Infrared Spectrograph
Data Handbook
Version 2.0

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Chapter 1

Introduction

The purpose of this document is to provide a short, yet comprehensive, guide to data from the Infrared Spectrograph (IRS) onboard the Spitzer Space Telescope. This handbook focuses on basic information for each data product, enabling the novice observer to get started quickly. It also provides comprehensive tables for all archive data products for ease of reference. Further information can be found in the documents listed at the end of this chapter.

The first chapter following this introduction gives an overview of the IRS data products and their respective processing stage. The data files include extensive headers whose most relevant keywords are explained in chapter 3. In chapter 4, we provide a brief description of the automatic pipeline processing of the raw data (up to the stage of fully calibrated spectra), how the photometric and wavelength calibration was derived, and the way in which the measurement errors are calculated in the pipeline. Following this there is a chapter on issues of which the observer must be aware to avoid misinterpreting the data, and a chapter on the content of the mask files which accompany the data to flag pixel status. Finally, there is a short description on how to take the data further, to make them suitable for publication.

Other documents of interest for the IRS data user are:

- Houck, J. R., et al. 2004, ApJS, 154, 18, "The Infrared Spectrograph on the Spitzer Space Telescope"
- Decin, L., et al. 2004, ApJS, 154, 408, "MARCS: Model Stellar Atmospheres and Their Application to the Photometric Calibration of the Spitzer Space Telescope Infrared Spectrograph (IRS)"

- *Spitzer Observer's Manual* (SOM)[1]
- *Spitzer Observation Planning Cookbook*[2]
- *Infrared Spectrograph Pipeline Handbook*[3]
- Post-BCD software and documentation for IRS, such as IRSCLEAN_MASK and SPICE[4]

The web page

`http://ssc.spitzer.caltech.edu/irs/`

gives up-to-date information on the instrument.

[1]See `http://ssc.spitzer.caltech.edu/documents/som/`.
[2]See `http://ssc.spitzer.caltech.edu/documents/cookbook/`.
[3]See `http://ssc.spitzer.caltech.edu/irs/documents/`.
[4]See `http://ssc.spitzer.caltech.edu/postbcd/`.

Chapter 2

Data Products

The basic unit of data is an IRS Data Collection Event (DCE): an observation bracketed by two detector resets. Each DCE has a number of different data products associated with it. These include bad pixel masks, files with different levels of processing, etc. In addition, there are associated calibration files, coadded data products, and more, the number of which varies with the type of Astronomical Observation Request (AOR).

In all, there are four classes of data products that can be downloaded from the archive: Raw Data, Basic Calibrated Data (BCD), Post BCD products (PBCD), and Calibration Data. The mechanics of downloading these products from the Spitzer Archive are explained in the Leopard manual (see ssc.spitzer.caltech.edu/documents/leopard/). The data will arrive from the archive as one or more zipped files. Upon unzipping, the user will end up with a directory tree, the top level of which will have the reqkey number, prefixed by an 'r'. The reqkey uniquely identifies a single AOR within the archive. Within this directory, there will be one subdirectory for each module observed in the AOR. Within each module subdirectory there may be `bcd`, `pbcd`, `cal`, and/or `raw` subdirectories, depending on what was selected for download.

2.1 Where to Begin

Incoming data from the spacecraft is automatically processed by a pipeline which can be conceptually divided in two parts: the Basic Calibrated Data (BCD) pipeline and the Extraction (or Post-BCD) pipeline. The former is mostly in charge of low-level processing (ramp fitting, dark subtraction, etc) while the latter performs spectrum extraction (for spectral data) or mosaics the data (for Peak-Up Imaging data). For the spectroscopic data, the steps of the Post-BCD pipeline can be replicated using the Spitzer IRS Custom Extraction (SPICE) software. For imaging data, the Post-BCD pipeline can be replicated using the MOsaicking and Point source Extraction (MOPEX) software. Both are available from the SSC website.

A master list of the archive products in the `raw`, `bcd`, `pbcd` directories is presented in Tables 2.1, 2.2, 6.1, and 6.2. The contents of the `cal` directory are provided in Tables 2.3 and 2.4. Not all these products will be available for a given AOR. The number of files generated for each AOR depends on the observing mode and observer inputs (see the SOM). For example, an observer might request two cycles in Staring Mode using the Short-Low (SL) module. In this case, the AOR would include two DCEs at each of two nod positions, for a total of four DCEs. The two cycles at each nod position are also coadded (averaged, see Figure 2.4) and extracted. In each subdirectory there will also be automatically generated README files with basic information about the target and the program.

Within each subdirectory, the files are delivered with the following naming convention:

`SPITZER_S+module_aorkey_expid_dcenum_version_type.suffix`,

where

- `S+module` = S0, S1, S2, or S3 corresponds to short-low (SL), short-high (SH), long-low (LL), or long-high (LH), respectively. S0 also corresponds to peak-up data

- `aorkey` = Unique ID number for each AOR.

- `expid` = Exposure ID number. This denotes a distinct array exposure command, corresponding to offset position in mapping mode and nod position in staring mode.

- `dcenum` = Observation cycle number.

- `version` = A counter that is incremented each time a data set is reprocessed, starting at 1 for the first processing.

For example, one might find the following file in the archive:

SPITZER_S0_3553792_0007_0000_1_bcd.fits,

which corresponds to the first processing of exposure 7 of the first cycle of an IRS SL or Peak-Up observation with AOR ID number 3553792.

"Coadded observations" are generated by averaging over several DCEs. The parameters `aorkey`, `expid`, and `version` are still used to identify the observation. However, `dcenum` is not used; instead, an additional "ensemble number" ("E" for ensemble product, or "A" for ancillary ensemble product, followed by the ensemble product ID) is inserted. The identifiers of the files that were used in the coadding can be found in the file `inlist.txt`. An example of this kind of file is:

SPITZER_S0_3553792_7_1_E173398_coa2d.fits.

Because the calibration files used to produce the data products are the same for many different AORs they appear without any reference to AOR, cycle number, etc.

The relationship between all those files is summarized in Figures 2.1 and 2.2 (see also §4). For a first look at the data, begin with the `bcd.fits` and `spect.tbl` files, within the `bcd` directory. These are the pipeline final products: the fully-reduced 2D images and the extracted spectra, respectively. Figures 2.3 and 2.4 show examples of `bcd.fits` images obtained in-orbit by Spitzer. Also, look at the `b*_wavsamp_wave.fits` file in the `cal` directory, which gives the wavelength associated with each pixel and may be useful in understanding the `bcd.fits` files. The `bmask.fits` files contain bit-flags that identify pixel status in the `bcd.fits` images (see §9). The `func.fits` files contain the uncertainties associated with ramp-fitting (See §7).

2.1.1 Spectroscopic 2D and 3D Products Units

- `raw.fits`: DN.
- `lnz.fits`, `lnzu.fits` : e^-.
- All other: e^-/sec.

Table 2.1: Files Delivered

Raw Data Products (N = number of samples per ramp)			
type.suffix	*Format*	*Data Type*	*File Size (kb)*
raw.fits*	$128 \times 128 \times n$	16-bit integer	≤ 600
Basic-Calibrated Data (BCD) (n = number of samples per ramp)			
type.suffix	*Format*	*Data Type*	*File Size (kb)*
bcd.fits*	128×128	32-bit real	≤ 87
bmask.fits*	128×128	16-bit integer	37
dmask.fits*	$128 \times 128 \times N$	16-bit integer	≤ 520
droop.fits*	128×128	32-bit real	98
drunc.fits*	128×128	32-bit real	67
f2ap.fits*	128×128	32-bit real	98
f2unc.fits*	128×128	32-bit real	67
func.fits*	128×128	32-bit real	67
lnz.fits*	$128 \times 128 \times N$	32-bit real	≤ 1000
lnzu.fits*	$128 \times 128 \times N$	32-bit real	≤ 1000
rsc.fits*	128×128	32-bit real	98
rscu.fits*	128×128	32-bit real	67
spect.tbl*	-	ASCII table	≤ 132
spec2.tbl*	-	ASCII table	≤ 132
Post-BCD Products			
type.suffix		*Data Type*	*File Size (kb)*
2dcoad.txt	-	ASCII table	< 1
bksub.fits	128×128	32-bit real	≤ 90
bkmsk.fits	128×128	16-bit integer	≤ 37
bkunc.fits	128×128	32-bit real	≤ 67
bksub.tbl	-	ASCII table	≤ 30
c2msk.fits	128×128	16-bit integer	37
c2unc.fits	128×128	32-bit real	67
coa2d.fits	128×128	32-bit real	≤ 90
ibsmk.txt	-	ASCII table	< 1
inlst.txt	-	ASCII table	< 1
out.pline	-	ASCII table	≤ 27
ridge.tbl	-	ASCII table	≤ 57
tune.tbl	-	ASCII table	≤ 134
xout.pline	-	ASCII table	≤ 15

* = Files produced for every spectral DCE.

Table 2.2: File Description

type.suffix	*Description*
raw.fits	Raw data cube
bcd.fits	Fully processed 2D spectroscopic data
bmask.fits	bcd.fits mask file
dmask.fits	Mask file for lnz.fits
droop.fits	2D data with "droop" correction: a constant number is subtracted from all the pixels
drunc.fits	Uncertainty file for droop.fits
f2ap.fits	Alternate BCD data without straylight removal or cross-talk correction
f2unc.fits	Unc. for f2ap.fits
func.fits	Unc. for bcd.fits
lnz.fits	3D data cube with linearized ramps
lnzu.fits	Uncertainty file for lnz.fits
rsc.fits	Data stray light & cross-talk corrected
rscu.fits	Unc. for rsc.fits
spect.tbl	Spectrum extracted from bcd.fits
spec2.tbl	Spectrum extracted from f2ap.fits
2dcoad.txt	List of coadd weights
bksub.fits	Coadded, nod-subtracted data
bkmask.fits	Mask file for bksub.fits
bkunc.fits	Unc. for bksub.fits
bksub.tbl	Coadded, nod-subtracted spectrum
c2msk.fits	Coa2d.fits mask file
c2unc.fits	Unc. for coa2d.fits
coa2d.fits	Coadded 2D data
ibsmk.txt	List of bmask files for coadd
inlst.txt	List of input files for coadd
out.pline	Output log
ridge.tbl	Extraction position table
tune.tbl	Extracted spectrum for coa2d
xout.pline	Pipeline log

Table 2.3: Calibration Files Delivered

For each module ('*' is the module number):			
Name	*Format*	*Data Type*	*File Size (kb)*
b*_flatfield.fits (a)	$128 \times 128 \times 2$	32-bit real	150
b*_flatfield_cmask.fits (a)	128×128	16-bit integer	37
b*_fovmask.fits	128×128	16-bit integer	37
b*_lincal.fits (a)	$128 \times 128 \times 3$	32-bit real	200
b*_lincal_cmask.fits (a)	128×128	16-bit integer	37
b*_wavsamp.tbl	-	ASCII table	32
b*_wavsamp_omask.fits	128×128	16-bit integer	37
b*_wavsamp_wave.fits	128×128	32-bit real	67
b*_wavsamp_offset.fits	128×128	32-bit real	67
b*_pmask.fits	$128 \times 128 \times N$	16-bit integer	37
b*_umask.fits	128×128	16-bit integer	37
b*_fluxcon.tbl (a)	-	ASCII table	5
b*_r#_dark.fits (a)	128×128	32-bit real	281
b*_r#_dark_unc.fits (a)	128×128	32-bit real	281
b*_r#_dark_cmask.fits (a)	128×128	16-bit integer	132
slit_pa_offsets.tbl	-	ASCII table	0.7
Module 0			
Name		*Data Type*	*File Size (kb)*
b0_pkumask.fits	128×128	16-bit integer	37
b0_lmask.fits	128×128	16-bit integer	37
b0_slt_coeffs.tbl	-	ASCII table	2
b0_psf_fov.tbl	-	ASCII table	2
Module 2			
Name		*Data Type*	*File Size (kb)*
b2_psf_fov.tbl	-	ASCII table	2

(a) For module 3, these are campaign dependent.

Table 2.4: Calibration File Description

Files present for all modules '*' is the module number	
Name	*Description*
b*_flatfield.fits	Flatfield and uncertainty
b*_flatfield_cmask.fits	Mask of regions to flat
b*_fovmask.fits	
b*_lincal.fits	Non-linearity model
b*_lincal_cmask.fits	Masks pixels not to be corrected by non-linearity
b*_wavsamp.tbl	Parameters of extraction pseudo-rectangles
b*_wavsamp_omask.fits	Mapping of orders into pixels, as used by wavsamp.tbl
b*_wavsamp_wave.fits	Mapping of wavelengths into pixels
b*_wavsamp_offset.fits	Distance to FOV center in arcsec
b*_pmask.fits	Mask of semi-permanent bad conditions in the array
b*_umask.fits	Un-illuminated region mask
b*_fluxcon.tbl	Transformation from e^{-}/sec to Jy
b*_r#_dark.fits	Darks
b*_r#_dark_unc.fits	Dark uncertainty
b*_r#_dark_cmask.fits	Masks unilluminated pixels to prevent division by flat.
slit_pa_offsets.tbl	Position angle offsets
Module 0	
b0_pkumask.fits	Mask unilluminated areas of the Peak-up arrays
b0_lmask.fits	Short Low Stray Light Correction Mask
b0_slt_coeffs.tbl	Stray Light Coefficients
b0_psf_fov.tbl	Slit field of view and PSF information
Module 2	
b2_psf_fov.tbl	Slit field of view and PSF information

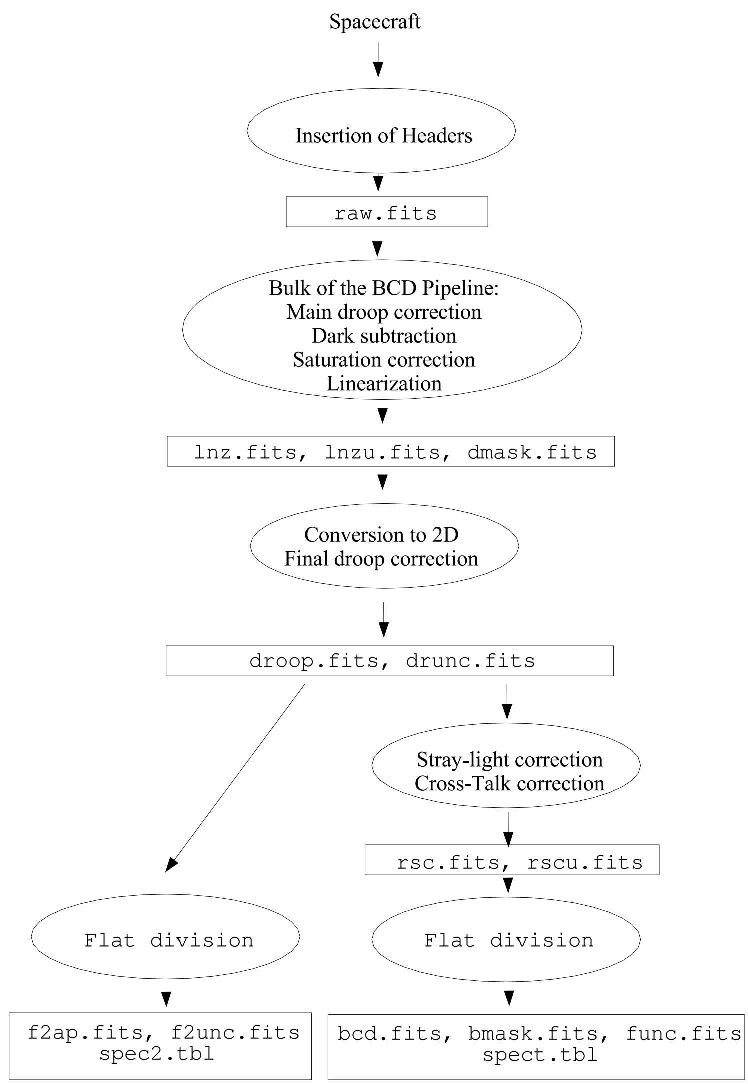

Figure 2.1: Schematic relationship BCD files. See §4.

