, siII, pah\_8, pah\_11\_3, extranuc=extranuclear region), ngcXXXX\_DR3\_MD#\_line\_cont.fits (line=neIII, siII) and ngcXXX\_extranuc\_\$\$\_DR3\_MD#\_cont\_13.fits
- *IRS 3D Cubes*: ngcXXXX\_DR3\_MD#\_cube.fits and ngcXXXX\_DR3\_MD#\_cube\_unc.fits (cube and cube's uncertainty, respectively)
- *Optical images/mosaics*: ngcXXXX\_#.fits (with #=B,V,R,I,H $\alpha$ ,H $\alpha$ \_sub e.g., ngc5194\_Ha.fits)
- *Optical 1D spectra*: ngcXXXX\_nuclear\_002\_5.txt, and ngcXXXX\_drift\_020\_020.txt.

### **3. IRAC Data Products and Post-BCD Processing**

#### **3.1 Introduction**

The SINGS 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 11 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 SINGS IRAC pipeline further processes these data to deal with a number of issues including frame geometric distortion and rotation, residual flat fielding, 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. Changes in the data processing between the second and third (current) delivery are described in section 3.9.

#### **3.2 Data Products**

The IRAC data products contained in this delivery are single-extension FITS files, one file for each IRAC band (\*.irac1.fits, \*.irac2.fits, etc.). The images are calibrated in MJy sr<sup>-1</sup>, and have pixel size of 0.75 arcsec.

The original header keywords are retained, plus others added as a result of the post-BCD processing. In particular, astrometry is stored using FITS standard WCS coordinate keywords; the flux scale is stored in the BUNIT keyword; and the background subtraction and its value are stored in the keywords BACK\_SUB (performed=T, not performed=F) and BACKGRND (value), respectively.

A note about background subtraction: only constant level backgrounds have been subtracted from the images. Spatially variable backgrounds (see, e.g., NGC6946) have not been removed.

#### **3.3 Observational Strategy**

Observations were carried out in accordance with the SINGS IRAC observing strategy (Kennicutt et al. 2003). For galaxies larger than the 5' size of the IRAC detectors, observations are taken in a mosaic pattern, offsetting the field of view by ~50% each time. This process is repeated twice, with observations separated by at least 24 hours to best correct for asteroids and detector artifacts. Points in the central mosaic regions are thus imaged eight times and the outermost regions four times. Galaxies fitting in a single IRAC field are imaged using two sets of four dithered observations, again resulting in points being observed eight times over the bulk of the final images. Observations are 30 seconds in duration with an additional one second exposure taken at each pointing to provide data in cases where the main observation is saturated.

### 3.4 Image Processing

The steps performed by the SINGS 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. The magnitude of these distortions is up to 2.2". These are corrected for in the SINGS IRAC pipeline using coefficient tables obtained from the GOODS team. Frames (single-exposure images) from the second set of exposures are also rotated to the orientation of the first using the header position angle difference between the first images of each observation set.

#### *b. Bias Structure*

At present there is some residual bias structure in the IRAC BCD data, particularly affecting band 3. To address this issue, IRAC band 3 frames for galaxies observed with a mosaic pattern are median combined and the result subtracted from each frame. This method is not applied to observations obtained with a dither pattern (small galaxies), as in this case the object occupies a large fraction of each frame, thus strongly affecting the median.

#### *c. Image Offsets*

Offsets between individual BCD images are determined through image cross-correlation. In this process, rough cosmic ray rejection is first carried out by comparing the short and long IRAC exposures at each pointing. Geometric distortion corrections are also applied. Any two frames with at least 10,000 pixels in common are cross-correlated with each other. Individual frame pair cross-correlation results from all four bands are combined for maximal accuracy, weighting offsets by their errors and applying outlier rejection. Within each band, a consistent solution for frame positions is then obtained through least square fitting. Accuracy for this process varies from galaxy to galaxy, but is generally in the range 0.1-0.2 pixels.

#### *d. Bias Drift*

IRAC images are at present still subject to full frame DC bias drift with time. To correct for this, the SINGS IRAC pipeline matches the median flux level in regions of overlap and determines any DC offset between overlapping frames. This offset is assumed to be due to the bias drift.  $\chi^2$  minimization is again applied to find a consistent solution for all frames and the appropriate DC offsets applied. It should therefore be noted that a small unphysical offset may be present in the SINGS IRAC images.

#### *e. Cosmic Rays*

Final cosmic ray masks are created using standard drizzle methods (see the HST Dither Handbook: [http://www.stsci.edu/instruments/wfpc2/Wfpc2\\_driz/dither\\_handbook.html](http://www.stsci.edu/instruments/wfpc2/Wfpc2_driz/dither_handbook.html)). Each image is first drizzled to correct for geometric distortion. The weight files from this step are also used to create pixel masks. Following this, the images are median combined to reject cosmic rays. These images are then 'blotted' - a step that effectively reverses the steps so far - to create images equivalent to the original input images but without cosmic rays. Finally, a spatial derivative is calculated to assess the effects of blurring in the

median image (Dither Handbook, page 60) and the original and blotted images are compared to obtain a cosmic ray mask for each image.

#### *f. Final Images*

The final step in the SINGS IRAC pipeline is to drizzle the original long exposures together, applying the geometric distortion and rotation corrections, cosmic ray masks and determined image offsets. In this process, the output pixels are scaled to 0.75 arcsec. A drop-size of 0.75 input pixels is applied. These values are chosen to yield fully sampled images with maximal resolution. A correction factor is also applied to the final images to maintain accurate photometry given the change in pixel size. Blank pixels in the final mosaic images are set to IEEE NaN (not a number).

The final drizzle step combines together the images from the two different AORs, thus removing asteroids in the process.

### **3.5 Known Problems and Image Artifacts**

In using the final images, users should be aware that at present the astrometry between bands has not been made fully consistent. As such, there may exist small offsets in object world coordinates between bands, typically less than 1 pixel (0.75"), with occasional peaks of 2 pixels.

Also, as mentioned earlier, small background level corrections have been applied to individual frames to correct for bias drift, potentially leading to an unphysical offset in the final images (i.e., slightly negative backgrounds). Users should be aware that images in this delivery are generally not background subtracted, with the exception of large, mosaiced galaxies in band 3, which have had a background component removed as part of the bias structure median correction process. The details of any background subtraction are given in the BACK\_SUB and BACKGRND header keywords.

A number of band 3 and 4 images show a persistent gradient in the background, which results in changes by (typically) up to 0.1 MJy/sr in the level between one side of the image and the other. Processing fixes are being considered for future deliveries to further alleviate BCD bias problems.

Finally, users are cautioned to be aware of standard IRAC detector artifacts that may also be present in the SINGS data. These are detailed extensively elsewhere (Hora et al. 2004, SPIE, in press; Fazio et al. 2004, ApJS 154, 10) 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. Because we combine two epochs of observations that are slightly rotated and we match the backgrounds between overlapping BCD images, some of the detector anomalies are mitigated in our final mosaics.

### **3.6 Important Note on Photometric Calibration**

The units of the SINGS IRAC mosaics are the same as the original BCDs delivered by the SSC. No aperture corrections have been applied to the final data products.

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. Corrections need to be applied for photometry at other aperture sizes or for photometry of extended sources. Correction factors are given in the Infrared Array Data Handbook, Version 2.0, section 5.5.