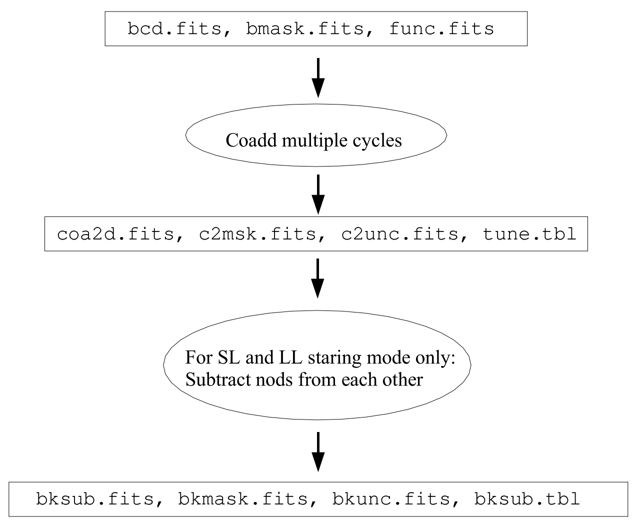

Figure 2.2: Schematic relationship between PBCD files. See §4.

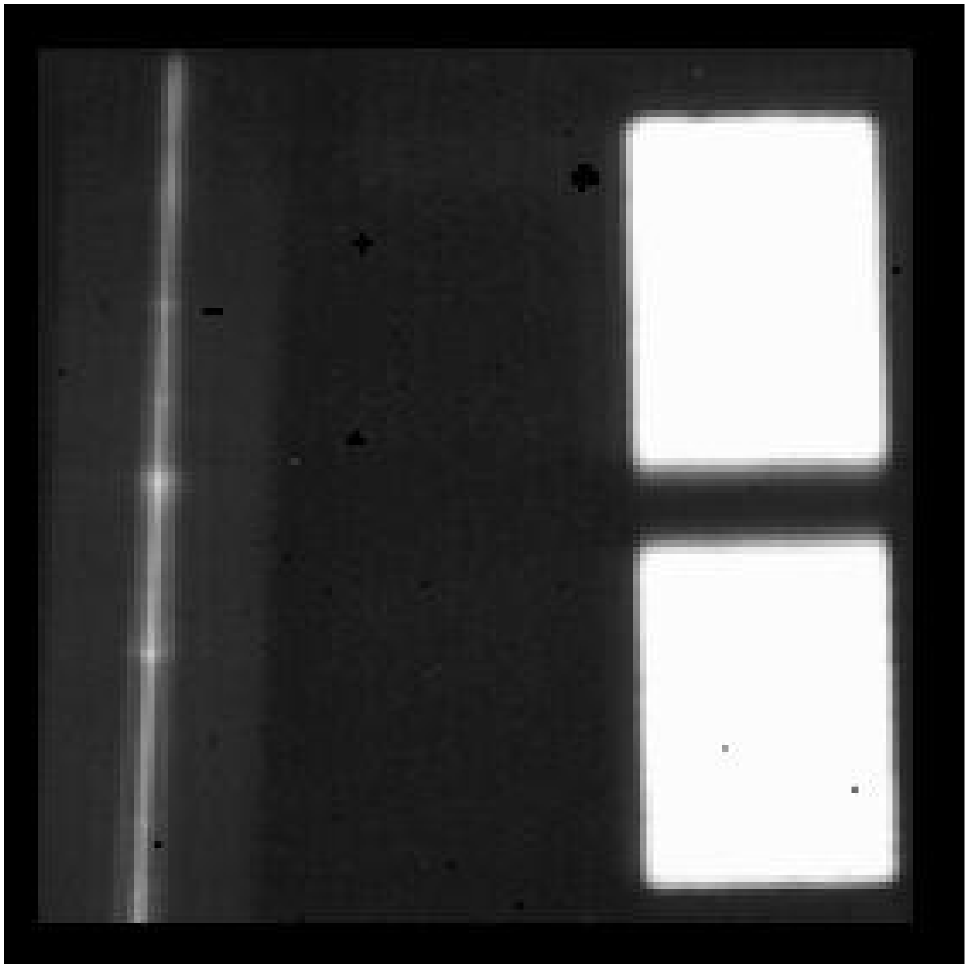

Figure 2.3: Example `bcd.fits` image of a galactic nucleus. In this case the galaxy was observed using the 1st order Short-Low sub-slit (SL1). The bright continuum can be seen running vertically down the image on the left. Two bright (and several faint) emission lines/bands are clearly detected as features of increased intensity superimposed on the continuum. The square regions to the right are the well-exposed peak-up apertures (top panel = red, bottom panel = blue). Note that light from the 2nd order SL sub-slit (SL2) is also deposited on the detector array to the right of SL1; however, SL2 is off-target (i.e., SL2 is looking at blank sky). This is because the SL2 sub-slit is located more than 1 arcminute away from the SL1 target position on the Spitzer focal plane. Consequently, there is no apparent SL2 spectrum.

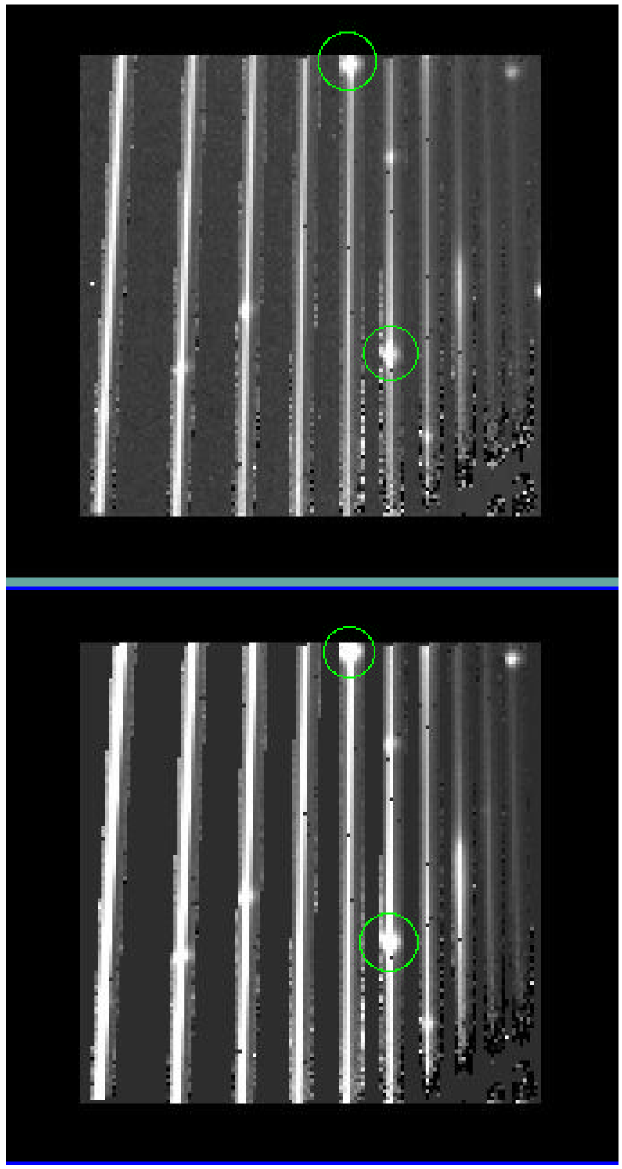

Figure 2.4: Example `bcd.fits` (top) and `coa2d.fits` (bottom) IRS data products for a bright (≈ 0.5 Jy at 15 microns) galaxy with strong emission lines observed using the Short-High (SH) module of IRS. The rest frame 12.81-micron [NeII] line, appearing in orders 15 and 16 at an observed wavelength of ≈ 13.1 microns, is circled in both images. The `bcd.fits` and `coa2d.fits` files are from the first nod position. Six individual nod frames were combined to produce the `coa2d.fits` image.

2.1.2 Peak-Up 2D and 3D Products Units

- `raw.fits`, `bcd.fits`: DN.
- `lnz.fits`, `lnzu.fits` : e^-.
- `bcdb.fits`, `bcdr.fits`, `uncb.fits`, `uncr.fits`, `b_mos.fits`, `r_mos.fits`, `b_unc.fits`, `r_unc.fits`: MJy/sr.
- All other: e^-/sec.

2.2 Spectroscopic Data Products

2.2.1 Raw Data

The IRS Raw Data consists of one or more DCEs that have been converted to FITS format files. Each individual DCE corresponds to a separate file. These files are presented as 3D data cubes, consisting of a number of non-destructive reads (samples) at fixed time intervals of the 128 × 128 pixel detector plane, where the number of reads N is determined by integration time and corresponds to the number of layers of the FITS data cube. Thus, the imaged spectra have dimensions of $128 \times 128 \times N$ in the DCE FITS file. Each data plane represents one readout of the array. All IRS spectra will contain either 4, 8, or 16 reads of the array between resets. Any ramp duration (exposure time) longer than 14 seconds results in a sixteen plane raw FITS data product. This "sample up the ramp" (SUR) mode is described in more detail in the SOM. The archive provides these data cubes under the name `raw.fits`.

The headers of raw FITS data files that are received by observers contain mainly edited instrument and spacecraft engineering telemetry keyword items that accompany the pixel data. The set of keywords is used to track the condition of hardware and software over the course of each DCE, and provides inputs needed for configuring pipeline run parameters. The programatically useful keywords are propagated and merged with pointing history keywords at the end of the pipeline.

2.2.2 Partially Processed Data

The archived IRS data files also include partially processed products. After the `raw.fits` data, the next partially processed product delivered is `lnz.fits`. This 3D data cube has been processed through all pipeline modules that operate on three-dimensional data (see §4). This data cube (in units of electrons) is the product that serves as input for the pipeline module that measures the slope of the ramp in order to determine e^{-}/s. The interested observer can examine the status of pixels in individual reads using the `dmask.fits` file, which gives a pixel status flag for each plane in the data cube. The two subsequent data products are two-dimensional: `droop.fits` (correction applied to absolute flux level) and `rsc.fits` (stray light and cross-talk removed).

2.2.3 Basic Calibrated Data

The IRS BCD file `bcd.fits` is the end product of the Science Data BCD pipeline. A BCD is either (1) a 2D echellogram for the high-resolution data (modules S1 and S3), (2) a long-slit 2D spectrum for the low-resolution data (modules S0 and S2), or (3) an image for the peak-up modes (modules S0). The `bcd.fits` files are accompanied by:

- `bmask.fits`, the pixel status mask (see §9).
- `func.fits`, the traceable uncertainty image.

In AORs with multiple cycles, DCEs at each telescope pointing are combined using a signal-weighted average to produce the coadded (averaged) product, `coa2d.fits`, and the corresponding uncertainty and mask files. The DCEs that contribute to each averaged product are listed in `inlist.txt`. For the low resolution modules in staring mode, the coadded products of one nod are subtracted from those of the other, to produce a sky-subtracted image (`bksub.fits`).

2.2.4 Basic Calibrated Data with One Less Correction

At the point of stray light removal (for SL) or cross-talk correction (for the high resolution modules), the pipeline bifurcates into two paths. One path includes these corrections, while the other does not. Uncorrected data provide an insurance against possible artifacts introduced by over- or under-correction of the stray light or the cross-talk. The corrected path generates the following data products: `bcd.fits`, `func.fits`, and `spect.tbl`. Only the products from this path are coadded. The uncorrected path generates the following products: `f2ap.fits`, `f2unc.fits`, and `spec2.tbl`. See the *IRS Pipeline Handbook* for a full description of cross-talk and SL stray light removal.

2.2.5 Extracted Spectra

One-dimensional spectra are extracted from each of `bcd.fits`, `f2ap.fits`, and, if applicable, `coa2d.fits` and `bksub.fits`. The extracted spectra have the names `spect.tbl`, `spect2.tbl`, `tune.tbl`, and `bksub.tbl` respectively. Each of these spectra is contained in a table file, with an extensive header and five data columns. The header propagates information from the source FITS file, and adds a history of the extraction pipeline (see §3). The data columns are: (1) spectral order, (2) wavelength in microns, (3) flux in Janskys, (4) flux uncertainty in Janskys, and (5) pixel status flag (see §9).

In comparing the extracted spectrum to the 2D dispersed image, the observer can use the `b*_wavsamp_wave.fits` file to associate an approximate wavelength with each pixel. Note that the extraction procedure involves interpolation, so this association is for informational purposes only, and is not appropriate for science quality extractions. The exact wavelength and cross-dispersion solution is provided in the `wavesamp.tbl` file (see §5.5).

WARNING: The scientifically validated portion of the wavelength range in the low resolution modules does not extend for the full length of the orders on the array. Valid wavelengths extend only up to 14.5 and 38.0 microns in SL and LL, respectively. Observers should not trust spectral features located at wavelengths beyond these limits, especially for blue sources.

2.3 Peak-Up Acquisition Products

If your observation included an IRS peak-up or was a Peak-up Only observation, then those peak-up data are also available in the archive. Peak-up images will not be delivered for PCRS peak-ups. In this section we provide a description of the products of the Peak-Up Acquisition mode. For information on the Peak-Up Science mode see §6.

Figure 2.5 shows an example of an IRS (red) peak-up array[1] image used for target acquisition. The main purpose of the peak-up is to determine the location of a source, to offset the telescope, and to accurately position the science target onto one of the IRS slits. In Peak-up Only mode, the peak-up algorithm is run, and a success/failure report plus narrow-field images from the peak-up arrays are delivered to the observer, but a spectrum of the science target is *not* obtained. This mode is typically used to test the validity of a questionable peak-up before committing to the spectrum exposure (See the SOM and the Observation Planning Cookbook).

The onboard peak-up algorithm measures the centroid of the brightest source in the selected peak-up array field-of-view. It performs two measurements. First an "acquisition" centroid (ACQ) is measured at the "blind" pointing of Spitzer. After this, the brightest source is moved to the "sweet spot" (SS) of the selected peak-up array and the centroid (of the brightest source in the field) is measured again. Finally, the SS centroid position of the peak-up target is used to move the science target to the first commanded slit for spectroscopic observations. The exposure number is 0000 for ACQ and 0001 for SS. At each position, three images (DCE numbers 0, 1, 2) are taken and processed onboard to produce the frame that is used by the peak-up algorithm. This fourth, processed frame is always DCE number 3 (see Figure 2.5).

In the processed peak-up images, any source that is bright enough for centroiding will be clearly visible. You will see that source near the center of the image. In the ACQ frame, it will be at or near pixel (107,30) for the blue peak-up array and (105,92) for the red peak-up array; for SS, it will be at or near pixel (108,28) or (106,94) for blue or red, respectively. The onboard software considers the center of the lower left corner pixel of the array to be (0,0); that is, pixel centers are labeled with integers and pixel edges are labeled with half-integers. Beginning in IRS25 the PU window has been trimmed to 24×24 pixels.

The FITS headers of the peak-up images contain information about the operation of the telescope and the peak-up algorithm (see below). The data in each FITS file shows the combination of the three individual exposures. The onboard processing includes cosmic ray rejection, flat-fielding, and background subtraction. The data are in units of DN (Data Number). An ap-

[1]The IRS peak-up "arrays" are actually sub-array regions of the SL module array.

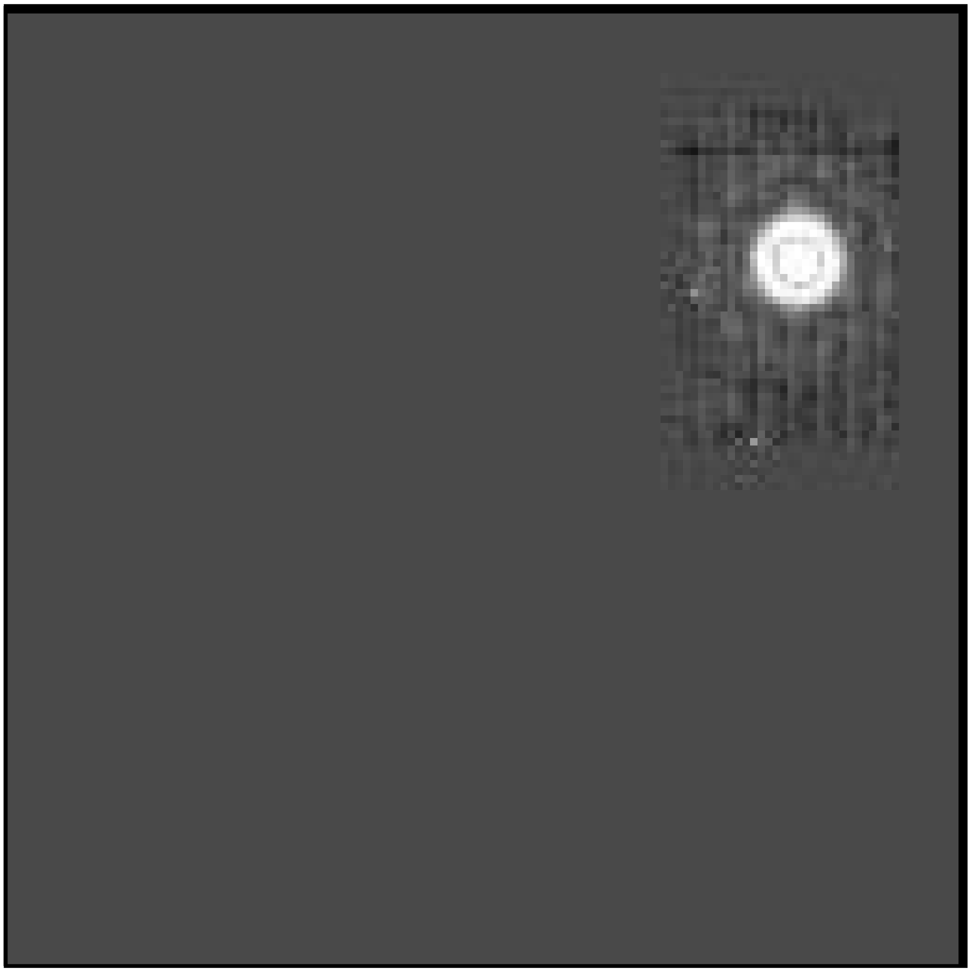

Figure 2.5: Example image of a star in the red IRS peak-up array. This image shows the onboard-processed DCE #3 (see text), with the rest of the image masked.

proximate conversion to physical units is given in §5. The world coordinate system (WCS) for the peak-up images is provided in the FITS header. The red and blue peak-up arrays share a common WCS. The WCS is described in the system `CTYPE1 = 'RA---TAN-SIP'` and `CTYPE2 = 'DEC--TAN-SIP'`, not `'RA--TAN'` and `'DEC--TAN'`. This system is the same as that used for IRAC and MIPS images, and includes non-linear distortion terms. In particular, image viewers like DS9, GAIA, and ATV used to display the full SL and peakup images will give coordinates valid for the peakup imaging fields of view.