### 3.7 Notes on Individual Galaxies

*NGC3198*: The channel 3 image of this galaxy shows a 'saddle-shaped' background, with a negative variation of 0.1 MJy/sr at the center relative to the edges.

*NGC 5408*: Mosaics contain some very bright foreground stars. The centers of some of these have been rejected in the Band 1 image by the cosmic ray flagging routine.

### 3.8 IRAC-MIPS World Coordinate Systems Comparison

Spot checks, using ¼ of the SINGS sample, have been performed to quantify how accurately the World Coordinate Systems (WCS) of the IRAC and MIPS images coincide. Typically, the sets of images from the two instruments have WCSs that overlap within 1''-1.5'', but occasionally offsets as large as 5''-9'' have been observed. The origin of these large offsets is being investigated.

For reference, the comparisons have been performed mainly between the IRAC 8 µm images and the MIPS 24 µm images, that have PSF FWHM of ~1.9'' and 6'', respectively.

### 3.9 Changes from the Second Data Release

A number of changes have been made to the SINGS IRAC pipeline between this data release and the second data release (data versions 5 and 4, respectively). Notably:

- Where available, the pipeline now uses the RFND coordinate parameters rather than the default header values in the input BCDs headers. These coordinates have undergone initial refinement by the global minimization of offsets between overlapping frames (see the Spitzer Pointingrefine document for full details). Original header values are used where no updated coordinate information is available.
- The background matching routine has been improved for galaxies with separate fields of view or fields of view with minimal overlap. An extra background offset was added between BCDs in separate views of field before the  $\chi^2$  minimization is carried out. Second data delivery galaxies this particularly affects are NGC0337, NGC1705, NGC2798, NGC3049, NGC3773, Tol189, NGC5408, NGC7552 and NGC2841.
- Similarly, extra positional offsets have been added for large (mosaiced) galaxies

with separate fields of view, improving the final astrometric solutions for these galaxies.

- Version 5 images are delivered in north up orientation using the quoted position angle, which is now set to zero.

## 4. MIPS Data Products and Post-BCD Processing

### 4.1 Introduction

The SINGS MIPS mosaics were 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 major observation and processing steps are detailed below.

### 4.2 Data Products

The SINGS MIPS data products are single-extension FITS files, one file for each MIPS band (\*\_mips24\_crop\_v3-#.fits, \*\_mips70\_crop\_v3-#.fits, and \*\_mips160\_crop\_v3-#.fits). The images are calibrated in MJy sr<sup>-1</sup>, and have pixel size 1.5, 4.5 and 9.0 arcsec for the 24  $\mu$ m, 70  $\mu$ m, and 160  $\mu$ m mosaics, respectively. The pixel sizes of the MIPS mosaics have been chosen to adequately sample 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 background, such as cirrus, 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, as for the IRAC images, 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 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 40, 20, and 4 times at 24, 70, and 160 microns, respectively, resulting in integration times per pixel of 160 s, 80 s, and 16 s, respectively.

### 4.4 Post-BCD Image Processing

The MIPS data were processed using the MIPS DAT versions 3.02 along with additional customized processing software. The processing steps are as follows.

1. For the 70 and 160  $\mu$ m 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.
2. The initial processing of the 24  $\mu\text{m}$  data is different from the 70 and 160  $\mu\text{m}$  data, as slopes are already fit to the 24  $\mu\text{m}$  data on the spacecraft. Thus, the 24  $\mu\text{m}$  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.
  3. Telescope optical signatures and time-dependent responsivity variations in the detector elements are removed from the data, in the following way:
    - a. For the 24  $\mu\text{m}$  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  $\mu\text{m}$  data (from bright sources and bright cosmic ray hits) are masked out after the flatfielding. Any frames with severe problems (such as severe “jailbar” pattern effects or deviations in the median values above the 10% level) are also masked out (unless they include the target). 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.
    - b. The stimflash frames taken by the telescope are used for responsivity corrections of the 70 and 160  $\mu\text{m}$  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.
  4. 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  $3\sigma$  level are masked out in the rewritten frames. This step effectively filters out cosmic rays and other transient phenomena.
  5. The individual data frames are visually and statistically inspected for erroneously high or low pixel values and bad frames. Any such data that are found are set to NaN for further data processing.

6. Final mosaics are made from the individual frames. Data from both AORs are mosaicked together. After this step, backgrounds are subtracted from the data in all wavebands using the following methods:
  - a. Constant-level backgrounds in the 24  $\mu\text{m}$  data are measured in multiple small circular regions specifically chosen by eye near the optical disk to avoid bright background or foreground sources.
  - b. Constant-level backgrounds in the 70 and 160 micron images are measured in two or more regions that straddle the target. These regions cover an area at least twice as large as the galaxy. They are chosen by eye so as to match the background region under the target itself and to avoid bright sources. These background values are then subtracted from the final map. Since the short-term drift removal does subtract most of the background, this step removes only a residual offset.
7. After the mosaics are created, the images are multiplied by a final calibration factor that converts the MIPS units into MJy  $\text{sr}^{-1}$ . The factors are the following (keyword JANSSCALE in the image headers):
  - 24  $\mu\text{m}$ : 0.0439 MJy  $\text{sr}^{-1}$  MIPS\_units<sup>-1</sup>
  - 70  $\mu\text{m}$ : 634 MJy  $\text{sr}^{-1}$  MIPS\_units<sup>-1</sup>
  - 160  $\mu\text{m}$ : 42.6 MJy  $\text{sr}^{-1}$  MIPS\_units<sup>-1</sup>

The mosaics in this delivery have been cropped to sizes that 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 Known Problems and Uncertainties

##### *Special processing for NGC 7331 70 $\mu\text{m}$ data*

The NGC 7331 70  $\mu\text{m}$  data were taken before the bias voltages of the MIPS 70  $\mu\text{m}$  detector were adjusted to their current values. As a result, the raw data contain significant latent images from the stimflash that need to be removed to process the data. Because of this, the NGC 7331 70  $\mu\text{m}$  data were not processed through the software that removes the short term drift variations. The quality of the data is also worse than the quality of the other 70 $\mu\text{m}$  data in this delivery.

##### *Streaking in the 70 $\mu\text{m}$ data*

Bright sources in the 70  $\mu\text{m}$  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

undersubtracted. Work is underway to correct the negative streaking, which should also lead to a reduction of the positive streaking.

In the current delivery, the following galaxies have the most severely ‘streak-affected’ 70  $\mu\text{m}$  images: NGC 1097, NGC 1266, NGC 1377, NGC 2798, NGC 3190, NGC 3351, NGC 3521, NGC 3627, NGC 4254, NGC 4321, NGC 4536, NGC 4569, NGC 4579, NGC 4736, NGC 4826, NGC 5713, NGC 7552

#### *Background Curvature in the 24 $\mu\text{m}$ data*

In some of the 24  $\mu\text{m}$  data, not all frames that contain emission from either the target galaxies or other bright sources were excluded when determining the polynomial function that describes the zodiacal background emission along each scan leg. As a result, a residual curvature is still present in some of the maps.

In the current delivery, the following 24  $\mu\text{m}$  images contain the worst background curvature: NGC 1097, NGC 1566, NGC 2841, NGC 3351, NGC 3627, and NGC 4254.

#### *Artifacts near Bright Sources in the 24 $\mu\text{m}$ data*

In some cases, bright sources in the 24  $\mu\text{m}$  data trigger a strong “jailbar” effect and a droop effect visible as a step function in the background. Work is underway to properly correct both of these effects.

In the current delivery, the only galaxies affected by this problem (on target) are NGC 1377, NGC 2798, and NGC 7552.

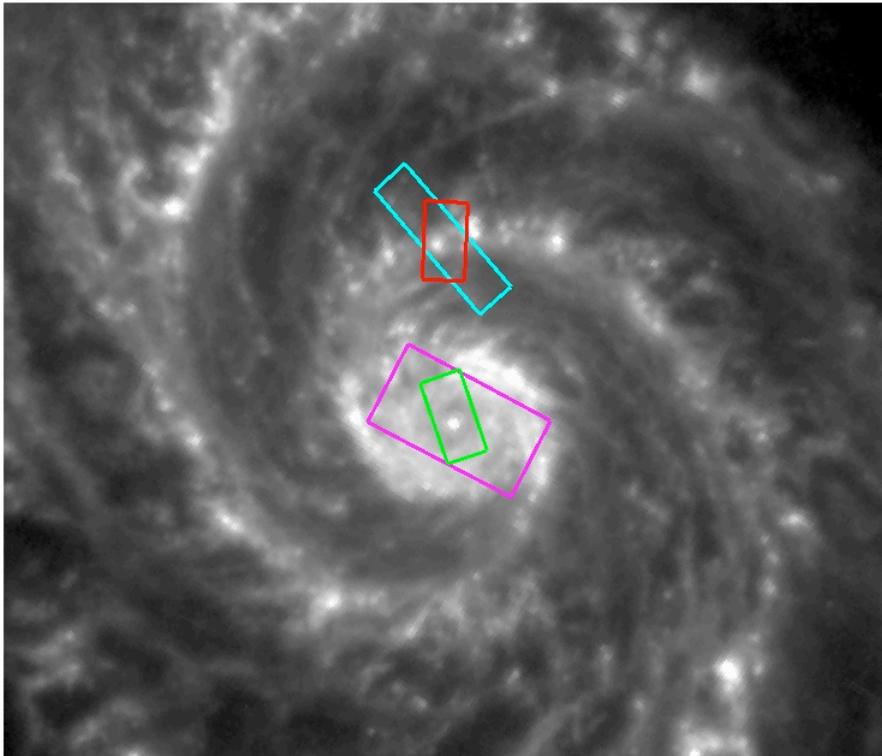
#### *Photometric Uncertainties*

Currently the estimated calibration uncertainties for MIPS extended object photometry are  $\sim 10\%$  for the 24  $\mu\text{m}$  data and  $\sim 20\%$  for the 70 and 160  $\mu\text{m}$  data.

## 5. IRS Data Products and Post-BCD Processing

### 5.1 Observations and Data Products

All SINGS IRS observations are taken in the Spectral Mapping Mode, in which the slit is moved in a raster pattern to build up a redundantly-sampled spectral map of the target region. In this third data release the most diverse set of spectral data products is provided. For 50 galaxies, six 2-dimensional maps of the nucleus (continuum-subtracted maps of [Ne III] and [Si II], complementary continuum maps at  $15\mu\text{m}$  and  $35\mu\text{m}$ , and maps of poly-cyclic aromatic hydrocarbon emission at  $7.6\mu\text{m}+8.6\mu\text{m}$  and  $11.3\mu\text{m}$ ) are delivered. One-dimensional spectra for each nuclear region in all four IRS modules are also delivered (Short-Low (SL)  $\lambda=5-15\mu\text{m}$ ; Long-Low (LL)  $\lambda=15-37\mu\text{m}$ ; Short-High (SH)  $\lambda=10-20\mu\text{m}$ ; and Long-High (LH)  $\lambda=20-37\mu\text{m}$ ), ranging in size from  $22.6''\times 14.8''$  (high resolution, SH and LH) to  $50''\times 33''$  (low resolution, SL and LL). An example illustrating these extraction regions overlaid on the  $8\mu\text{m}$  image of M51 is shown in Fig. 1.



**Figure 1:** The  $8\mu\text{m}$  image of M51, with example extraction regions for the IRS spectra in this delivery, shown with the following overlays: magenta: low resolution nuclear spectra, green: high resolution nuclear spectra, red: high resolution extra-nuclear region 00, and cyan: low resolution extra-nuclear region 00. In this particular case, the region mapped around the extra-nuclear region is not perfectly centered on the  $8\mu\text{m}$  peak because the region was optically selected and the peak of emission is offset from the mid-infrared emission.

For 25 of the 50 galaxies, a full three-dimensional spectral cube in FITS format for all the modules and orders is provided for the first time. These are indicated in Table 2. Finally, maps and spectra of 26 extra-nuclear, optically selected regions from five galaxies (HoII, NGC 0628, NGC 3031, NGC 5194, and NGC 6946) are also delivered. These comprise three 2-dimensional maps (PAH emission at 7.7+8.6  $\mu\text{m}$ , and 11.3  $\mu\text{m}$  and a continuum map from 13.06--13.43  $\mu\text{m}$ ) and a corresponding one-dimensional spectrum in the SH, LH and SL modules. An example of one such extra-nuclear region is also shown in Figure 1.

## 5.2 File Format and Naming Convention

All spectra are formatted as ASCII files in the IPAC table format. The headers give the date of each observation, corresponding to the first data collection event in the spectral map, as well as the location of the regions over which the data were extracted. Compared to the previous delivery, there are two important enhancements: a) An estimate of the uncertainties is provided with both the one-dimensional spectra and the cubes, and b) In addition to an aperture loss correction, a theoretical slit loss correction factor has been calculated and applied to the data (see details in §5.3).

*Low-Resolution Spectra* are divided by module and order, with the naming convention:

ngcXXXX\_DR3\_MD#\_nuc\_sp.tbl (nuclear spectra)  
ngcXXXX\_extranuc\_\$\$\_DR3\_MD#\_sp.tbl (extra-nuclear spectra)

where "MD" is the module (SL, LL), "#" is the order (1 or 2), and "\$\$" is the number of the extra-nuclear region ordered according to the observations date. Each file consists of a header followed by the data in three columns: wavelength (in  $\mu\text{m}$ ), and flux intensity (in MJy/sr), and uncertainty in flux intensity (MJy/sr).

For those sources listed as "Model 1D" in the second column of Table 2, estimated background spectra for SL1 and SL2 are provided, with names

ngcXXXX\_DR3\_SL#sky\_sp.tbl.

*High-Resolution* spectra are also divided by module, with the naming convention

ngcXXXX\_DR3\_MD\_nuc\_sp.tbl (nuclear spectra)  
ngcXXXX\_extranuc\_\$\$\_DR3\_MD\_sp.tbl (extra-nuclear spectra)

where "MD" is the module, either "SH" or "LH", and "\$\$" is the number of the extra-nuclear region. Each file consists of a header followed by the data in three columns: wavelength (in  $\mu\text{m}$ ), and flux intensity (in MJy/sr), and the uncertainty in the flux intensity (MJy/sr). Data from overlapping orders are interpolated and averaged in each high-resolution spectrum.