If the peak-up algorithm does not find a valid centroid, then it will report a failure. In the peak-up images, particularly the processed DCE (see above), there will be no visible source. You can also identify these failures from the FITS header by looking at the value of the "PU centroid quality code," which is 0 for a failure and 1 for a success.

The peak-up algorithm can also result in a false positive. In this case, the peak-up software centroids on something other than the intended target and reports a success. You can look at the peak-up images to see if your intended source is at the centroid position reported in the header. The value of the centroid is given in the `AXCNTRD1` and `AYCNTRD1` keywords; note that these values are given in centipixels, so must be divided by 100.0 in order to compare with pixel coordinates in the peak-up images. In addition, the value of the `PTGDIFF` keyword in the header gives the difference in arcseconds between the requested and reconstructed pointing. This value is almost always less than 1 arcsecond, which indicates that the intended coordinates were placed on either the acquisition or sweet spot.

Accurate photomery of the sources in the Peak-Up fields may be obtained by using the Peak-Up Imaging observation mode (see §6). Approximate photometry for peak-up acquisition fields is given in §5.

Chapter 3

BCD Header Keywords

The FITS header keywords in an IRS BCD data file provide detailed information about the observation. The header is updated late in the pipeline as part of the creation of the BCD file. Thus, the `bcd.fits` file contains the updated header, while partially-processed products from earlier in the pipeline may have different keywords. In addition, a history of the pipeline processing is provided at the end of the FITS header. In this chapter, we review the keywords in the spectroscopic `bcd.fits` header. Many keywords are self-explanatory, so we highlight only those of greatest interest to the observer. An example FITS header is given as an appendix to this handbook (see Appendix A). The meaning of most keywords is the same for Peak-Up Imaging observations.

3.1 Basic Keywords

- `CAL_SET` indicates the version of the calibration files used to produce the data product.
- `CREATOR` indicates the latest pipeline version used to reprocess the files. Note: In some circumstances, the pipeline version displayed by Leopard for a given AOR will not be the same as the pipeline version in the CREATOR keyword. This will happen when changes in the pipeline do not affect certain data products. If the CREATOR keyword for a recently downloaded product does not coincide with the latest version given by Leopard, it means that the latest archive reprocessing did not update the product, because the changes did not pertain to it. From

the user's standpoint, the more relevant keyword is CAL_SET, which indicates the actual calibration files used in the product.

- AORKEY (also called "reqkey" in some contexts) is a unique 7-digit identification number for each set of observations. It is part of the file name for each BCD, as discussed in §2.
- PROGID gives the program ID under which the current data were obtained. This ID can be used in SPOT (Spitzer Planning Observations Tool) to obtain the AORs used to plan the observation.
- FOVNAME is the name of the field-of-view used for the observation. For example, a Staring Mode observation using SL1 will result in DCEs acquired with the target (given by header keywords RA_RQST and DEC_RQST) positioned first at 'IRS_Short-Lo_1st_Order_1st_Position', and then at 'IRS_Short-Lo_1st_Order_2nd_Position', corresponding to each of the designated nod positions.
- BUNIT gives the units of the data; e.g., "e^-/s".
- FLUXCON gives the conversion factors from electrons per second to Janskys. This keyword is given for each spectral order, but pertains only to the module associated with the BCD. The conversions are only the amplitude, *FluxCon*, not the "tuning" coefficients (see §5.4).
- For bookkeeping, it may be useful to search for particular targets by looking at OBJECT = Target Name.
- The IRS peak-up keywords are mostly relevant to the peak-up DCEs (see §2.3). In spectral DCEs the only peak-up keyword of interest is APKUPCEN. If the value of this keyword is 1, then the corresponding peak-up was successful, meaning that the centroid of the brightest source in the peak-up array field-of-view was returned.

3.2 Exposure Time

There are several integration-time-related keywords. Of greatest interest to the observer is the "effective integration time", which is the time on-chip between the first and last non-destructive reads for each pixel (see §7.1.4.1.3 in the SOM). It is called

RAMPTIME = Total integration time for the current DCE.

The value of RAMPTIME gives the usable portion of the integration ramp, occurring between the beginning of the first read and the end of the last read. It excludes detector array pre-conditioning time. It may also be of interest to know the exposure time at other points along the ramp. The SUR sequence consists of the time taken at the beginning of a SUR sequence to condition the array (header keyword DEADTIME), the time taken to complete one read and one spin through the array (GRPTIME), and the non-destructive reads separated by uniform wait times. The wait consists of "clocking" through the array without reading or resetting. The time it takes to clock through the array once is given by the SAMPTIME keyword. So, for an N-read ramp:

RAMPTIME = 2*(N−1)*SAMPTIME

and

DCE duration = DEADTIME + GRPTIME + RAMPTIME.

Note that peak-up data is not obtained in SUR mode. It is obtained in Double Correlated Sampling (DCS) mode. In that case, the exposure time is given by

RAMPTIME = [GRPTIME/2 + 1]*SAMPTIME.

3.3 Reconstructed Pointing

The RA, DEC, and position angle of the observation are recorded in several ways. The FITS header includes information on both the requested pointing and the actual position of the telescope, as measured during the time of the observation and corrected for proper motion, as entered in SPOT. All reconstructed values are averaged over the time interval of the DCE. The pointing-related keywords include:

- RA_RQST, DEC_RQST, PA_RQST, and UNCRTPA give the requested values for the current DCE. Here the position angle is given for the +Z axis of the telescope (see Figure 4.5 in the SOM), measured East of North. Its uncertainty can be found in the keyword UNCRTPA. The observer can check relative orientations using the visualization tools in SPOT.

- RA_REF and DEC_REF give the original target position. If the observation is part of a group (e.g., cluster target type or Spectral Mapping mode), then the central target position may be different from the requested position of the current DCE.

- RA_FOV, DEC_FOV, and PA_FOV give the field-of-view pointing, while RA_SLT, DEC_SLT, and PA_SLT give the center of the slit pointing. The reconstructed pointing of the telescope is recorded for both the requested field-of-view and the center of the slit. So, in a Staring Mode observation of a single target, the pointing on the center of the slit will change at the two nod positions, but the two fields-of-view will each be pointed at the same position (with some small pointing uncertainty). Field-of-view and center of the slit positions will be the same for Spectral Mapping mode in which the slit centers have been requested.

- PTGDIFF is the difference between the reconstructed pointing (for the field-of-view) and the requested pointing. The requested and reconstructed pointings are computed with double-precision, but the reconstructed pointing and, therefore, the value of PTGDIFF is accurate only to 0.8 arcsec (1σ radial). This uncertainty applies equally to the above _FOV and _SLT keywords. For data taken before December 2004, pointing control was based on gyros, resulting in relatively large values of PTGDIFF. Since December 2004, pointing control has been based on the star tracker. If an IRS or PCRS peak-up operation fails, then the telescope cannot make a correction to the attitude, and by default assumes the correction to be zero. In this case, the value of PTGDIFF may be misleadingly small. This is also the result if no peak-up is requested. A false positive peak-up, on the other hand, may lead to large PTGDIFF values by virtue of differences between the reference (commanded) positioning and the attitude measured from the star tracker.

Chapter 4

Pipeline Processing

The datasets that are available from the archive have been processed through the "batch mode/non-interactive pipeline." This BCD pipeline performs certain tasks, such as cosmic ray corrections and slope estimation (see §4.1). The BCD pipeline data flow is depicted in Figure 4.1. After the BCD pipeline, the data are processed by the extraction pipeline, described in §4.2. For a more complete description see the *IRS Pipeline Handbook*. In what follows we concentrate on the pipeline description applicable to spectroscopic data. Chapter §6 discusses the steps applicable to Imaging data.

4.1 BCD Pipeline

TRANHEAD: The TRANHEAD module modifies the FITS keywords in the input data and reduces their number compared to the DCE as it arrives at the Spitzer Science Center (SSC) from the Multimission Image Processing Laboratory (MIPL). The data remain the same.

CVTI2R4: This module converts the 16-bit integer values in the input FITS data to 32-bit float types. Subsequent modules operate only on data in that format. Digitally saturated pixels are detected and the corresponding bit is set in the `dmask.fits` file. The `pipe0.fits` files are the output of this module (after pointing transfer and final product generator – see below).

SNESTIMATOR: The uncertainty estimate is performed at this stage. The computation is described in §7. The output is, of course, in the same units as the data cube for which the standard deviations are calculated. The

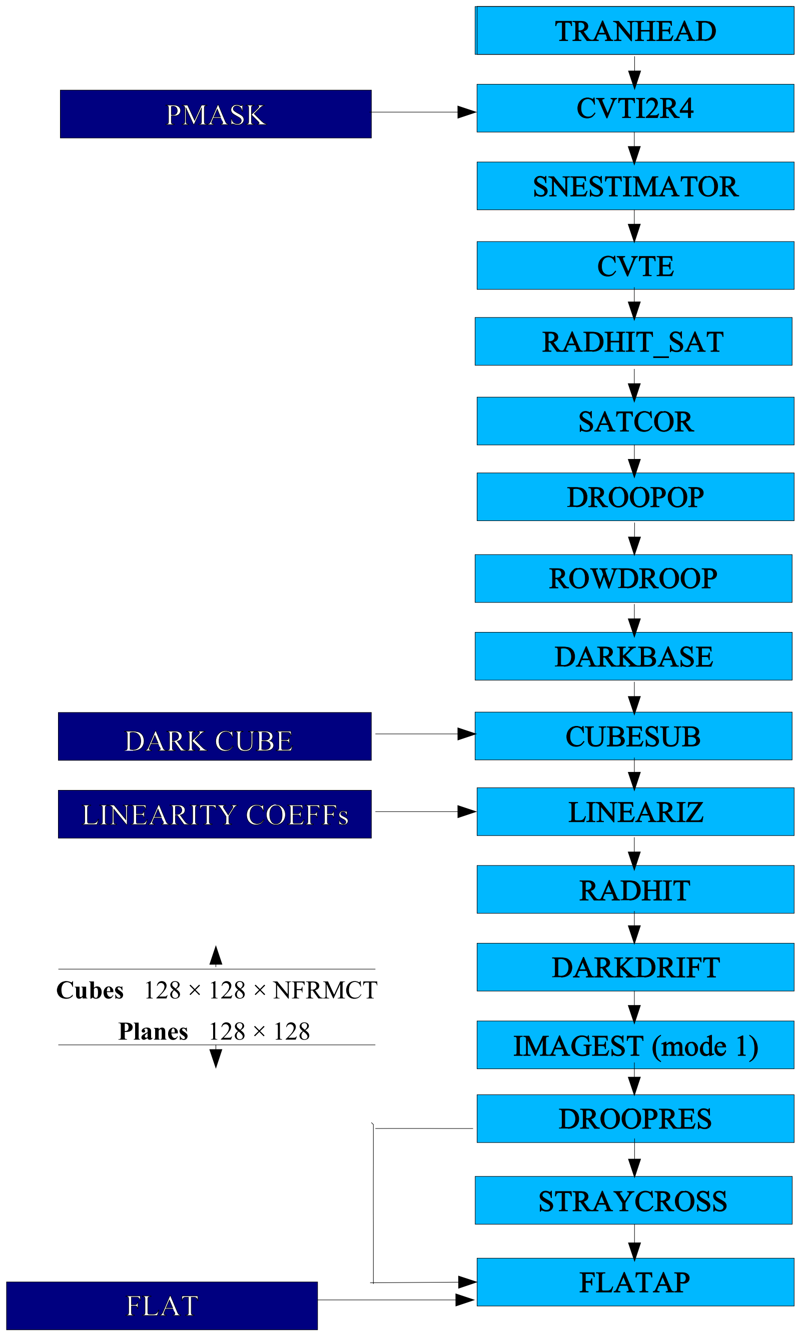

Figure 4.1: Schematic diagram of the IRS BCD pipeline.

output of this module is not currently propagated beyond the IMAGEST stage.

CVTE: The next step in the science pipeline thread consists of converting the raw data values, now in floating point, to numbers of electrons by multiplying by the gain factors for each channel. Currently, the gain is the same for all channels (4.6 e^-/DN). The gain correction is applied to every pixel and all planes in both the signal and the uncertainty data cubes. The data format remains unchanged.

RADHIT_SAT/SATCOR: The RADHIT module identifies cosmic ray events along the signal ramps and flags them in the `dmask` file. SATCOR then uses good data (without a jump caused by a particle hit) to extrapolate and estimate the signal of saturated pixels. This estimate is used only to estimate droop (see next).

DROOPOP/ROWDROOP: The measured charge on a pixel may change as a function of the total flux incident on the array. This effect, known as "droop", is corrected by the DROOPOP module. The correction is performed plane by plane on a pixel-by-pixel basis. The ROWDROOP module corrects for a related phenomenon, in which the value of a pixel can change as a function of the total flux in the row in which the pixel is located. ROWDROOP removes the effect channel by channel within each plane (see the SOM for a discussion of the readout channels on the IRS arrays). The output of both modules is a FITS data cube with the same dimension and format as the input data.

DARKBASE: This module estimates the baseline level (DC offset) and subtracts it from the pixel values for all planes of the input data. The estimate is based on an extrapolation to zero exposure time within an unilluminated region (defined with the `*umask.fits` file) for each module. The baseline value and the coordinates of the region are written to the FITS header of the output image. The latter is an image file with the same number of planes as the input file.

CUBESUB: In this step, a calibration file with the reference dark current is subtracted from the science data. The expression "dark current" is incorrect in that this value is measured on the sky without a shutter (but pointing at an area in the sky with little infrared emission: RA = $258\overset{\circ}{.}96$, DEC = $+65\overset{\circ}{.}43$). The reference dark cube has the same number of planes as the science data and is obtained with the same exposure time. The dark current subtraction is performed at a plane-to-plane level and results in an output FITS file with the same dimensions as the input data cube.

LINEARIZ: The next step in the science thread linearizes the data signal ramps assuming a quadratic model and pre-determined linearity coefficients which describe the linearity behavior for each pixel. This module outputs a FITS data cube containing the linearized data, and updates the `dmask` file with pixels that were found to be saturated. The products of this module are available from the archive (`dmask.fits`, `lnz.fits`, and `lnzu.fits`).

The linearity coefficients are (pre-)determined by measuring the non-linear behavior of pixels in the array through observations of stars and stim-flashes obtained during routine calibration observations. Currently the same linearity coefficients are applied to each pixel in a given detector–array. In effect, this method assumes (as appears consistent with observation) that any scatter in the linearity from pixel to pixel across the array is smaller than the measurement error associated with the estimate of the linearity coefficient for the array as a whole. As our ability to measure the linearity for every pixel in the array improves, this assumption may be refined.

RADHIT: This module re-measures and flags cosmic ray events along each signal ramp. Its sensitivity is controlled mostly by the threshold, which must be exceeded by a signal jump to be considered a particle hit. Its output is contained in an updated `dmask` file where bits are raised for the radhit events found. The considerable processing of the ramps that has occurred up to this stage of the pipeline makes it possible to detect cosmic ray events that were missed in the first attempt (RADHIT_SAT).