All maps are formatted as FITS files with header information describing the wavelength range of the continuum region used to construct the map. The maps are labeled

```
ngcXXXX_DR3_MD#_{neIII,siII,pah_8,pah_11_3}.fits  
ngcXXXX_extranuc_$$_DR3_MD#_{neIII,siII,pah_8,pah_11_3}.fits
```

where neIII, siII are the continuum subtracted neon and silicon line maps, the pah\_8 and pah\_11\_3 are the 7.6 $\mu\text{m}$ +8.6 $\mu\text{m}$  and 11.3 $\mu\text{m}$  maps respectively. The associated continuum maps are labeled

```
ngcXXXX_DR3_MD#_{neIII,siII}_cont.fits
```

The continuum map for the extranuclear regions is labeled:

```
ngcXXXX_extranuc_$$_DR3_MD#_cont_13.fits
```

Note that the units of [NeIII] and [SiII] line maps are  $\text{W m}^{-2} \text{sr}^{-1}$ , while all other maps and spectra have units MJy/sr. Examples of some of these products are shown in Figure 2.

The spectral cubes and uncertainty cubes are in standard 3D FITS Format, with the coordinates of the spectral dimension specified in a look-up table following the new spectral FITS standard of Greisen et al. (2005). Since this standard is new, most existing tools do not yet handle spectral coordinate axes properly. The vector specifying wavelengths for each plane of the spectral cube can be retrieved from the binary table in the first and only FITS extension.

The cubes are labeled as follows:

```
ngcXXXX_DR3_MD#_cube.fits and ngcXXXX_DR3_MD#_cube_unc.fits
```

The cubes can be viewed and manipulated using the CUBISM software. CUBISM is being developed by the SINGS team and will be released by the SSC in 2006. Until then, these data are in the standard fits format and can be examined using any number of available software packages. We have tested the ease of manipulating the cube with the DS9, and KARMA<sup>1</sup> software packages and found it to be compatible with these standard packages for spectral cube analysis. The cubes were readable in MIRIAD<sup>2</sup> but some of the data were masked incorrectly.

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<sup>1</sup> See <http://www.atnf.csiro.au/computing/software/karma/>

<sup>2</sup> See <http://bima.astro.umd.edu/miriad/>

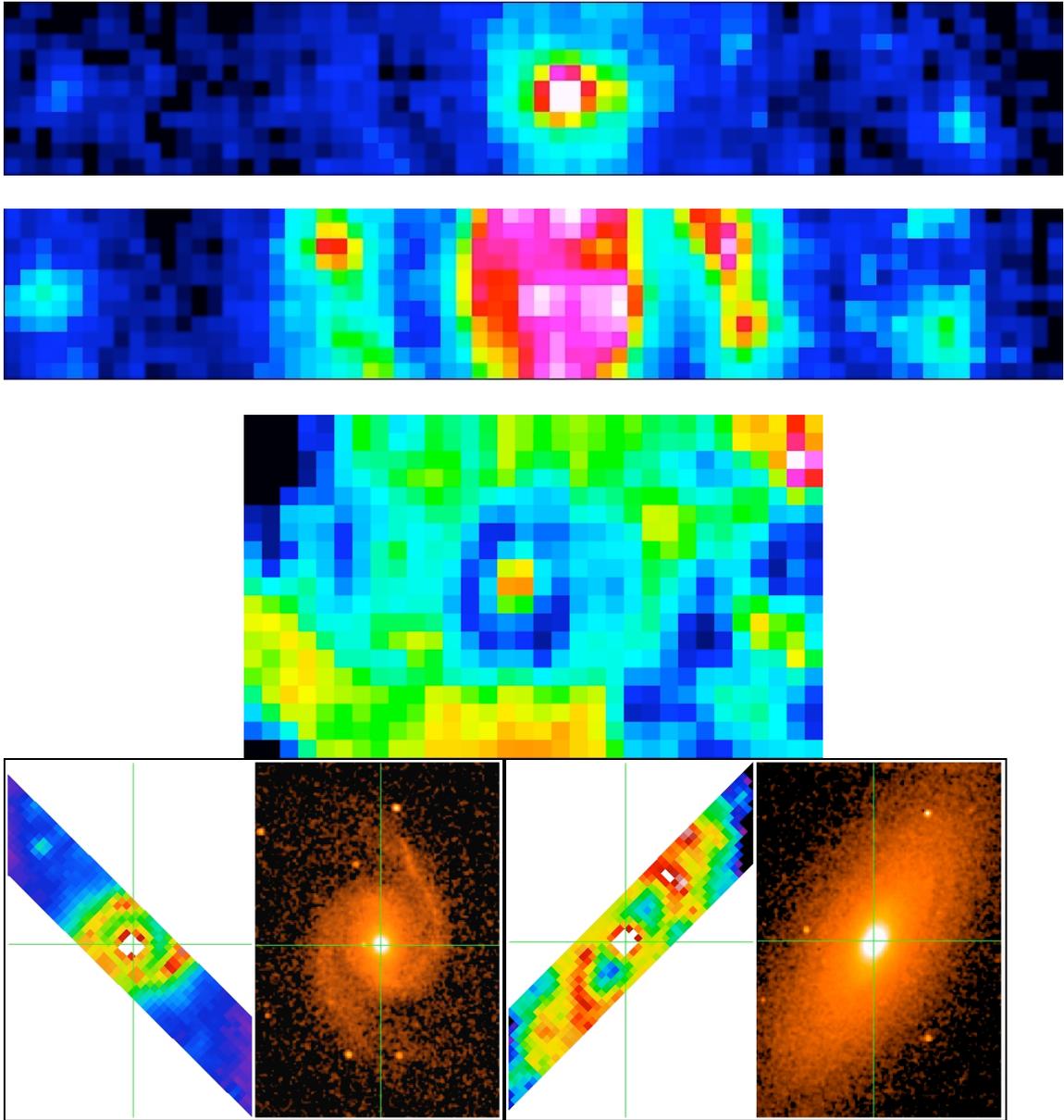


Figure 2. Top 3 panels are examples of DR3 products for NGC 5194. Top panel is the central portion of the continuum-subtracted [NeIII] emission. It is highly centrally concentrated compared to the continuum-subtracted [SiII] emission, shown in the second panel; it shows bright emission in the nucleus and the spiral arms. The third panel shows the integrated PAH emission at  $8\mu\text{m}$ . The fourth and fifth panels show a side-by-side comparison of a 2MASS K-band image and a LL1 map for NGC 1566 and NGC 2841 respectively. The IRS maps have very good astrometry, typically within  $1''$  of the 2MASS coordinates, as indicated by the cross hairs in the last two panels.

### 5.3 Data Processing & Mapping

S12 processed BCD data were used for this delivery. Below the processing and mapping for the low and high resolution products is discussed separately.

#### *Low-Resolution Products*

The low resolution spectral mapping data were assembled into three-dimensional spectral cubes using CUBISM, a tool specifically designed for this purpose (see Kennicutt et al, 2003, Sect. 6.2, for more information). Bad pixels are flagged and removed in situ in the redundantly sampled map (typically 10-50 per frame). Background subtraction and flux calibration (described in more detail below) are performed on each cube.

Maps of the nuclear regions are made by averaging the cube along the wavelength dimension over the extraction regions noted above. Line maps are made by continuum-subtracting and integrating the cube over a suitably red shifted wavelength range for the line or feature. The continuum is estimated using a weighted average of nearby continuum values, with weight that varies inversely with the wavelength offset.

A matched rectangular region of 30"×52" was used to extract the low-resolution spectra. (An exception is for NGC7331, our validation galaxy, for which a smaller SL map was obtained, yielding a smaller extraction regions of 15"×52"). Non-calibrated data at the ends of orders are trimmed in the final spectrum.