DARKDRIFT: This module removes residual column-to-column variations ("jail-bars") by estimating the four-readout-channel variations based on pixel values across the four channels. Its output is a 3D FITS image.

IMAGEST: The IMAGEST module fits the signal ramp and measures the slope. Thus, the output is two collapsed (2D) FITS files: one contains the image corresponding to the slopes for each pixel, while the other contains the uncertainties associated with the fitting of the slopes. The uncertainty values are given in §7 and do not contain uncertainties introduced by previous pipeline modules. From this step forward only the collapsed slope image (with units of electrons per second) is used for further reduction.

DROOPRES: At this stage of the processing, the unilluminated pixels in the image (as marked in `*umask.fits`) should have a median value of zero.

DROOPRES checks whether this is the case in an unilluminated portion of the array, and then corrects all pixels of that channel by subtracting a constant. The products of this module are available from the archive (`droop.fits` and `drunc.fits`).

STRAYCROSS: The action during this pipeline step depends on the instrument channel. Data from SL are corrected for stray light falling on its spectral orders from the peak-up sub-arrays. Data from SH and LH can be affected by optical cross-talk between orders; this effect is estimated and removed. Data from LL remain unchanged. The output files have the same dimensions as the input file and are available from the archive (`rsc.fits` and `rscu.fits`).

FLATAP: The last step in the BCD science data processing is to apply the flat-field in order to correct for pixel-to-pixel response variations. The flat-field is a calibration file specific to each instrument module and is described in more detail in §5. The output of FLATAP is a single-plane image file in FITS format, converted by the next steps into `bcd.fits`, accompanied by a file with the corresponding uncertainties, `func.fits`. The corresponding products that do not undergo the step of STRAYCROSS are `f2ap.fits` and `f2unc.fits`.

Pointing Transfer and Final Product Generation: These modules do not alter the data values, but operate instead on the FITS headers. Pointing Transfer updates the reconstructed pointing keywords. The Final Product Generator inserts other keywords to track information on the current AOR, and renames many of the existing keywords to be more easily understood. The output of these modules is the `bcd.fits` file. The uncertainty file remains the same (`func.fits`).

4.2 Post-BCD spectroscopic (Extraction) Pipeline

Table 4.2 provides an overview of the modules that run within the extraction pipeline. It runs after the BCD Pipeline and extracts one-dimensional spectra from two-dimensional slope images. The input of the thread is a two-dimensional BCD image in FITS format. The output from the thread is a table file containing the extracted spectrum. The thread also takes mask and uncertainty files as input, and propagates uncertainties and status flags into the file table. The extraction pipeline produces `spect.tbl` (from `bcd.fits`),

Table 4.2: IRS Extraction Pipeline

Module	*Function*
PROFILE	Creates a wavelength-collapsed average spatial profile for the slit(s) used in the observation.
RIDGE	Finds the peak of the spatial profile along the dispersion direction.
EXTRACT	Takes the information from RIDGE and extracts a 1D spectrum along that position in accordance with the wavelength-dependent point spread function and the exact shape of the spectrum on the chip.
IRS_TUNE	Applies a set of photometric tuning and flux conversion factors to 1D spectral extractions created by EXTRACT.

`spec2.tbl` (from `f2ap.fits`), `tune.tbl` (from `coa2d.fits`), and, in the case of IRS Staring mode in low resolution, `bksub.tbl` (from `bksub.fits`).

Only one intermediate product of this pipeline, the output of the RIDGE module for the BCD data, `ridge.tbl`, is delivered to the user. This file specifies the location of the extracted source within the entrance slit with the pixel coordinates of the "ridge," or flux peak, along each order in the two-dimensional image. If RIDGE does not find the spectrum (for example, if the source is too faint) it will return a default trace (33% or 66% of the slit width, for IRS Stare, and 50% otherwise). `ridge.tbl` follows the format of the `wavsamp.tbl` calibration file (see §5.5) for the first 11 data columns. The remaining 4 columns give the location of the center of the object position. In some cases, it may be useful to plot the ridge location (from the last two columns in `ridge.tbl`) on top of the dispersed spectrum image (from `bcd.fits`). The spectrum is extracted along the ridge path; the width of the extraction scales with wavelength when sub-slit extraction is performed. The IRS pipeline does not perform flux-weighted (optimal) extraction.

The source spectrum incident on the array is not rectilinear in either the spectral or cross-dispersed directions. As a result, the EXTRACT module must perform an interpolation to the known shape of the spectral orders. Also, the extraction window must account for curvature of the spectrum in the spatial direction, as well as the wavelength solution within each spectral order. The extraction window is defined in the `wavsamp.tbl` file (see §5.5).

The extraction algorithm will automatically interpolate over any NANs that lie in the extraction aperture using a pixel replacement scheme similar to that used in the IRSCLEAN_MASK package available on the web at the SSC site[1]. Alternatively, SPICE provides the oportunity of ignoring the NaN-ed pixels altogether. The observer should be cautious about parts of the spectrum that contain large numbers of NANs. In addition, the extraction will ignore any fatally flagged pixels. The fatal flags are currently bits 7,12,13 and 14 in the `bmask.fits` file associated with the given BCD (see §9). More sophisticated extractions that avoid some of the problems of rogue pixels can be made outside the pipeline using SPICE in combination with the rogue-pixel treatment program IRSCLEAN_MASK.

Spectra are initially extracted in units of electrons per second. These one-dimensional data are converted to Janskys by the IRS_TUNE module. This module also corrects the slope and curvature of each order by applying the polynomial coefficients in the `fluxcon.tbl` file. This correction, referred to as "order tuning" (see §5.4), is based on an order-by-order comparison of calibration data to standard star model spectra. Spectral orders within each module are normalized to each other, using the *FluxCon* amplitude.

[1]See `http://ssc.spitzer.caltech.edu/archanaly/contributed/irsclean/`

Chapter 5

IRS Photometric and Wavelength Calibration Products

This chapter provides a brief description of the calibration files that are included with each observation.

5.1 Dark Subtraction Cube

b*_rτ_dark.fits (where * = 0,1,2,3 corresponds to IRS channel number and τ = integration time)**:** Because the IRS does not have a shutter, dark observations are made using Staring Mode observations of selected regions of the sky that are mostly free from significant zodiacal light or cirrus emission (RA = $258\overset{\circ}{.}96$, DEC = $+65\overset{\circ}{.}43$). However, note that the background is still non-zero at this location but is in the range 4.01-4.55 MJy/sr at 100 μm and 13.2-17.31 MJy/sr at 24 μm. In consequence, science observations of very dark regions may result in negative pixels values in the final BCD images. This should not affect the results of any extraction made on background–subtracted data, or Peak-up mapping data in which the amplitude of the adjacent sky is taken into account.

Dark–observations are obtained for each IRS module, with each allowable Astronomical Observation Template (AOT) integration time for that module (for example, darks that are obtained for SL would have the allowable AOT integration times of 6, 14, 60, and 240 seconds). The darks corresponding to the selected AOR are delivered to the observer.

The format of the dark data is a 3D FITS data cube, obtained in SUR mode. The raw dark data for the cube is processed through a special-purpose calibration pipeline to convert these data to floating point, and apply standard offsets and corrections (e.g., standard droop corrections, cosmic ray removal, darkbase offset subtraction, etc.) Typically, many observations (> 30) are made for each dark cube, and these data are median-averaged to further remove outlying points. These 3D "superdarks" will be modified and refined during the course of the Spitzer mission, using dark observations made routinely during every IRS campaign to monitor changes in array parameters. Because the number and strength of rogue pixels is most variable for LH, the darks for this module are campaign dependent. The units of the dark observations are e^-.

Pipeline Application: The superdarks obtained for all relevant integration times and IRS modules are maintained within the IRS data pipeline environment by the IRS Instrument Support Team at the SSC. The dark subtraction is performed in the 3D data cube domain. The pipeline determines how many samples are present in a given target observation and the appropriate dark is subtracted from that observation, plane by plane, by the science pipeline routine CUBESUB. As described above, each plane in either data cube corresponds to the SUR image at a given sample read. In this way, repeatable (instrumental) behavior which may be present in both the observation and the dark cube as a function of SUR read time (e.g., possible post-reset transients, etc.) will be removed, resulting in better temporal behavior of the ramps in the dark-subtracted science observation. The dark cube subtracted from each observation is included in the archive as `b*_rτ_dark.fits`.

5.2 Non-Linearity Model Cube

b*_lincal.fits: The departure of each SUR value from a linear function of time is modeled in the IRS pipelines as a quadratic function,

$$S_{obs} = \alpha S_{linear}^2 + S_{linear},$$

where S_{obs} is the observed sample value (in e^-), and S_{linear} (in e^-) is the corresponding value if the detector response were perfectly linear. The α parameter is the "non-linearity coefficient".

There is a different non-linearity model cube for each of the four IRS modules. Calibration of the non-linearity is performed using a combination of stimulator-lamp measurements and bright stars. The best results are obtained with bright-stars because the stimulators tend to introduce large droop-effects of the arrays which complicate the interpretation of the non-linearity calculations. A model is fit to each ramp in the stimulator/and or star observations, yielding the non-linearity coefficient and its uncertainty for each pixel. The best results for IRS observations are obtained if the non-linearity is assumed to be the same for every pixel in the given detector array, as it is difficult to obtain consistent high-signal to noise estimates of the non-linearity for every pixel in the array. An iterative test of the final non-linearity coefficients is made by measuring the degree of non-linearity left after applying the corrections to the calibration data. In some cases further adjustments are made to the non-linearity coefficients to provide the best average coefficient for that detector array. Care has been taken to decouple non-linearity effects from detector droop-corrections since having an incorrect droop correction will seriously impact the non-linearity coefficients. Deriving consistent linearity coefficients for observations made under a variety of illumination conditions is the key to breaking the degeneracy of these two important effects.

The calibration product `b*_lincal.fits`, referred to as the non-linearity model, is a 3D FITS image (data cube), of dimensions $128 \times 128 \times 3$. Each pixel of the IRS detectors is assumed to have unique non-linearity characteristics. The first plane of `b*_lincal.fits` contains the α coefficients of each pixel. The second plane contains, for each pixel, the signal threshold (upper limit, in e^-) for applicability of the non-linearity model. Samples that exceed this threshold are not corrected in the pipeline. The third plane contains the uncertainties of each α coefficient.

b*_lincal_cmask.fits: Pixels whose linearity is not corrected are set to have values of 4096 in this file.

Pipeline Application: The `b*_lincal.fits` calibration product is used for ramp linearization in the BCD science thread and other calibration threads in which slope estimation is performed. Linearization is done by the LINEARIZ module, after dark current subtraction and before slope estimation. The application consists of inverting the quadratic model equation given above to solve for S_{linear} as a function of S_{obs} and α. The model is not applied if S_{obs} exceeds the non-linearity threshold, or when S_{obs} or α are so large (the

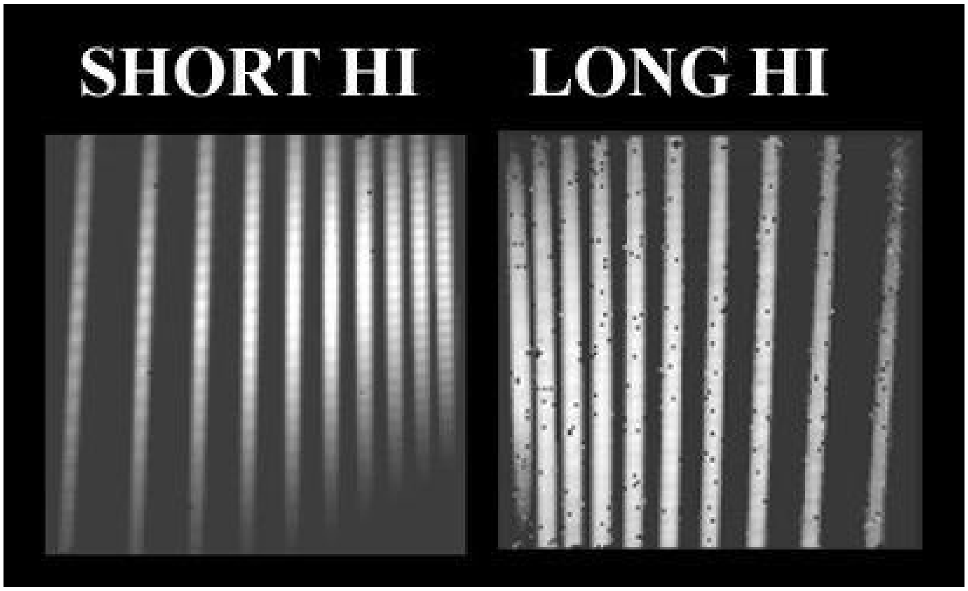

Figure 5.1: Example of flat-field images for the IRS high-resolution modules. The dark spots in LH indicate regions NaN(ed) from the flat because of damage to the detector caused by the powerful solar storm that occurred early in the Spitzer mission.

latter in absolute value) that the solution of S_{linear} is not a real number.

5.3 Flat-Field Products

b*_flatfield.fits: Flat-field image files have dimensions of $128 \times 128 \times 2$. A two-dimensional flat-field image is stored in the first data plane of this image, while the second data plane contains the uncertainty image (nominally set to 0.001) associated with the flat. The "flat-field" image is, in reality, a combined spatial flat-field *and* Relative Spectral Response Function (RSRF) measured in 2D (see figures 5.1 and 5.2). The aim of the flat-field image is to correct 2D BCD images for the combined effect of spatial and spectral optical throughput effects and detector responsivity.

A full description of the process by which the flat-field images are created will be given in the *IRS Pipeline Handbook*; it is described only briefly here. The process for creating the flat-field images is module dependent. The procedure involves moving a standard star in sub-pixel steps along and across

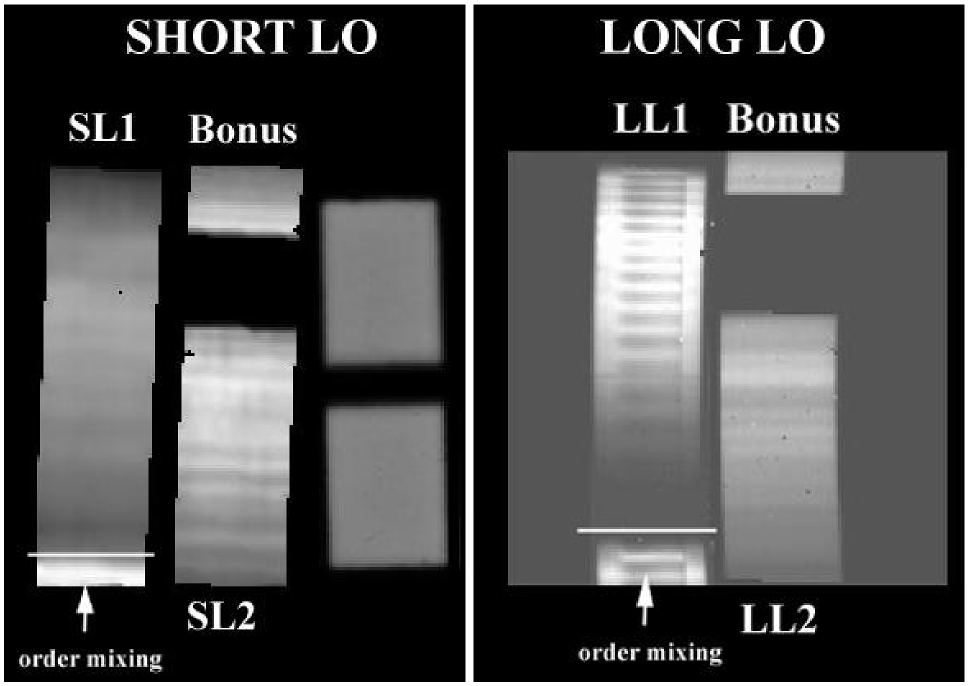

Figure 5.2: Example of flat-field images for the IRS low-resolution modules. The red (top) and blue (bottom) peak-up fields can be seen in the SL module image. Fringes are clearly seen in the flat-field image of LL1. They are caused by filter delamination. A similar fringe pattern appears in LL science observations, so flat-fielding of those images in the data processing pipeline usually reduces the fringe amplitudes significantly. If they are still present in the extracted 1D spectra, then they can be removed with IRS-FRINGE, a stand-alone IDL routine that is available on the SSC website at `http://ssc.spitzer.caltech.edu/postbcd/defringer.html`.

the slit. This approach is necessary to fully sample the PSF at all wavelengths for the module in question (especially at the blue end where the full width at half maximum of the PSF is often less than a pixel). The spectral signature of the star itself is removed in the two-dimensional image – the standard star model spectrum is mapped to the 2D geometry of the dispersed image, and divided into the data. Next, deep spatially-dithered, median-averaged observations of the zodiacal light are used to correct the spatial component of the flat.

The final flat-field image is created by masking out unilluminated pixels (see the explanation of `b*_flatfield_cmask.fits` below), and normalizing the illuminated area. This normalization sets the median of the *illuminated portion* of the array (including all of the spectral orders) to unity. This has the advantage that the flat-field image provides a first-order indication of the relative throughput (or responsivity) of the spectral orders within a given module. (Note that individual orders in the flat-field image are not normalized to unity.) For the low-resolution modules, the normalization is performed over the illuminated portions of the first, second, and third (bonus) orders together (excluding the peak-up array for SL). For the high-resolution modules, the median normalization is performed over all 10 illuminated orders together.

The peak-up arrays are also incorporated into the flat-field of the SL module. These were obtained in separate observations of the zodiacal light. The normalization for the peak-up flats is such that each peak-up array has a median value of unity.

Since the flat-field operates on the whole image, an observation made in a given sub-slit (e.g., SL1) will cause the other sub-slits in that module (SL2 and the peak-up arrays for SL) to also be flattened. The flat-field image may contain pixels labeled as NaNs. The operation of the flat-field transmits these NaNs to the final BCD output image if they lie within the range of the illuminated region as defined by the CMASK (see below). The NaNs in the flat-field represent pixels deemed to be either fatally flagged or unreliable.

b*_flatfield_cmask.fits: This file contains a 16-bit image mask used by the pipeline to decide which part of an image is to be divided by a flat-field and which part will be left unaltered. The region of the image which will have the flat-field applied contains the value zero. Regions in the flat-field which are deemed "uncertain" (mainly regions at the very edge of the illuminated regions which are heavily vignetted) are give values 256 (bit 8). Regions which are not to be flat-fielded (i.e. lie outside the valid region, as determined by wavsamp_omask) are set to 128 (bit 7).

The pipeline routine FLATAP, which applies the flat-field will not apply the flat-field to regions in which bit 7 has been set. Regions of uncertain flat field (indicated by bit 8 of the being set) cause bit 7 of the `bmask.fits` file to be set. From the S13 pipeline onward, this bit is read as a fatal bit by the EXTRACT module. Under certain circumstances (for example, if a bright sources lies very close to the edge of the slit) a user may want to consider unselecting bit 7 within SPICE, and therefore allowing the regions of uncertain flat-field to be included in the extraction. Under most circumstances this will lead to a noisier result.

Pipeline Application: The division of the science data by the flat-field is performed at the end of the IRS BCD science pipeline by the routine FLATAP. At this stage in the pipeline, the science data to be flat-fielded have already been converted from a raw SUR cube structure to a 2D slope image, with units of e^-/s. Since the flat-field contains dimensionless units, the science data output from FLATAP also has units of e^-/s. Conversion to physical flux units (i.e., Jy) for the science data is not done until spectra are extracted in the post-BCD pipeline.

5.4 Flux Conversion Table

5.4.1 Point Source Flux Conversion

b*_fluxcon.tbl: This is an ASCII table used by the pipeline routine IRS_TUNE to convert extracted spectra from e^-/s into flux-calibrated units (Jy). The routine performs "order tuning", the process of normalizing the slope and removing the curvature of each spectral order. The `fluxcon` table contains order-dependent tuning coefficients and absolute scaling constants from electrons per second to Janskys. The tuning coefficients are the coefficients of a polynomial of up to 5^{th} order in wavelength which represent the final tuning applied to a spectrum after it has been extracted from a flat-fielded BCD (note that in practice it is rare for polynomials of order higher than 3 to be used).

The operation of IRS_TUNE is to divide the extracted (flat-fielded) science spectrum by $y \times FluxCon$, where $FluxCon$ is the conversion factor from e^-/s to Jy and y is a correction factor computed with the tuning coefficients.

$$y = a_0 + a_1 \times (\lambda - \lambda_0) + a_2 \times (\lambda - \lambda_0)^2 \qquad (5.1)$$

The `fluxcon` table has a total of 20 columns; the following are the most useful of these: Column 1 = spectral order; Column 2 = key wavelength (λ_0 in microns); Column 8 = flux conversion factor ($FluxCon$), in (e^-/s)/Jy (measured over the key wavelength passband); Column 9 = 1-sigma uncertainty in the flux conversion factor, in (e^-/s)/Jy; Column 10 = a_0, Column 12 = a_1, Column 14 = a_2, Column 16 = a_3, Column 18 = a_4, Column 20 = a_5, where a_0, a_1,...a_5 are the coefficients in the polynomial fit.

The values of the coefficients are determined using a set of standard stars with well-determined model spectra[1]. For the low resolution modules, the primary calibrator is HR 7341 (HD 181597). For the high resolution modules, HR 6688 (ksiDra, HD 163588) is the primary calibrator. The stars are periodically observed with high-accuracy peak-up. The observations are sky subtracted, using the off-order (for the low-resolution modules) or dedicated off observations (for the high-resolution modules) to measure the sky. The multiple sky-subtracted observations are median-combined to increase the signal-to-noise. The spectra are extracted using SPICE, with exactly the same parameters as in the pipeline. Within the extracted spectra, each order is trimmed as indicated in Table 5.1. The observed spectra are then made to match the MARCS models (Decin et al. 2004) of these stars, using a low-order polynomial and an overall multiplicative constant (the $FluxCon$). The coefficients of these polynomials and the constant (a different set for each order) are supplied to the user in the `fluxcon.tbl` table. Observations of other stars with MARCS models are used as a check.

5.4.2 Extended Source Flux Conversion

Beginning with the S13 pipeline, users have the ability to use SPICE to estimate the spectrophotometric calibration for extended sources. The calibration is not exact because the source structure varies from object to object. To derive this calibration, it is assumed that the source is spectrally and spatially flat. With these assumptions, two functions are derived: one transforms the SPICE point source calibration to one valid for a full slit and the second transforms the spectrum from that of a stellar point source to a that of (spatially and spectrally) flat source. More details are given in the SPICE manual.

5.4.3 Peak-up Imaging Calibration Products

Data in the peak-up array can be taken in two modes: as part of the target acquisition observations and as part of the imaging mode observations. These data are taken in Double correlated sampling (DCS) and Sample-up-the-ramp (SUR) formats, respectively, and therefore have different calibration

[1]See `http://ssc.spitzer.caltech.edu/irs/calib/overview.html`

Table 5.1: Wavelength ranges for `fluxcon.tbl`

Order	λ_0 (μm)	λ_1 (μm)
SL2	5.21725	7.57612
SL3	7.39467	8.42289
SL1	7.57612	14.71319 *
LL2	14.32338	21.18221
LL3	19.48867	21.52092
LL1	20.50480	35.06922
SH20	9.87869	10.6440
SH19	10.3852	11.2675
SH18	10.9597	11.9091
SH17	11.5927	12.7138
SH16	12.3191	13.5208
SH15	13.1111	14.4122
SH14	14.0293	15.4572
SH13	15.0813	16.6290
SH12	16.3248	17.9587
SH11	17.7800	19.5444
LH20	18.9396	20.6026
LH19	19.7948	21.6951
LH18	20.8270	22.9791
LH17	22.0597	24.2784
LH16	23.4238	25.8011
LH15	24.9553	27.4423
LH14	26.6979	29.3342
LH13	28.7533	31.6452
LH12	31.0186	34.1098
LH11	33.7986	37.0124

* = teardrop starts at $\approx$ 13.44 μm, see chapter §8

parameters. Here we give the approximate calibration for the Acquisition mode. The calibration for the Imaging mode is given in Chapter §6.

Some users may be interested in obtaining rough photometry of the sources in the peak-up acquisition windows. The photometry derived in this way has ∼15% error and it was derived for blue sources (i.e. stars). As discussed in §2, the Peak-Up acquisition algorithm involves taking a set of 3 images for acquisition (ACQ) and a set of 3 images for the sweet spot (SS). Each of these sets of 3 is stacked onboard (without flux conservation) to create an image with units of DN. Thus, there are a total of (3+1) + (3+1) Peak-Up acquisition images. The user should not use the final stacked image (image number 0003) because of the lack of flux conservation.

The units of each of the 6 other images are DN. Convert these to electrons/sec using the following formula:

counts [e^-/sec] = counts [DN] * 4.6 [e^-/DN] / (8 × `SAMPTIME` [sec])

The value of `SAMPTIME` is given by the header. The images can then be combined properly while conserving flux. To convert the resulting aperture photometry from e^-/sec to Jy, multiply by one of the following values:

- Blue - 16μm: 7.29×10^5, when using aperture radius of 3 pixels, with a sky ring from 8 to 14 pixels.
- Red - 22μm: 6.20×10^5, when using aperture radius of 4 pixels, with a sky ring from 8 to 14 pixels.

5.5 Wavelength Calibration Products

b*_wavsamp.tbl: The IRS pipeline, for the purposes of spectral extraction, does not extract whole pixels, but rather subdivides the array into a network of polygon-shaped sampling elements referred to as "pseudo-rectangles" that do not necessarily overlap the rectangular pixel grid. These elements allow Nyquist sampling of spectra in the dispersion direction (to maximize the signal-to-noise at the full resolution), and also accommodate the slight curvature of some of the spectral orders when projected onto the 128×128 pixel grid of the detector arrays. Extraction is performed, therefore, by calculating the signal that would fall within the boundaries of the pseudo-rectangles.

The `b*_wavsamp.tbl` file is an ASCII table that defines the parameters of the pseudo-rectangles in array pixel coordinates. The columns of the table are defined as follows: Column 1 = spectral order, Columns 2 and 3 = x and y coordinates of the center of a given pseudo-rectangle, Column 4 = wavelength (microns) associated with that rectangle. Subsequent columns define the corners of the rectangles. Each pseudo-rectangle will contain some pixels that only fractionally contribute to that element; light is assumed to be evenly distributed within a pixel for the purpose of extraction.

Helpful Aids to the Extraction Process and its Assumptions: The `b*_wavsamp.tbl` file (and its partial-pixel sampling of the 2D image) is the fundamental element of the wavelength calibration (and is used directly within many pipeline modules). The following files are provided for informational purposes. They are not science quality products since they are approximations of the `b*_wavsamp.tbl` file mapped to individual pixels. They do, however, help the observer visualize various useful properties of the 2D BCD images.

b*_wavsamp_omask.fits: A FITS file showing the order number associated with a given region in an image. For the low-resolution modules (LL and SL), the first and second order spectral regions are denoted by 1 and 2 respectively. The bonus order is denoted by the number 3 (although it is really a first order spectrum). For the high-resolution modules (SH and LH), the echelle orders range from m=11 (reddest) to m=20 (bluest).

b*_wavsamp_wave.fits: A wavelength map for a given module showing the wavelength associated with a given pixel. As discussed above, this is only an approximation to the `b*_wavsamp.tbl` file which is used for 1D spectral extraction. (See Figures 5.3 and 5.4.)

b*_wavsamp_offset.fits: A FITS file that gives the distance on the sky in arcsecs from a given pixel to the ridge-line of the field-of-view center.

Figure 5.3: Position of orders in a b*_wavsamp_wave.fits image for SL. First order on the left, second order on the right with the third (bonus) order on top. (This figure is best viewed in color.)

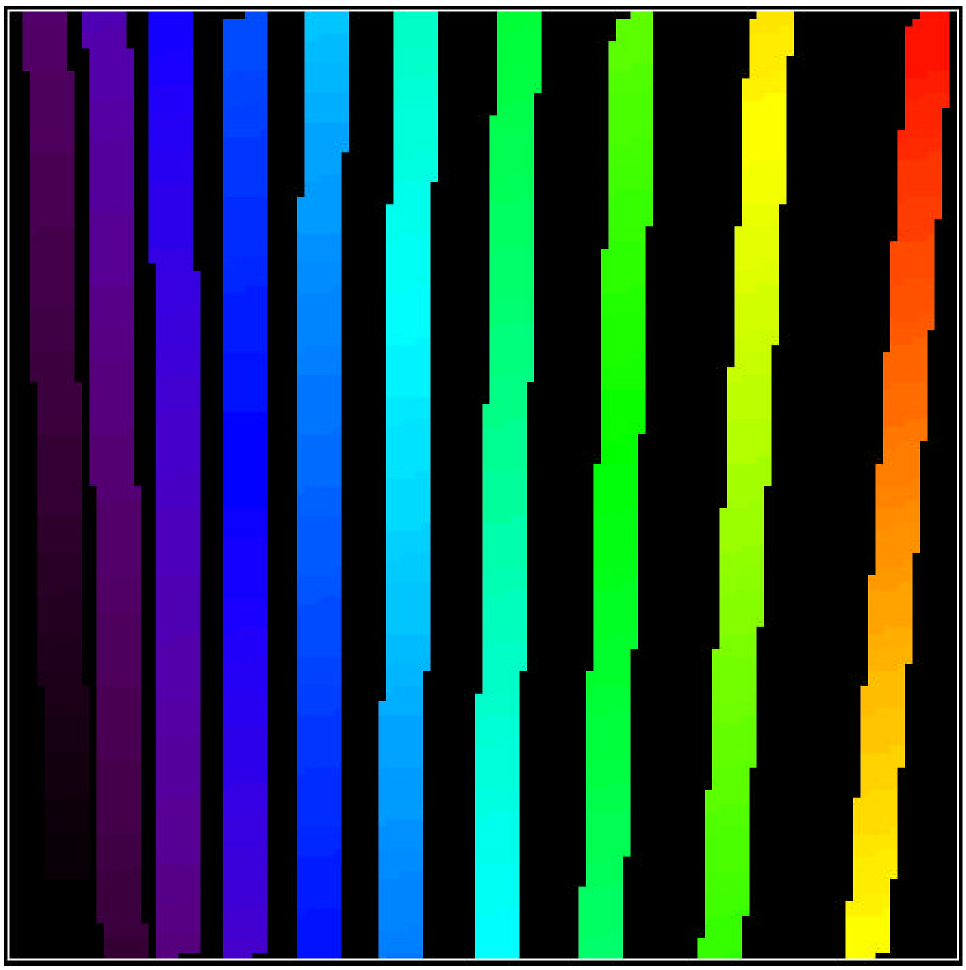

Figure 5.4: Position of orders in a `b*_wavsamp_wave.fits` image for LH. Order 20 is on the left, order 11 is on the right. Wavelengths decrease within an order from top to bottom. (This figure is best viewed in color.)

Chapter 6

Peak-Up Imaging Science Mode

The IRS Peak-Up arrays provide science-quality imaging. Both the red (18.5-26.0 μm) and blue (13.3-18.7 μm) filters are available in this mode. The red filter provides wavelength coverage similar to the MIPS 24 μm mode, but the blue filter covers the wavelength range between that covered by IRAC and MIPS. Peak-Up Imaging (PUI) observations are obtained using a separate AOT and are processed with a separate post-BCD pipeline. Unlike peak-up images taken for the purpose of aligning objects in the slit for spectroscopy, the PUI mode produces science-quality data obtained in the sample-up-the-ramp readout. Tables 6.1 and 6.2 give a list of the products specifically delivered for the Peak-Up Imaging mode.

6.1 Peak-Up Image Characteristics

Parallel red and blue peak-up images are obtained simultaneously on the SL detector. The system's response is shown in Figure 6.1. The field of view seen by each filter is $54'' \times 81''$, and they are separated by a $33''$ wide vignetted zone (see Figure 2.3). The images are 35×45 pixels in size and have a plate scale of $\sim 1.8''$/pixel. The position of the images on the detector is an accurate representation of their position on the sky; that is, the two fields-of-view together with the vignetted region see a contiguous $54'' \times 195''$ area. However, the image distortion varies across this area and is most accurately represented by a separate World Coordinate System (WCS) for red and blue.

Table 6.1: PUI Files Delivered

Basic-Calibrated Data (BCD)			
type.suffix	*Format*	*Data Type*	*File Size (kb)*
full.fits*	128×128	32-bit real	107
func.fits*	128×128	32-bit real	67
bmask.fits	128×128	16-bit integer	37
bcdb.fits*	41×56	32-bit real	31
bcdr.fits*	41×56	32-bit real	31
mskb.fits*	41×56	16-bit integer	8.4
mskr.fits*	41×56	16-bit integer	8.4
uncb.fits*	41×56	32-bit real	48
uncr.fits*	41×56	32-bit real	48
b_msk.fits*	41×56	8-bit integer	22
r_msk.fits*	41×56	8-bit integer	22
Post-BCD Products			
type.suffix		*Data Type*	*File Size (kb)*
b_mos.fits	63×201	32-bit real	59
b_unc.fits	63×201	32-bit real	59
b_cov.fits	63×201	32-bit real	59
r_mos.fits	63×201	32-bit real	59
r_cov.fits	63×201	32-bit real	59
r_unc.fits	63×201	32-bit real	59
mopex.log	-	ASCII table	91
cdf.log	-	ASCII table	0.3
mopex.nl	-	ASCII table	4
Cal files			
type.suffix		*Data Type*	*File Size (kb)*
b0_prf_blue.fits	125×127	32-bit real	67
b0_prf_red.fits	125×127	32-bit real	67

* = Files produced for every DCE.