#### *High-Resolution Products*

High resolution maps were also created with CUBISM. In the LH module, the noise is dominated by time varying warm pixels which respond to light, but vary on timescales of days to weeks. This problem is also present in the LL module but is mitigated by background subtraction using the outrigger BCDs (see more below). The SH and SL modules are much less affected by these warm pixels. See the SSC page at <http://ssc.spitzer.caltech.edu/irs/roguepixels/> for a more detailed discussion of the behavior and corrections for these pixels. In all cases, the bad pixels were flagged and rejected from the cube building process. In addition, noisy areas at the red and blue ends of each spectral order have been trimmed to create the final, full SH or LH spectral cube, from which fully stitched spectra are extracted. The full low- and high-resolution apertures are not the same size, and their relative orientation depends on the exact dates of the observations because the IRS slits are not parallel in the Spitzer focal plane, and the pixel scale and spatial resolution vary with wavelength. A matched aperture for the full size of the 3×5 SH map, roughly 23"×15", was used for both high-resolution extractions.

### *Sky or Background (and Foreground) Subtraction*

The sky emission is estimated or taken directly from the maps, and subtracted from all low-resolution maps and spectra. No sky emission was removed from the high-resolution spectra; estimating equivalent widths or other continuum-sensitive measures in high-resolution spectra will require the use of an estimated background spectrum. This may become significant for point sources (either nuclear or extranuclear) with continuum flux densities of 20–30 mJy, or less, or extended sources with a integrated flux of 20–30 mJy over the SL map area. A model of the background at any date and position can be obtained from within SPOT. The background / foreground emission subtraction adopted in this delivery for the low resolution data is described below.

LL: The LL maps, assembled from long radial strips that extend 10' or more across the galaxy, contain a robust measure of the nearby zodiacal and cirrus "background" (which actually is mostly foreground emission). Typically 10-30 spectral frames were averaged together with min/max trimming for subtraction in the 2D spectral image. This process not only removes the background, but also restores many of the time-varying bad pixels to the proper scale.

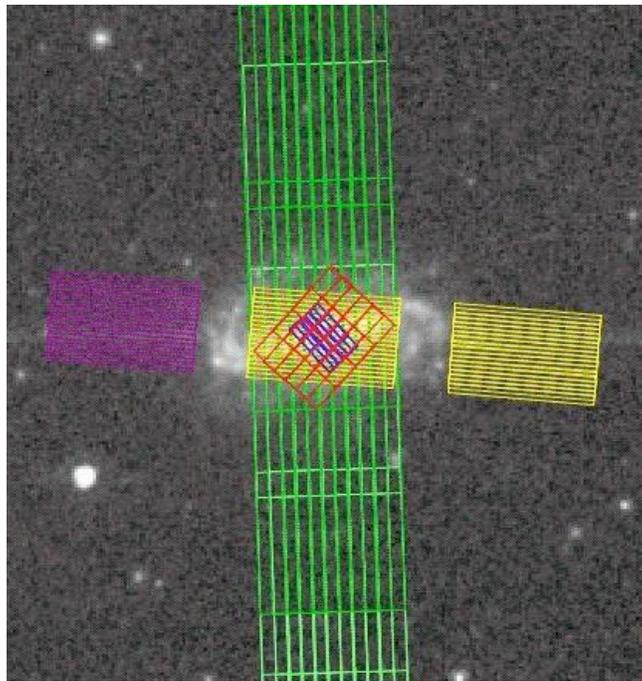


Figure 3: An overlay of the IRS observations on NGC 3049. Notice how the “outrigger” SL2 and SL1 observations serve as a short-low background for this small galaxy. The LL background is determined from the LL BCDs at the ends of the radial strip.

SL: Unlike the LL maps, the SL maps are much smaller, and the background cannot always be measured using the outermost portions of the maps. However, for small galaxies, the areas mapped by the outrigger order may be used for background subtraction. An example where an outrigger map may be used for sky estimation is NGC3049, as shown in Figure 3. This method of using SL outrigger data for sky subtraction was possible for 20 of the 50 galaxies in this release (see Table 2). For another 7 galaxies in this release dedicated off-galaxy sky observations were obtained (labeled "Dedicated" in Table 2). For the remaining 23 galaxies in this release, the approach to SL sky subtraction is outlined below.

For galaxies without outrigger or dedicated background spectra, the Spitzer archive was searched for low resolution observations of blank sky within three days of the SINGS observations at approximately the same ecliptic latitude (within 20 degrees). The flux of the background observation(s) was then scaled by linearly combining the background BCDs until the flux in the peak up array of the composite background matched the flux in the galaxy observations. This method produces a SL spectrum which approximates the sky emission for that particular location and time. This was possible in all but three cases (NGC 2841, NGC 3521, NGC 4736).

For these three galaxies where no suitable background could be found, the sky spectrum from the suite of outrigger and dedicated background data obtained for other galaxies was interpolated. The key to this scheme is the interpolating parameter. In general, the shape and amplitude of the background spectrum over SL wavelengths can be parameterized by the 24 $\mu$ m flux. The parameterization works well using the 24 $\mu$ m background flux from either MIPS imaging or the predictions from the background models. In all three cases, predictions from the background models were used. Note that for these three galaxies, the SL products delivered here are the same as those previously delivered in the second delivery.

In practice, polynomials are fit to each 1D sky spectrum. To generate a 1D background estimate spectrum for galaxies without outrigger and dedicated sky observations, an interpolation amongst the suite of polynomial fits is adopted using the 24 $\mu$ m flux as the interpolating value. In general this method serves well to remove the overall background level with wavelength but does not remove residual spectral or spatial features in the data as a real background subtraction would otherwise.

### *Flux Calibration*

The flux calibration in the SSC pipeline is optimized for point sources. For these, the extraction aperture is a wavelength-matched expanding aperture chosen to minimize jumps between orders and modules induced by varying fractions of the point spread function. The extracted spectra are trimmed at the ends of orders and fit to a stellar models using a low-order polynomial. For extended sources, however, an expanding aperture is inappropriate since the emission fills the slit<sup>3</sup>. Moreover, the implicit correction for out-of-slit light losses as a function of wavelength, that are applied as a part of the calibration for a point source, need to be *removed* for an extended source. The former correction is referred to as an aperture loss correction function (ALCF) and the latter is referred to as a slit loss correction function (SLCF). We employ an ALCF by deriving a new flux calibration for well-modeled standard stars using a large 28-pixel (non-expanding) extraction aperture. The SLCF for all modules is estimated using a theoretical model of the slit width and instrumental PSF derived from STinyTim.

The SLCF is an exact correction only for perfectly uniform (spatially and spectrally) extended sources. Though SINGS sources span a full range of structures, the same uniform slit loss correction is applied to all sources. To estimate the unknown effective pixel solid angles (which relate to the integral across the slit of the beam profile), matched photometry using SINGS MIPS and IRAC maps was employed. We compared the imaging and spectral photometry at 5.7 $\mu\text{m}$  (SL2 vs. IRAC3), 8 $\mu\text{m}$  (SL1+SL2 vs. IRAC4), and 24 $\mu\text{m}$  (LL1 vs. MIPS24). The imaging filter transmission curves were applied to the extracted IRS spectra and the simulated broad band fluxes were compared to the observed fluxes from the IRAC and MIPS images over the same region in all the galaxies; the results of these comparisons were used to derive the effective cube pixel solid angle. The IRAC fluxes, especially in channels 3 and 4 are uncertain for extended sources. Although current understanding of this problem suggests a downward correction on the order of  $\sim 20\text{-}30\%$ , the exact dependence of the correction on the extraction aperture and source color, etc. is not well known. Therefore the SL data were not scaled to match the IRAC photometric points.