Table 6.2: PUI Files Description

type.suffix	*Description*
	BCD products
full.fits	2D data before cropping or fluxcal
func.fits	Uncertainty for full.fits
bmask.fits	2D pixel status mask before cropping
bcdb.fits	Cropped, calibrated blue image
bcdr.fits	Cropped, calibrated red image
mskb.fits	BMASK for blue
mskr.fits	BMASK for red
uncb.fits	Uncertainty for blue
uncr.fits	Uncertainty for red
r_msk.fits	MOPEX RMASK for blue
b_msk.fits	MOPEX RMASK for red
out.pline	log of pipeline processing
	Post-BCD products
b_mos.fits	MOPEX mosaic of blue
b_unc.fits	Uncertainty for blue mosaic
b_cov.fits	Coverage map for blue mosaic
r_mos.fits	MOPEX mosaic of red
r_cov.fits	Coverage map for blue mosaic
r_unc.fits	Uncertainty for red mosaic
2mopex.log	log of MOPEX processing
cdf.log	list of post-BCD namelist files
mopex.nl	MOPEX namelist file
	Cal products
b0_prf_blue.fits	PRF for blue
b0_prf_red.fits	PRF for red
other cal files	see Table 2.3 and 2.4

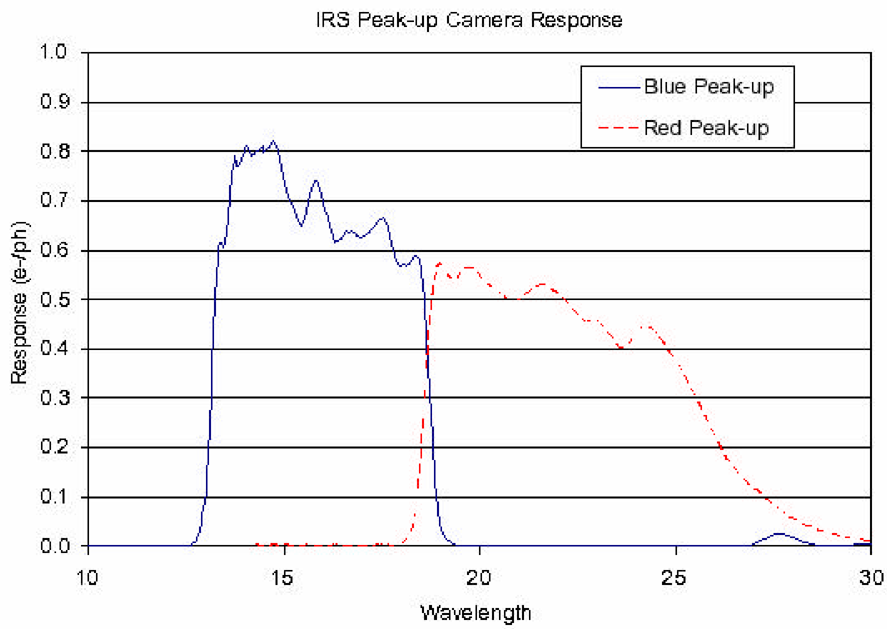

Figure 6.1: PUI response functions, in e^-/photon. This is the product of the detector's responsive quantum efficiency (QE times photoconductive gain) and the filter transmission.

6.1.1 Image Quality

The IRS provides diffraction-limited images through both peak-up filters. The geometric distortion has been accurately mapped and found to be small (see figure 7.31 in the SOM). The plate scale is 1.85″/pixel in the detector X direction, and 1.82″/pixel in the detector Y direction. The magnitude of the distortion causes no more than 1/2 pixel shift at the edge compared to the center of either peak-up array field-of-view. The distortion coefficients are applied to the astrometric solution in the WCS provided in the FITS header of the pipeline-processed data.

The full-width-at-half-maximum (FWHM) of the point spread function (PSF) is ~ 2 (3.6″) in the blue filter, and ~ 2.5 pixels (4.5″) in the red filter. The radius containing 50% of the encircled energy is 1.6 pixels (3.0″) in the blue filter, and 2.2 pixels (3.9″) in the red filter. The curve of growth is discussed below.

6.2 Data Processing

The basic data processing steps for PUI are virtually identical to those for spectroscopy on the SL detector These steps are described elsewhere in this handbook. The sky darks and flat-fields are created specifically for PUI but are applied together with the spectroscopy equivalents whenever the SL detector data is processed:

- **Sky Darks:** As with spectroscopic observations, multiple observations of low background regions of the sky are combined into a calibration file to be subtracted, plane-by-plane in the SUR data, from the science observations. While this sky dark calibration is meant primarily to remove the detector bias voltage and the (relatively small) dark current that accumulates during the exposure, sky emission is also subtracted. However, the zodiacal background is a function of position on the sky and of the time when the data were taken. As a result, many calibrated observations will still have substantial residual sky background. As with all infrared data, it is necessary to plan the observations to provide sufficient measurement of the local sky at the time. Note that the variation of the zodiacal emission during the year may also result in observations in which the standard calibration will over-subtract the background.

- **Sky Flats:** Flat fields are generated from observations of regions of extended emission (e.g., high zodiacal light background). The flat fields are very uniform over the peak-up array fields-of-view, with a standard deviation in relative pixel response of $\approx 1.2\%$.

- **Uncertainties:** The uncertainties provided with PUI are calculated in the same manner used for other IRS data on the SL detector.

- **Cropping:** PUI data are cropped into separate red and blue BCD frames, each 30×45 pixels. The corresponding `bmask.fits` and uncertainty files are cropped in the same way. The edges of the cropped images are slightly vignetted and those pixels are indicated in the `bmask.fits` by the setting of bit 7, which indicates problematic flat-fielding. This bit is considered fatal in the default mosaics, but these pixels may be of interest to some users.

- **WCS update:** Each cropped PUI data file has its FITS header updated to incorporate the world coordinate system, including the FOV-specific distortion corrections.

- **Flux calibration:** The calibration is discussed below. The final BCD pixels have units of MJy/sr. The pixels are rectangular, with an area of 3.367 square arcseconds. Rectified, shifted, coadded images are produced by MOPEX.

PUI observations are taken in dithered and/or mosaicked patterns, similar to those used by IRAC (see section 7.2.3.4 of the SOM). The post-BCD pipeline produces image mosaics using the MOPEX software[1]. The mosaics in the archive do not include a sky subtraction and users may wish to reprocess the BCD data to create sky frames, subtract the sky from the images, and create the mosaic after sky subtraction.

6.3 Photometry

PUI BCD and post-BCD data products have units of MJy/sr, similar to IRAC and MIPS. Photometry may be performed using either the APEX software provided by the Spitzer Science Center[2] or with any standard astronomical software. To convert from the per steradian units of the PUI images to the more familiar flux density units (Jy), multiply by the number of pixels and the number of steradians per pixel. BCD products have a plate scale of 3.367 square arcseconds per pixel. The delivered PBCD products are resampled to $1.8^2 = 3.24$ square arcseconds per pixel.

The PUI calibration assumes that photometry will be measured from the total flux of a source. For example, the calibration is appropriate for the optimal (weighted) point source measurement performed by APEX, using knowledge of the point spread function (PSF). This information is provided in the form of the Pixel Response Function (PRF) provided in the archive; PSF files are available from the SSC website[3], where the difference between the PSF and PRF is discussed in detail.

[1]See `http://ssc.spitzer.caltech.edu/postbcd/`
[2]See `http://ssc.spitzer.caltech.edu/postbcd/`
[3]See `http://ssc.spitzer.caltech.edu/irs/puipsf/`

6.3.1 Photometric Calibration

PUI photometric calibration is performed using observations of standard stars which were selected as primary calibrators of IRAC and MIPS. Standard star "truth" spectra were created from the Kurucz spectra. Standard observations were processed by pipeline S12.0.2. Aperture photometry was performed over an area of 3 and 4 pixel radius for blue and red PU respectively. The sky was subtracted based on a median pixel value in an annular sky region. The zeropoint was corrected from the small aperture to the total using an aperture correction (see below).

A 6% uncertainty is seen between the zeropoints inferred from different standard stars. Repeated observations of one of the stars have so far no shown significant variation in the zeropoint. The calibration was cross checked against red and blue sources sources (galaxies and stars) for which both IRS spectra and PU images exist. Integrating under the spectrum of the sources using the filter throughput and transmission curves gave results which were consistent to the PU values within the reported 6% uncertainty. Photometry was also compared to MIPS24 measurements of extragalactic objects and it was also found generally consistent; however, this comparison will need to be repeated for sources with IRS spectra.

The flux conversion factor from e^-/sec to MJy/sr is 0.01375 MJy/sr/e^-/sec for blue peak-up images. For red peak-up images is 0.01617 MJy/sr/e^-/sec. These flux conversion factors assume that the source spectrum is $\nu F_\nu = \lambda F_\lambda = constant$. A color correction will likely be required. See Section §6.3.3.

6.3.2 Aperture Correction

While PUI calibration assumes that all of the flux from a point source will be measured in photometry, in practice it is often necessary to measure only within a small aperture. Multiplicative point source aperture corrections derived from the PRFs are given below. Note that PUI observations are diffraction-limited, so these corrections will be different for sources with different colors.

```
radius (pix)      blue correction     red correction
------------      ---------------     --------------
```

2	1.69	2.13
3	1.38	1.57
4	1.16	1.36
5	1.07	1.18
6	1.05	1.07
7	1.04	1.03
8	1.03	1.02
9	1.02	1.02
10	1.01	1.01
11	1.00	1.01
12	1.00	1.01

6.3.3 Color Correction

For Peak Up Imaging observations, SSC provides photometrically calibrated data, assuming the source spectrum has the spectral shape $\nu F_\nu = \lambda F_\lambda =$ *constant*. The calculations take into account the full spectral response of the instrument. Due to the so-called "Red Leak" (a small increase in response at about 28 microns) some emission will be detected in the Blue Peak-Up for very cold sources that would not have been detected in a system without the red leak. This translates into small correction factors for very cold sources ($T < 50$ K) observed with the blue filter. While these numbers are formally correct, observers should be very wary of blindly applying them to the data. Longer wavelength observations are advised in this case.

To get the peak-up flux for a non $\nu F_\nu =$ *constant* slope, multiply the flux by the appropriate color correction factor, as given in the SSC website[4].

6.4 Detector Artifacts

Two detector artifacts may affect the quality of processed data:

- **Latent Images:** Bright objects falling on the IRS SL detector can result in persistent charge that appears as a latent image of the object in subsequent exposures. The magnitude of this effect is less than 2% of the source flux, but has a relatively long decay time. Proper dithering

[4]See `http://ssc.spitzer.caltech.edu/irs/calib/colorcorr/`

strategies will mitigate the latent image problem, although with some loss of signal-to-noise on the affected pixels.

A second source of latent charge on the detector is simply the background. As a result, during very long PUI AORs or those in very high background regions, the background level may be seen to rise slowly over time. This effect is stable and varies smoothly, so users may fit the (small) rise in the background and subtract it.

- **Rogue Pixels:** A rogue pixel is a pixel with abnormally high dark current and/or photon responsivity (a "hot" pixel) that manifests as pattern noise in an IRS BCD image[5]. The term "rogue" was used originally to distinguish pixels whose hotness was unpredictable, but now rogue pixel masks include those that are permanently as well as temporarily hot. At current bias levels there are very few rogue pixels in the peak-up windows, however a few are present in some AORs. Proper dithering will mitigate the effect of rogue pixels, but they should be masked before mosaicking.

6.5 Delivered Products

PUI data are delivered with both blue and red products. Each product is described in the table. The processing logs are provided along with the data products. As discussed above, BCD data are individual cropped images from each DCE, while post-BCD processing includes mosaicking by MOPEX. The rough outline of products is:

- **Raw data:** Unprocessed data are provided in a `raw` directory, if they are requested from the archive.

- **Intermediate Data Products:** The archive provides several intermediate products created during pipeline processing. These data are all in units of electrons per second per pixel. These include the last step of 3D data cube processing before the slope is measured (`lnz.fits`), the 2D processed image before flat-fielding (`droop.fits`), the flat-fielded 2D image before cropping (`full.fits`). Along with these products, the corresponding uncertainty and mask files are also provided.

[5] See `http://ssc.spitzer.caltech.edu/irs/roguepixels/faq.html`

- **BCD data:** The red and blue cropped images, after flux calibration, are provided along with their corresponding uncertainty and mask files. The pixels are rectangular. In addition, the RMASK files produced by MOPEX for each blue and red DCE are also provided (see MOPEX documentation for a description).

- **post-BCD data:** The red and blue mosaics, together with their uncertainties and coverage maps are provided. The images have been re-sampled to square pixels. **NOTE: Currently, the headers of the red peak-up post-BCD products are incorrect: they are just copies of the blue products. This issue does not affect the data itself and it will be fixed in a future pipeline update**.

- **cal data:** A large number of cal files are provided with each AOR, most of which are standard for the IRS and are described elsewhere in this document. The PUI specific PRF file for use by APEX is also provided.

Chapter 7

Measurement Uncertainties

This chapter explains the uncertainties associated with all the processing steps.

7.1 BCD Uncertainties

While previous versions of the IRS pipeline did not propagate usable uncertainty estimates along, beginning with S12 the data does include an estimate of a critical part of these uncertainties, namely those associated with fitting the ramp slopes. They are delivered in the file `func.fits`.

These uncertainties are calculated by the IMAGEST module of the pipeline. This module fits slopes and converts from 3D cubes to 2D images (e^-/s). If there are N usable values in the integration ramp of a given pixel and $N \geq 2$ – the usual case – then the mean and standard deviation of the ramp's slope are calculated according to the formulae:

$$D = S_1/N$$

and

$$\sigma_{sample} = \sqrt{S_2/N - D^2},$$

where S_1 = the sum of slopes between neighboring points on the ramp, and S_2 = the sum of the squares of slopes between neighboring points on the ramp.

On a second processing pass, those points on the ramp that differ by more than the standard deviation just calculated are excluded from the averaging process, and the new value for the uncertainty becomes:

$$\sigma_{image} = N_{planes} \times \sigma_{sample}/\sqrt{N-1}$$

where N_{planes} = the total number of planes. This corresponds to the uncertainty in the average highest plane image pixel values.

These uncertainties are typically 0.1% at 5 Jy (for 6 to 14 sec ramps), 0.5 - 1% at 500 mJy (for 30 to 60 sec ramps), and about 10% at 20 mJy (for 120 to 240 sec ramps) in low resolution. At high resolution, they are about 1% at 10 Jy (for 30 to 60 sec ramps).

The uncertainties are propagated during spectral extractions from individual BCDs. During extraction, the BCD uncertainties of individual pixels are summed in quadrature, within a wavelength resolution element, to get the uncertainties quoted in the extraction tables. These uncertainties are in column 4 of the `spect.tbl` and `spect2.tbl` files. However, the part of the pipeline that averages multiple cycles (the 2-D coadder) does not use the uncertainties from the BCD products. The 2-D coadder output uncertainties, in files `c2unc.fits`, are obtained from the standard deviation of the pixel values of individual BCDs. The output spectral uncertainties extracted from 2-D coadder products (col. 4 of the `tune.tbl` files), are based only on the `c2unc.fits` statistical uncertainties. The same is true for the `bkunc.fits` and `bksub.tbl` files.

There are several processing steps in the pipeline that can introduce systematic errors; for example, dark current subtraction or flat-fielding (because dark current and responsivity might not be absolutely constant; also see §8), but the processing does not yet account for any of these. For this and other reasons, the uncertainty values in the science pipeline products usually differ from the true measurement uncertainties that translate into flux density uncertainties. It is important that observers examine the repeatability of their spectra, across multiple cycles and nod positions, to further assess statistical and systematic uncertainties.

7.2 Spectroscopic Flux Calibration Uncertainties

The default PBCD products delivered to the observer assume that the source is a point source. The spectra can then be calibrated by comparing the observations to a model spectrum. As mentioned in §5, for the low resolution modules, HR 7341 (HD 181597) is the primary calibrator. For the high resolution modules, HR 6688 (ksi Dra, HD 163588) is the primary calibrator. The photometric uncertainty introduced by uncertainty in the angular sizes of the standard stars and their spectral types is ± 5%. This is then the smallest uncertainty possible in the absolute flux calibration of the spectroscopic products delivered by SSC. Comparisons with other Spitzer instruments show differences of at most 10%.

Observers using the IRS Staring mode may notice a systematic 5% difference in flux between the extracted spectra at the two nod positions in the low-res modules. This difference is due to uncertainties in the slit positions in the telescope field-of-view. Within a given nod position, pointing uncertanties with high accuracy peak-up will result in photometric uncertainties of ± 2%. Order mismatches between different low-res modules may be as large as 5%.

For the high resolution modules, nod differences are unimportant. Photometric uncertainties due to pointing using high accuracy peak-ups vary from ± 1% (at order 11) to ± 5% (at order 20). In these modules, order curvature of ≈5% (peak-to-peak) is sometimes observed. These may be due to remant errors in the non-linearity or droop corrections, but its exact cause is unknown. In general, order mistmatches are less than 5%.

Even for a noiseless source, line detection is limited by errors induced by uncertainties in the pipeline processing. These uncertainies amount to ±0.5 % per pixel in the low-resolution modules and ±2 % per pixel in the high-resolution ones. For low resolution, these limit the peak of the smallest detectable line to ≈1% of the continuum (if the position is known) or ≈4% of the continuum (if the position is unknown). For the high resolution modules, the values are ≈5% of the continuum (if the position is known) and ≈10% of the continuum (if the position is unknown).

We expect the absolute photometry of the IRS 1D spectral data to improve with future pipeline releases, but we recommend that all observers carefully check their spectra against known photometric values and scale where appropriate, as they would for all narrow-slit spectra taken with any ground- or space-based platform. Also note that within SPICE we provide flux calibration for extended sources assuming a spatially flat profile for the source over the slit and a flat spectrum ($F_\nu \propto \nu^0$). Details about this are given in the SPICE manual.

7.2.1 On Background Subtraction

The mid-infrared background, predominantly from zodiacal light at IRS wavelengths, can contribute significantly to observations of faint targets with the IRS. The arrays are sufficiently sensitive to detect levels of 20 MJy/sr or more at any wavelength. Consequently, we recommend that observers examine their BCD data and use the background estimation tool in SPOT to gauge the background levels, and then weigh these against their science goals.

Ideally, background subtraction should be performed on IRS SL and LL data before any absolute photometric scaling. Since science targets taken in the staring mode are placed at two nod positions along the IRS slits, this background subtraction can be accomplished by differencing the nod positions at the BCD level. Alternatively, off-target spectra for the desired sub-slit that are obtained during observations with the adjacent sub-slit in the same module can be used for background subtraction at the BCD level (e.g., the off-target SL1 spectrum obtained automatically during an SL2-configured observation can be used to background-correct an on-target SL1 spectrum). In this case, the integration time for the adjacent sub-slit observation must be the same as that of the target sub-slit spectrum (it is possible to request different integration times for different sub-slits in the same AOR – this makes background subtraction using the other sub-slit impossible.)

Starting with S13, IRS pipeline performs automated background subtraction on SL and LL Staring mode data using the nodding-method. However, the nodding-method of background subtraction cannot be used with SH or LH data, due to the small size of the slits and size of the PSF. It is also important to realize that even in the low resolution modules, the local background may not be suited to using the nods or alternate slit data for correction of zodiacal light if, for example, the area is crowded or contains extended emission around the science target. Additionally, the AOR itself may have been designed by the original observer in such a way that data suited to background correction were not obtained. These are the principal reasons why the automated background subtraction products called (`bksub.tbl`) should be treated with caution.

If 2D corrections cannot be performed, a first order correction can be made to the extracted spectra based on the expected background. The background estimation tool in SPOT gives a wavelength-dependent estimate of the total background (zodiacal light, cirrus, etc.) for the location and date of a given observation. A crude background spectrum can thus be obtained and, after smoothing, subtracted from the science spectrum.

NOTE: If background corrections are done by the observer using the SL or LL BCDs, then he/she will also need to extract the spectra manually. See the SPICE manual for details on how to extract your own 1D spectrum from IRS data. SPICE also allows observers to specify a region for extraction of a background 1D spectrum, which can then be subtracted from the 1D pipeline products without doing any subtraction at the 2D level.

7.3 Wavelength Calibration Uncertainties

Wavelength calibrations are built up primarily from observations of P Cyg, HDE 316285, NGC7027 and NGC6543, SMP 83, y Cas, and WR 6, exhibiting "usable" lines of H I, He II, [Ne II], [Ne III], [Ne V], [S III], [S IV], [Si II], [Fe II], [Fe III]. Bright extragalactic line measurements have also proven essential to adjusting the calibration in spectral regions that do not include bright Galactic lines. The SH calibration has been refined further by using observations of Titan.

The IRS wavelength calibration is generally good to $\approx 1/5$ of a resolution element. Following are the r.m.s. wavelenght residuals for the lines used in the calibration. For spectral regions that are not well-covered by calibrations lines, larger errors are posible. The high resolution modules r.m.s. values are averaged over all orders. To transform to per pixel values, the user should remember that the unresolved line width is always assumed to be 2 pixels.

- SL1:$\pm 0.009\mu$m
- SL2:$\pm 0.006\mu$m
- SL3:$\pm 0.007\mu$m
- LL1:$\pm 0.036\mu$m

- LL2:$\pm 0.034\mu$m
- LL3:$\pm 0.028\mu$m
- SH: $\pm 0.003\mu$m
- LH: $\pm 0.01\mu$m

Some orders were difficult to cover with spectral lines from calibration sources (e.g., SH order 14) and the wavelength solutions for these have been updated by referencing nearby galaxies with accurate recessional velocities and strong lines.

It should also be emphasized that a pointing offset could cause a shift in the wavelength of a line. For example, a 0.5 pixel offset (due to pointing error or incorrect coordinates) in the position of a source within the slit could shift the wavelengths of that observation by a few tens of a pixel.

The wavelength calibration solution does not take into account the spacecraft velocity which can be ± 30 km/s. Observers who care about this level of precision in their wavelength calibration are encouraged to determine the spacecraft velocity along the line of sight to their target using the JPL Horizons web-based calculator[1].

We have also measured the variation of spectral resolution with wavelength for the different modules. For the SH and LH modules, the resolution is constant at R$\sim$600 with wavelength. For the SL and LL modules, the resolution varies from the blue end of the spectrum to the red end as shown in Figures 7.1 and 7.2.

[1] See `http://ssd.jpl.nasa.gov/?horizons#note`

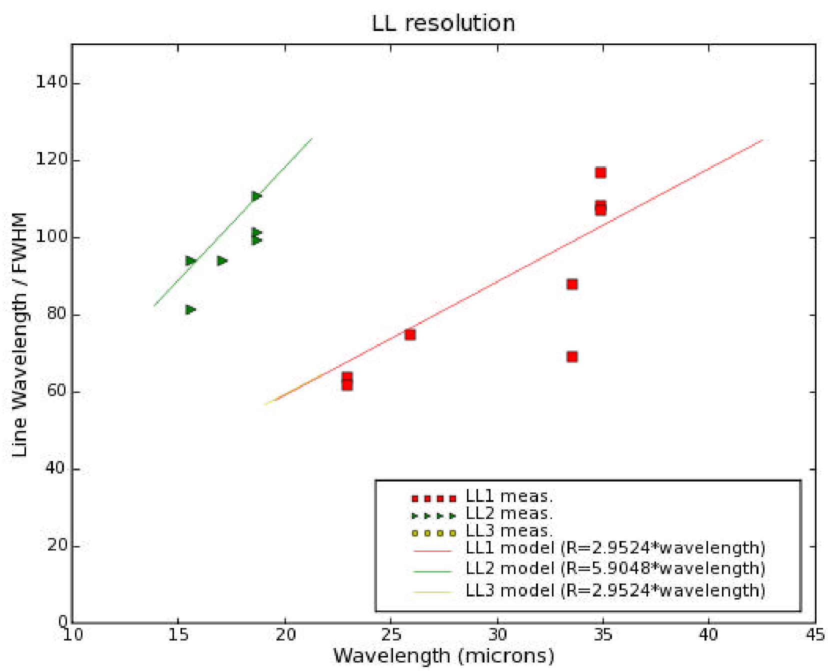

Figure 7.1: Measured LL resolution. The scatter is due to PSF undersampling and pointing errors

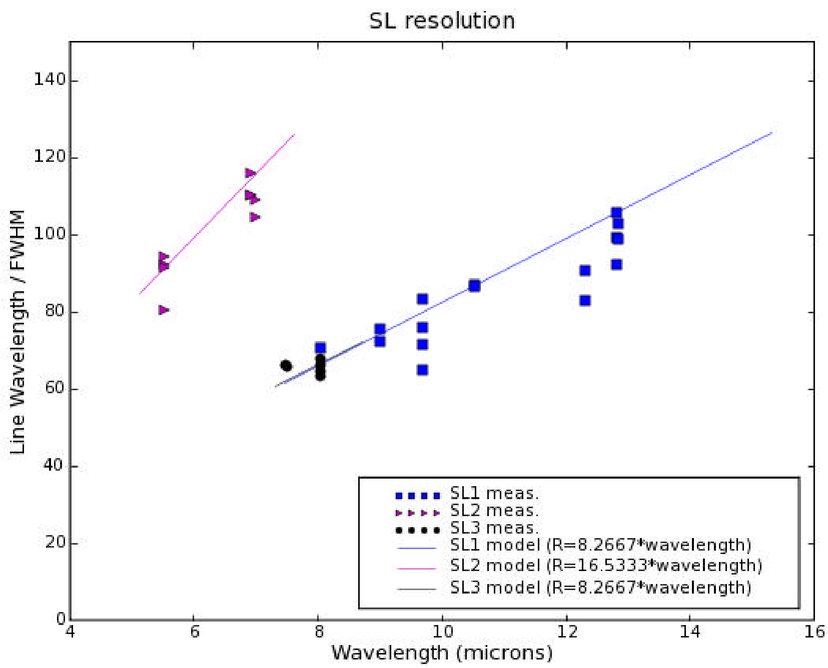

Figure 7.2: Measured SL resolution.

Chapter 8

Characteristics of the Processed Data

While the data produced by the pipeline are generally of very high quality, there are a number of characteristics which are apparent and require some explanation.

8.0.1 The Teardrop

IRS observers using the SL1 (Short-Low, first order) module may notice excess emission between 13.2 and 15 microns in their pipeline-processed data (for pipelines S13 and above). We refer to this feature as the "14 micron teardrop", and it is shown in Figure 8.1. While this excess was present in previous pipeline-processed data, it is only the improved quality of the calibration for S13 and beyond that has allowed us to isolate this feature. We now remove this wavelength region from our fits to the calibrator spectra. We believe that the teardrop is a type of scattered light, but it's origins are not well understood, and are currently under investigation. The amplitude of the excess varies with the source strength and the extraction aperture, since the teardrop is spatially extended. The difference between the S12 and S13 processing for a point source extraction can be 10% as shown in Figure 8.2. For a point source, the flux ratio between the default point source extraction width (8 pixels at 12 microns) and full slit extraction shows an excess of up to 15%, longward of 13.2 microns, compared to the ratios at adjacent shorter wavelengths. We strongly caution the users against interpreting any broad features longward of 13.2 microns in SL1.

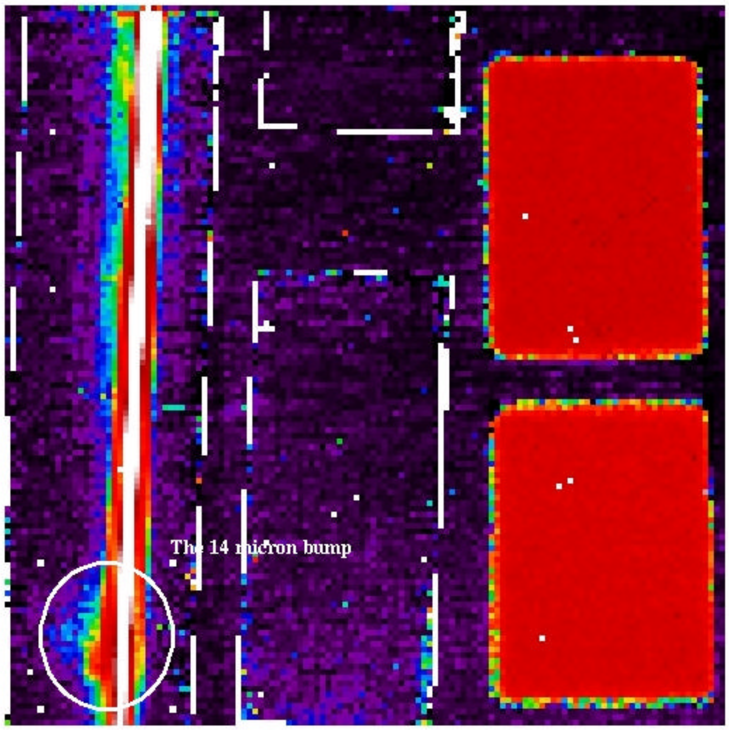

Figure 8.1: The teardrop, which appears as an excess emission at about 14 microns.

8.1 Warm/bad Pixels and NaNs in IRS data

Early in the mission, all four IRS arrays were subjected to powerful solar flares that deposited the equivalent dose of protons expected over 2.5 years in only two days. This damaged 1% of the SL and SH pixels, and 4% of the LL and LH pixels. The greatest science impact is to the LH module because the illuminated portion of the orders subtends only a few pixels in the spatial direction, making it more difficult to recover lost information by nodding the source along the slit. These damaged pixels are masked from data processing, by assigning NaN status to them. This prevents numerical operations from being affected by their presence. Assigning any other real number would lead

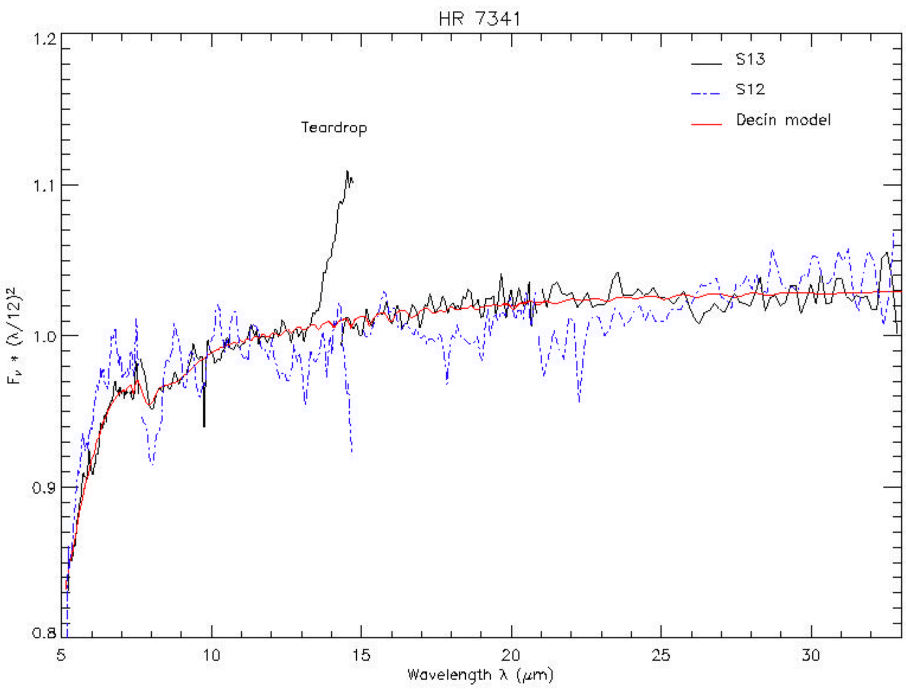

Figure 8.2: Difference between S12 and S13 processing for HR 7341. Before S13, the teardrop was "absorbed" in the rest of the order.

to improper processing of the surrounding signal information, such as during the extraction process. By default, EXTRACT interpolates over the NaN pixels.

Occasionally, it is possible for warm/unstable pixels to propagate through the pipeline without being flagged as NaNs. In this case, these spurious pixel values will be extracted and appear as sharp spikes in the final spectrum. Such features should be readily recognizable as spectral features which are too sharp to be real. The IRSCLEAN_MASK routine which was been released by the SSC[1] enables observers to visually inspect such pixels and interpolate over them. If there is any doubt about the reality of a given spectral feature seen in an extracted spectrum, we recommend that the observer always examines the 2D BCD images to confirm that the feature shows the expected spatial and spectral dispersion on the array.