For LL, the photometric comparison with MIPS yields a good match between the pixel solid angle and the empirically measured slit width. To estimate the true SL effective pixel solid angle, we used the overlap with LL at 15 $\mu\text{m}$ . The comparison suggests an effective pixel solid angle that is smaller than the empirically measured slit width. This correction is consistent with the unknown but downward correction expected for the extended source IRAC calibration. It is also possible that the Slit Loss Correction Factor is incorrect because our sources are extended with unknown a priori spatial and spectral structure.

Since we have not attempted to remove the background from the high-resolution spectra, they have in general a much higher continuum fluxes than the corresponding low-resolution spectra extracted nearby. Users are urged to estimate the background using the Reach et al. (2003) models available in Spot if they wish to estimate accurate equivalent widths for emission or absorption features.

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<sup>3</sup> See <http://ssc.spitzer.caltech.edu/ost/workshop/2005data2/talks/ksheth.pdf>

### *Effective Integration Times*

All spectra delivered are the composite of multiple exposures. For the high resolution data, 30 (15) individual DCE's totaling 15.73 min (15.24 min) of integration time were combined to produce a single SH (LH) nuclear spectrum. For SL spectra, the full maps required only 8.8 min (4.4 min each for SL1 and SL2), and the majority of the on order data were averaged together to produce the spectrum. The much larger LL strip maps ranged from 20.97 min to 41.95 min total integration time. The effective integration times per pixel were 58.7 sec in SL, and 125.84 sec in LL.

For a given peak source flux, the signal-to-noise in the resulting spectra depends critically on the spatial distribution of the source. For galaxies with significant extended emission in the extraction regions (e.g. NGC5194), the relative S/N achieved is much higher than for galaxies whose mid-infrared flux is concentrated in the nucleus (e.g. NGC5408). In many cases, higher S/N spectra could be achieved by extracting over smaller regions. However, for consistency among our data products all regions were chosen to be the same size.

### **5.4 An Estimate of the Uncertainties**

Starting with version S12, the SSC pipeline delivers uncertainties in the measurement of the spectra. The uncertainties consist of ramp slope estimation uncertainties that are then propagated during the spectral extractions from individual BCDs. These uncertainties are typically 0.1% at 5 Jy; 0.5--1% at 500 mJy; and 10% at 20 mJy (at low resolution). At high resolution, they are about 1% at 10 Jy. These uncertainties have been incorporated into CUBISM and propagated through the cube building process. Note that the estimates of the uncertainty do not include uncertainties from other sources such as flat-fielding and flux-calibration. As we note below, systematic uncertainties are on the order of 15-20% but the magnitude of the systematic uncertainty can vary as function of wavelength, module and order.

Details of the estimation of uncertainties are described in a presentation at this URL: <http://ssc.spitzer.caltech.edu/ost/workshop/2005data2/talks/pappleton.pdf>.

### **5.5 Data Artifacts and Known Problems**

#### *Spectral Mismatch and Astrometric Uncertainty*

The 4 segments of the low-resolution spectra (SL2, SL1, LL2, LL1, in order of increasing

wavelength) are derived from separate spectral cubes with individual astrometric solutions. Astrometric errors typically of order 1.5" can contribute to a mismatch between SL and LL, and, to a lesser degree, to mismatch between orders in the same spectral module (SL1 and SL2, LL1 and LL2). Also contributing to the mismatch is the unknown aperture correction that is made by applying the SLCF which assumes a smooth source brightness distribution.

#### *Extended Source Flux Calibration*

All the spectra have been treated with an aperture loss correction factor, and an approximate slit loss correction factor; the residual systematic uncertainty in these spectra is 15%. Note that the high resolution data do not need an extraction aperture correction because the point source calibration at the SSC is derived by integrating over the full slit. There is uncertainty in the exact correction for extended sources. We mitigate this problem somewhat by scaling the spectra to match the broadband photometric point from MIPS but the correction is only approximate because the source brightness distribution is not known a priori. Users are encouraged to keep in mind these corrections especially when estimating line flux ratios, especially for lines in different modules. Users are also reminded that the SH and LH data do not have a background subtracted from them.

#### *Residual Time-Varying Pixels*

Responsive, yet time-varying warm pixels are present in all IRS arrays, but they are most problematic for Long-high and Long-low - the two Si:Sb arrays. In particular, Long-High spectra are most affected, since there are many more of these time-varying pixels, and the echelle orders cover a large fraction of the array. For further details about this effect see the discussion on this webpage: <http://ssc.spitzer.caltech.edu/irs/roguepixels/>. These pixels appear as "spikes" in the final, extracted one-dimensional spectra. While subtraction of campaign-based darks reduces the effect to some degree, much of the SINGS data were taken early in the mission before the problem was fully diagnosed, and before the frequency of dark measurements was increased. We have made a careful attempt to remove residual warm pixels from the two-dimensional BCDs before spectral extraction, but observers are strongly encouraged to inspect the BCDs if spurious features (sharper than a single resolution element) are present in their spectra.

#### *Wavelength Calibration Errors*

At present the average wavelength uncertainties are less than 0.07 $\mu\text{m}$  in the low resolution data, and less than 0.01 $\mu\text{m}$  in the high resolution data<sup>4</sup>. However there are a few remaining wavelength offsets in the S12 data. In SH, the largest offset is 0.3 pixels in order 20. In LH, orders 15,16, 19 and 20 are too red by 0.01, 0.04, 0.02 and 0.03  $\mu\text{m}$  respectively. There is also an offset of 0.5 pixels in LH order 11 in the S12 pipeline data. We have corrected for this offset in this delivery of SINGS products, although it will be present in S12 IRS data that has not been assembled with CUBISM. These and other minor errors will be mitigated in the pipeline processed data for S13.

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<sup>4</sup> See the presentation by D. Shupe for the Spitzer Data Analysis workshop at this URL: <http://ssc.spitzer.caltech.edu/ost/workshops/2005data/talks/shupe1.pdf>

### *Use of the Emission Line Maps*

The emission line maps are most useful for assessing the spatial distribution of the line of interest. Accurate line fluxes should be obtained by measuring the line(s) from extracted 1D spectra of the region(s) of interest. Significant uncertainties of order 30% (for a signal to noise ratio greater than 10, and substantially higher for lower signal to noise ratios) are expected for line intensities measured directly from the 2D maps; Users are strongly encouraged to measure line fluxes from the three-dimensional cubes instead of the 2D maps.

## **5.6 Notes on Individual Galaxies**

*HolmbergII*: No SL, SH or LH data. For the Long-Low spectrum, a square extraction aperture has been employed. The infrared emission peaks 40'' from the center of the LL strip.

*Tol89*: Brightest infrared source is located at the edge of the IRS maps, and is only barely visible in the LL, SL, and LH strips.

*NGC 5408*: The infrared emission peaks 20'' from the center of the IRS strips. The peak is absent from the SH and SL strips, and only a portion of it is present in the LH strip. A source external to NGC5408 appears in one of the SL outtrigger fields.

*NGC 3184* – There is a problem with the SL2 data for this galaxy when extracted over a large aperture. It has a steep, and rather unphysical slope that may be related to an improper estimation of the background. The problem is decreased if the aperture of extraction is reduced to the brighter part of the emission. Users are cautioned against using the SL2 data as provided while the issue is being investigated.

*NGC 6822* – No SL, SH or LH data

**Table 2**

Galaxy (a)	Type of background (b)	Galaxy (a)	Type of background (b)
NGC 3773†	Outrigger	NGC 0584†	Outrigger
NGC 3190†	Outrigger	NGC 1266†	Outrigger & Dedicated
NGC 2798†	Outrigger	NGC 1377†	Outrigger
NGC 4736	Model 1-D	NGC 1404	Outrigger
NGC 4826†	Outrigger	NGC 3265	Outrigger
NGC 4725†	Archive	NGC 4125	Outrigger
NGC 3049†	Outrigger	NGC 4552	Outrigger
NGC 2841	Model 1-D	NGC 5866	Outrigger
NGC 7331†	Dedicated	NGC 4569	Archive
NGC 3627†	Archive	NGC 1097	Archive
NGC 4579†	Dedicated	NGC 4321	Archive
NGC 3351†	Dedicated	NGC 4536	Outrigger
NGC 1566†	Dedicated	NGC 5713	Outrigger
NGC 3521	Model 1-D	NGC 0628	Dedicated
NGC 5194†	Archive	NGC 3184	Archive* (c)
NGC 2976†	Archive	NGC 4254	Archive
NGC 3938†	Archival	NGC 2915	Outrigger
NGC 7552†	Outrigger	HoIX	Outrigger
NGC 3198†	Archive	DDO 053	Outrigger
NGC 7793†	Dedicated	DDO 165	Outrigger
NGC 0337†	Outrigger	Mrk 33	Outrigger
Tol 89†	Outrigger	IC 4710	Outrigger
Ho II†	No SL data	NGC 6822	No SL data
NGC 1705†	Outrigger		
NGC 5408†	Outrigger		

- (a) Galaxies with IRS data in this delivery of SINGS products, arranged according to Hubble type. † indicates galaxies for which we are delivering the full three dimensional cubes.
- (b) Different types of backgrounds as indicated in the text. Dedicated means sky observations obtained immediately following the mapping, Outrigger indicates sky background estimated from outer parts of a SL or LL map, Archive means that the background was estimated from nearest in time archive spectra, Model-1D indicates an approximation to the background based on models and the observed 24 $\mu$ m flux.
- (c) Use SL data for NGC 3184 with care. See note above.

## 6. Ancillary Data

### 6.1 Optical Imaging

#### *Observations*

Optical images for the galaxies in the SINGS sample were obtained at NOAO, as part of the Legacy Project, over the course of about 3 years (2001-2003). Observations were carried out at both the KPNO 2.1-m and the CTIO 1.5-m telescopes, using standard broad band B, V, R, and I filters, and a set of narrow-band filters in correspondence of the redshifted H $\alpha$  line emission (0.6563  $\mu$ m). For the 50 galaxies in the present delivery, the characteristics of the narrow-band filters (from the NOAO Web pages) are as follows:

Filter Name	Central Wavelength	FWHM	Peak Transmission
KP1468 (KPNO)	6567 A	84 A	72 %
KP1563 (KPNO)	6573 A	67 A	83 %
KP1390 (KPNO)	6587 A	72 A	67 %
KP1564 (KPNO)	6618 A	74 A	79 %
CT6568 (CTIO)	6568 A	19 A	70 %
CT6586 (CTIO)	6583 A	20 A	71 %
CT6602 (CTIO)	6596 A	18 A	70 %

The 2Kx2K CCDs used for the observations have field-of-view (FOV) of 10' and 14.5', and pixel scale 0."305 and 0."433, at the KPNO-2.1-m and at the CTIO-1.5-m telescopes, respectively. Galaxies more extended than the CCD FOVs were imaged at multiple, overlapping pointings.

Exposure times ranged from 240 seconds to 1400 seconds (typically split into 2 separate exposures for cosmic ray removal.), in order to reach uniform depth of about 25 mag/arcsec<sup>2</sup> with signal-to-noise ratio of  $\sim 10$  in the broad-band filters. Exposure times in the narrow-band filters were typically 1800 seconds, split into two separate exposures. In a minority of cases, a single narrow-band exposure was available.

#### *Data Processing*

Data reduction consisted of bias subtraction (using also the overscan region in the case of the KPNO images), flat-fielding (with both dome- and twilight-flats), single-image cosmic ray removal, and combination of pairs (or multiple) images at the same pointing/filter.

The southern 3' of the CCD FOV at the KPNO-2.1-m suffers from pronounced **vignetting**, whose intensity is pointing-dependent. We developed a routine to remove as much as possible of the vignetting effect from each frame. The corrected frames were

then used to create the final mosaics. See the section on 'Known Problems' below for a quantification of the effectiveness of the vignetting-removal routine.

Astrometric solutions were derived for all optical images/mosaics, and the appropriate WCS keywords (FITS standard) stored in the image headers. All delivered optical images/mosaics have been rotated to the standard NE orientation.

Photometric and spectrophotometric standard stars were observed during each observing run to flux calibrate the images/mosaics. The spectrophotometric stars (e.g., Feige 34, HZ44) were used to obtain flux calibrations for the narrow-band filters. Effects of vignetting were negligible on the standard star frames, as the stars were usually centered on the CCD FOV, thus avoiding the vignetted edge.

### ***Data Characteristics***

All delivered optical images are in units of counts-per-seconds (CPS, stored in the UNITS keyword). The flux conversion keyword is PHOTFLAM, with units of Jy\*sec/DN/pixel, as given by the keyword ZUNITS. Zeropoints are stored in the keyword ZPOINT (in Jy).

The images in this delivery are **not** background-subtracted. The narrow-band images (\*\_H $\alpha$ .fits) generally contain emission from H $\alpha$ , as well as the [NII]( $\lambda\lambda$  6548,6584), along with underlying stellar continuum. **Stellar continuum-subtracted narrow-band** images are also provided as \*\_H $\alpha$ \_sub.fits for most of the galaxies (this is the only optical image delivered for NGC5408, together with its rescaled continuum). Users can also construct their own pure emission-line images by scaling and subtracting the R-band images from the narrow-band images.

Most images have photometric accuracy within 5% (broad band) or 10% (narrow band). Care was taken to re-observe in photometric conditions any galaxy that had been previously acquired in non-photometric conditions. When this could not be accomplished (or there were larger-than-usual uncertainties in the standard stars calibrations) a COMMENT keyword was added to the image header. When more than one comment line is present, suffixes (COMMENT1, COMMENT2, etc.) are used.

In addition to astrometric and photometric keywords, the image headers contain other useful keywords detailing the observations (e.g., telescope, camera, filters, exposure times, etc.).

### ***Conversion from count-rates to fluxes/magnitudes***

Conversions from count-rates (CPS) to standard (Vega) magnitude scales for the optical images are accomplished with the following formula:

$$m = -2.5 * [\log(\text{CPS} * \text{PHOTFLAM}) - \log(\text{ZPOINT})]$$

To convert continuum-subtracted narrow-band images from CPS to more familiar units for emission lines, e.g., erg s<sup>-1</sup> cm<sup>-2</sup>:

$$F(\text{erg s}^{-1} \text{ cm}^{-2}) = 3\text{E-}5 * \text{CPS} * \text{PHOTFLAM} * \text{FWHM} / \text{CW}^2$$

where FWHM and CW are the full-width half maximum and the central wavelength of the narrow-band filter, respectively. If the emission line(s) are shifted from the center of the filter's bandwidth, additional corrections for the filter's transmission curve need to be included in the above formula.

### ***Known Problems***

Comparison of the fluxes of stars in common between adjacent, overlapping pointings indicate that the vignetting-correction routine usually brings stellar fluxes into agreement within 2%-3%, but deviations as large as 5%-10% are not uncommon. Such residuals are often visible as 'seams' at the overlapping points of adjacent frames.

### ***Notes on individual galaxies:***

*DDO053 and HoIX*: no H $\alpha$  images available for these galaxies.

*NGC2798*: residual fixed pattern noise present in all images. This is present in both unreduced and reduced images, and in the dark and bias frames as well.

*NGC2915*: no B and H $\alpha$  images available.

*NGC2976 and NGC3049*: residual fixed pattern noise is present in the narrow-band images.

*NGC3198*: Marginal seeing conditions (broad PSF).

*NGC3351 and NGC3521*: BVI images for these galaxies are from the KPNO-4m plus MOSAIC Imager. The pixel scale is 0.27 arcsec/pixel. For NGC3351, no continuum-subtracted narrow-band image is delivered. The V-band image of NGC3521 shows a high-noise banding across the target.

*NGC3627*: KP1564 was used as H $\alpha$  filter; in the filter's bandpass, H $\alpha$  is at ~30% level in the transmission curve, while [NII](6584 A) is at 70%.

*NGC3773*: Fixed pattern noise is present in the I and narrow band images.

*NGC4569*: No optical images for this galaxy.

*NGC4725*: Only the NE frame is available for the B band.

*NGC4736*: KP1564 was used as H $\alpha$  filter; however, its bandpass does not contain the H $\alpha$  emission from the galaxy, and only the [NII](6584 A) emission was observed. The narrow band image for NGC4736 is delivered as `ngc4736_NII.fits` and `ngc4736_NII_sub.fits`.

*NGC4826*: Optical images are from the SONG collaboration. The pixel scale is approximately 0.777 arcsec/pixel. The H $\alpha$  image is already continuum-subtracted (information stored in the image header as COMMENT\* keyword). A few bad columns (190-195) have been interpolated across, for the B, V, R, and I images. No calibration scales could be obtained for the R and I bands. No zeropoints available.

*NGC5194*: In addition to the nominal mosaics, a set of short-exposure mosaics are delivered for the V, R, and I bands, to aid treatment of the saturated nucleus of the galaxy. Residual vignetting is particularly noticeable in the R and I-band images of this galaxy, along the EW seam between the two overlapping pointings, and especially at the western side of the seam. In this latter region, the effect of the residual vignetting translates into an 8% variation in the surface brightness of the galaxy across the seam, at a position located 174 arcsec west of the nucleus. The surface brightness at this location is about 360 times fainter than the nuclear one. The effects of residual vignetting become worse westward of this point, and quickly decrease in magnitude eastward of this point.

## 6.2 Optical Spectroscopy

### *Observations*

Optical spectra for the SINGS galaxies in the wavelength range 0.36-0.70  $\mu\text{m}$ , with resolution  $\sim 8$  Angstrom, were obtained at the 2.3-meter Bok telescope with the B&C spectrograph, and at the 1.5-meter CTIO telescope with CSPEC.

Three types of long-slit spectra were obtained:

- Nuclear spectra: a 2".5 wide aperture (3" at CTIO) was pointed at the brightest central spot of the galaxy;
- 20" drift scans: the slit was drifted for 20" around the central region, while exposing;
- 55" drift scans: similar to the 20" drift scans, with a scan length of 55".

The data were taken during clear, photometric or semi-photometric conditions. A minimum of two sequential exposures were taken to facilitate cosmic-ray rejection. The total exposure times ranged from 600 seconds for the nuclear pointings to 900-2400 seconds for the 20" and 55" drift-scanned spectra. In the drift-scanned spectra the *effective* exposure time,  $t_{\text{effective}}$ , spent on a single spatial position of the galaxy is given by:

$$t_{\text{effective}} = t_{\text{exposure}} * (\text{Aperture} / \Delta),$$

where  $t_{\text{exposure}}$  is the actual exposure time,  $\Delta$  is the length of the scan in arcseconds (here, 20" or 55"), and Aperture is the slit width in arcseconds (here, 2.5" or 3"; see Kennicutt 1992, ApJS, 79, 255, and Moustakas & Kennicutt 2005, ApJS, submitted, for details).

### *Data Processing*

The two-dimensional spectra were reduced with iSPEC2d, a customized longslit data reduction package developed in IDL by John Moustakas (UofA). The data were overscan- and bias-subtracted, trimmed, flat-fielded, and corrected for a low-order illumination pattern. The two-dimensional sky spectrum was subtracted from each image before rebinning using the technique described in Kelson (2003, PASP, 115, 688).

Sequential exposures were combined to reject cosmic rays; residual cosmic rays and hot pixels were flagged using LA\_COSMIC (van Dokkum 2001, PASP, 113, 1420) and interpolated. The data were then wavelength- and flux-calibrated. Although standard stars were taken through good sky and seeing conditions, absolute spectrophotometric accuracy is not guaranteed, especially for the 2.5 arcsec nuclear spectra where slit losses from seeing may be significant. The relative spectrophotometric accuracy ranges from 1-4% based on the relative scatter in the derived sensitivity function. Two-dimensional error maps are generated using the known noise properties of the CCD and assuming Poisson statistics. These error maps are processed identically to the data.

One-dimensional data, error, and sky spectra were extracted in a 2.5" aperture for the nuclear spectra and a 20" aperture for the drift-scanned spectra using a low-order trace. A small wavelength shift was applied to the final wavelength solution by centroiding on the [O I] 5577 night sky line. The spectra have been de-reddened for foreground Galactic extinction assuming the O'Donnell (1994, ApJ, 422, 158) extinction curve and using the Schlegel, Finkbeiner, & Davis (1998, ApJ, 500, 525) reddening maps. The 20" drift-scan spectra accompany the equivalent-size extraction 1D IRS spectra.

### ***Data Characteristics***

The data are stored as ASCII files with the following columns:

1 – wavelength	[Angstrom]
2 – sky-subtracted data spectrum	[erg s <sup>-1</sup> cm <sup>-2</sup> A <sup>-1</sup> ]
3 - error spectrum	[erg s <sup>-1</sup> cm <sup>-2</sup> A <sup>-1</sup> ]
4 - sky spectrum	[erg s <sup>-1</sup> cm <sup>-2</sup> A <sup>-1</sup> ]

At the beginning of each file, basic information on the slit center is also reported.

The file names indicate the type of spectrum ("drift" or "nuclear"), the drift scan length, and the extraction aperture in arcseconds. For example, in "ngc0337\_drift\_020\_020.txt", the first "020" is the scan-length while the second "020" is the aperture width. In "ngc0337\_nuclear\_002.5.txt" only one number appears indicating the extraction aperture.

### ***Notes on individual galaxies:***

*Ngc0337*: Ill-defined nucleus, the tracing (placement of the extraction aperture's center) along the wavelength direction was not optimal.

*DDO053, HolmbergIX, IC2574, DDO165, NGC2976 and Tol89*: only the central 20"x20" drift-scan spectrum is available.

*NGC5713*: only the nuclear spectrum is available.

*DDO154, HombergII, IC4710, NGC5408, NGC6822, and NGC7552*: No spectra available for these galaxies.

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