[1]See `http://ssc.spitzer.caltech.edu/archanaly/contributed/browse.html`

8.2 Order Mismatches between SL and LL

In some cases, observers may see "jumps" in flux between the SL and LL spectral orders for a source observed with both modules. These jumps are typically less than 5%, once background emission from zodiacal dust and cirrus have been removed. Note that the point source calibration is based on an average of multiple observations of the standard star. Due to differences in the fluxes of each nod (Section §7.2) an individual observation may show order mismatches between SL and LL.

Application of the extended source calibration might also cause order mismatches since the extended source calibration functions assume a spatial and spectral profile for the source that may be different from the target of interest. The best way to calibrate order mismatches is through broadband photometry of the source.

8.3 Horizontal Stripes in SL (and possibly in SH and LH) Data

Horizontal stripes (of reduced signal), which stretch from the peak-up areas through the SL spectra, may be present in some SL BCD products. When present, the stripes can be seen in the `bcd.fits` product, and manifest themselves as unexpected absorption features in the spectral extractions (1D data). The stripes are caused by an over-subtraction of the peak-up stray light (see the discussion in the SOM) at the locations of the spectral orders. Figure 8.3 shows an example of this kind of problem. The key distinguishing factor between this effect and a real absorption feature is that the stray light over-subtraction will extend over a large part of the array, and is not limited to the SL2 or SL1 spectral orders. Observers should examine the 2D BCDs in all cases, but especially when an unexpected absorption feature is seen in the 1D spectra. The SL stray light removal algorithm uses a mask file and bad pixel map that are frequently updated at the SSC. However, in cases of severe stray light or if new bad pixels appear that are not yet masked, then the correction can go awry.

A similar (though not identical) effect can occur in the high-resolution modules, for which a row-by-row fit is made to the shape of the spectral orders for inter-order cross-talk correction. As with SL stray light, a cluster of new bad pixels could potentially cause the SH or LH inter-order stray

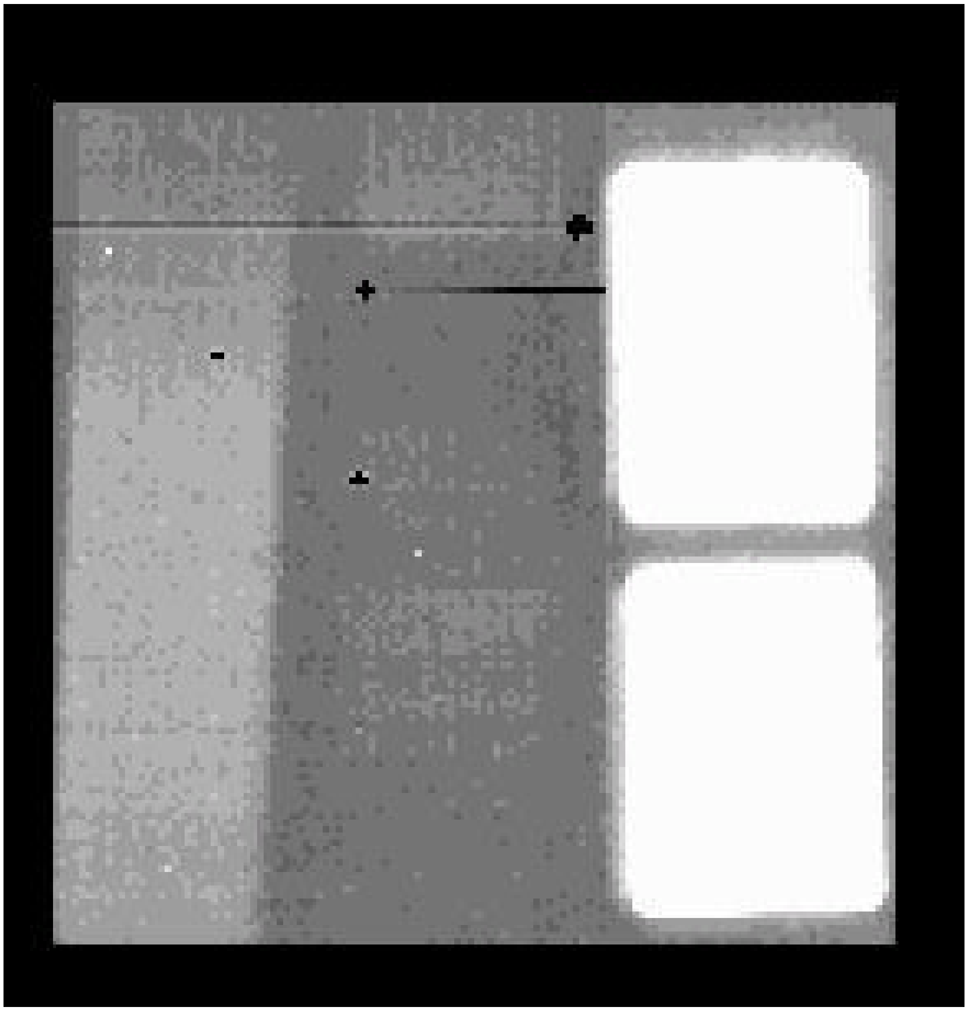

Figure 8.3: SL image affected by horizontal stripes. Notice that the dark horizontal rows are not confined to the spectral orders, and terminate in clusters of bad pixels.

light correction to misbehave, leading to a spurious apparent absorption or emission feature. This latter problem was seen in earlier versions of the pipeline, and safeguards are in place to mitigate against this effect. The incidence of this problem is likely to be very low in the current pipeline, but observers should be aware of it as a potential problem – especially if the radiation environment of the detectors was to change suddenly as a result of a solar storm. Observers are advised to carefully inspect the BCD data for any suspicious horizontal (row) bands of negative or positive pixels that extend over the full width of one or more high-resolution spectral orders in the same row. The problem, if it occurs, will be obvious in the stray-light-corrected product. Unlike the SL overcorrection problem, the high-resolution effect does not generally extend over the full length of a row, but affects only one or more orders over a limited number of rows.

As insurance against possible artifacts introduced by over- or under-correction of the stray light, in all SL, SH, and LH data, we provide both corrected (`bcd.fits`) and uncorrected (`f2ap.fits`) 2D data, and provide extractions from both products (`spect.tbl` and `spec2.tbl`). If an apparently "new" deep absorption feature is found in data from any of these modules in an unexpected place in the spectrum, then the observer can compare the corrected and uncorrected spectra to see if the feature has been introduced by the stray light correction. If the suspicious feature is only seen in the corrected spectra, then this is a strong indication of a problem, and the observer should then inspect the BCD data to identify the problem.

SPICE allows observers to extract 1D spectra from BCDs that have not been stray-light-corrected if the corrected extractions provided by the SSC at this stage do not meet the observers' science needs.

Chapter 9

Bit Masks

Pixel status is tracked in the pipeline with several masks. In each mask, individual bits are set for each pixel that meets a particular condition. Some conditions are permanent, while others are peculiar to the current DCE (such as cosmic ray hits). Several steps in the pipeline update the current pixel status. Ultimately, each wavelength in the extracted spectrum will have a status flag that is derived from all pixels that contribute to that wavelength. In this chapter, we describe the most important masks and the condition that causes each bit in them to be set. Here we describe the masks that are of most interest to the user. **WARNING: Different masks do not always use the same bit to indicate the same condition.**

9.1 Pixel Mask – `pmask.fits`

The two-dimensional "pixel mask" **`pmask.fits`** tracks semi-permanent bad pixel conditions. This file is the same for many different AORs. Table 9.1 describes the bit flags set in the PMASK. For example, "hot" pixels are saturated all of the time. "Warm" pixels are those immediately adjacent to permanently hot pixels; some bleeding into the former is evident. Typically, a hot pixel is surrounded by ~4 warm pixels.

9.2 DCE Mask – `dmask.fits`

The three-dimensional "DCE mask" **`dmask.fits`** stores pixel conditions encountered during a pipeline run. It is created by CVTI2R4 module very early

Table 9.1: PMASK Bit Settings

Bit #	*Condition*
0	Not used
1	Not used
2	Not used
3	Not used
4	Not used
5	Not used
6	Not used
7	Dark current is too variable (dark calibration accuracy will be unacceptably low)
8	Response to light is too variable (photometric accuracy will be unacceptably low)
9	Pixel response to light is too high (unacceptably fast saturation)
10	Pixel dark current is too excessive (pixel is hot)
11	Not used
12	Not used
13	Not used
14	Pixel's response to light is too low (pixel is dead)
15	Reserved: sign bit

in the pipeline, and updated up to the last step in the pipeline that operates on the 3D data cube, LINEARIZE. Typical conditions masked are saturation, radiation hits, data "missing" in downlink, uncorrectable non-linearity, etc. Each of these conditions are identified sample-by-sample in the 3D FITS file. Table 9.2 describes the conditions that cause each bit to be set. This mask may be useful in the case of a solar storm, which will result in an unusually high number of cosmic rays. In this case, bit 9 will be set in each sample that received a hit. If more than one sample per pixel has bit 9 set, the data from that pixel should be regarded with suspicion.

9.3 BCD Mask – `bmask.fits`

The two-dimensional "BCD mask" `bmask.fits` is the pixel status mask associated with the fully processed two-dimensional BCD product. The `bmask` is used to describe the status of both the `bcd.fits` data and the `f2ap.fits`

Table 9.2: DMASK Bit Settings

Bit #	*Condition*
0	Incomplete or questionable mux bleed correction (MUXBLEED-CORR)
1	No row droop correction applied (ROWDROOP)
2	Radhit detection was done (RADHIT)
3	Digital saturation detected (CVTI2R4)
4	Saturation corrected by IMAGEST mode 2
5	Latent-image flag
6	Droop removed using questionable value (DROOPOP)
7	Not used
8	Not used
9	RADHIT detection
10	Baseline adjustment failed (reserved for BASECAL)
11	Data bad (initial `dmask`; RADHIT checks this bit)
12	Non-linearity correction could not be computed (LINEARIZ)
13	Saturated - beyond correctable non-linearity (LINEARIZ)
14	Data missing in downlink (CVTI2R4)
15	Reserved: sign bit

data. It stores pixel conditions encountered during the entire pipeline run. The `bmask` uses the `dmask` as input, masking the same conditions. However, sample-to-sample information is not retained. Instead, if one or more samples along a ramp are flagged in the `dmask`, then the corresponding pixel is flagged in the `bmask`. Additional conditions flagged in the `bmask` (on a pixel-by-pixel basis) are:

- Only one or zero samples were used to compute a slope (bits 12 or 13)
- Flat-field was not applied or was questionable (bits 7 or 8).
- Stray light removal or cross-talk correction was not applied (bit 9).
- Pixel masked in the `pmask` (bit 14).

Table 9.3 describes the conditions that cause each bit to be set. The extraction pipeline considers bits 7, 12, 13, and 14 as fatal and it ignores them. Bit 7 is considered fatal because it is used to signal the region in which the flat

Table 9.3: BMASK Bit Settings

Bit #	*Condition*
0	Not used
1	Latent-image flag
2	Digital saturation detected in sample(s) along ramp
3	RADHIT detection along ramp in sample(s) along ramp
4	Non-linearity correction could not be computed in sample(s) along ramp
5	Data bad (initial `dmask`; RADHIT checks this bit) in sample(s) along ramp
6	Droop or rowdroop removed using questionable value in sample(s) along ramp
7	Flat-field applied using questionable value (FLATAP)
8	Flat-field could not be applied (FLATAP)
9	Stray-light removal or cross-talk correction not applied
10	Saturated – beyond correctable non-linearity in sample(s) along ramp
11	Data missing in downlink in sample(s) along ramp
12	Only one usable plane
13	No usable planes
14	Pixel masked in `pmask`
15	Reserved: sign bit

changes very rapidly (at the edges of the slit). Although the setting of bit 8 ("no flat applied") also marks a 'fatal' condition, it is used on un-illuminated regions of the slit, and is irrelevant for the extraction pipeline.

9.4 Coadd Mask – `c2msk.fits`

The two-dimensional "Coadd 2D mask" `c2msk.fits` is produced by the 2D coadder. The coadd module generates a weighted average of multiple DCEs and performs outlier rejection; it omits pixels that are fatally flagged in the `bmask`. The output mask, the `c2msk`, does not preserve information on which fatal bit condition was set. The only conditions masked are: too few values were coadded for the pixel (currently < 1), and pixel fatally masked in `bmask`. Table 9.4 describes the conditions that cause each bit to be set.

Table 9.4: C2MSK Bit Settings

Bit #	*Condition*
0	Not used
1	Not used
2	Not used
3	Not used
4	Not used
5	Not used
6	Not used
7	Flat-field applied using questionable value
8	Not used
9	Not used
10	Not used
11	Not used
12	Not used
13	Not valid planes are available to coadd
14	Not used
15	Reserved: sign bit

9.5 Masked Pixels in the Extracted Spectra – `spect.tbl`, `spec2.tbl`, `tune.tbl`, `bksub.tbl`

Extracted spectrum tables include a status flag for each wavelength. Multiple pixels contribute to each wavelength, and some wavelengths include fractions of some pixels. The status flag is the result of a bit-wise "OR" operation on the pixel status flags in the 2D mask file for all contributing pixels. That is, each bit in the spectrum flag is set if it was set in any of the contributing pixels, even those that contribute only fractionally to the wavelength. No information is retained about which of the contributing pixels had which status.

The definition of the bits in the status flag is the same as in the mask corresponding to the data from which the spectrum was extracted. Thus, the `spect.tbl` and `spect2.tbl` tables have flags with the same definition as the `bmask.fits` (see Table 9.3); `tune.tbl` tables have flags with the same definition as the `c2msk.fits` (see Table 9.4). Some status flags in the `bmask` are "fatal," meaning that no usable information was contained in the flagged pixel. For example, bit 13 ("no usable planes") is fatal. Other flags suggest that the pixel is highly suspect, but may still be of interest for some programs.

Chapter 10

How to Reduce Spectroscopic Data

Beyond the delivered pipeline products, it is likely that the user will want to carry out the reduction further. A general description of the required procedures is provided here. The main tool provided by the SSC to reduce spectroscopic IRS data is the Spitzer IRS Custom Extraction (SPICE) software. SPICE is mainly an interface to the extraction pipeline and it does execute the same extraction modules in order. Other software programs, like SMART, are also available. See `ssc.spitzer.caltech.edu/archanaly/contributed`.

Notice that if the user is interested in low resolution observations of point sources in relatively empty fields, the sky-subtracted product `bksub.tbl` may be enough for most of his/her purposes.

10.1 Basic Information

1. Identify the date/time and campaign in which your IRS data were taken.

2. Download the campaign dependent rogue pixel masks for your data from http://ssc.spitzer.caltech.edu/irs/roguepixels/

3. Download and install `IRSCLEAN_MASK`, an IDL based package to detect and clean hot pixels. Also download and install SPICE, the main tool to extract IRS spectra from the data files.

4. If you have extended sources or low S/N point sources, download the calibration star data taken in that campaign using Leopard: this will be useful to apply flux calibration corrections for different extraction aperture widths. Calibration data are typically taken as Program ID 14xy where xy is the Campaign number. So, for example, cal data taken in Campaign 19 will be in PID 1419. Also, cal stars typically have sky observations with them: download these as well. A list of the cal stars taken in the last campaigns is available from the SSC website (ssc.spitzer.caltech.edu/irs/calib/Campaign_List.html).

10.2 Sky Estimates

10.2.1 High Resolution Data

5. If you have SH/LH data (or have extended sources which fill your slit in LL/SL) you should have taken sky observations close in time to your science observations. In addition to correcting for the strong, variable background, the sky observations help significantly alleviate the effects of rogue pixels, which are numerous in LH.

6. If for some reason, you have not taken dedicated sky observations, search the archive for blank sky observations taken within 24 hours of your target data. If these sky observations are not at similar ecliptic latitudes as your targets, you will have to apply a background scaling factor to be able to use these as a sky for your data. Also, be careful that you do not add noise to your data in the sky subtraction phase by choosing archival data which have comparable/longer integration times than your data frames. There is no guarantee that such sky observations exist in the archive so if you have not considered step 5 when designing your AORs, you are risking significant flux calibration uncertainties.

7. If you have low res observations taken close in time, you can interpolate the sky values extracted from those data to derive the background at high res wavelengths.

8. You can obtain approximate background values for the date of your observations for a range of wavelengths using SPOT. These are in MJy/sr

and you will have to multiply these by the solid angle of the slit width $\times$ extraction width and convert to Jy before subtracting them from your data. This is the least accurate technique.

10.2.2 Low Resolution Data: Point Sources

9. If you have SL/LL staring mode data, since a point source does not fill the slit, you can do a sky subtraction by subtracting the BCDs between the two nod positions. This is the preferred option if the slit does not have other sources in it and your target is faint.

10. Alternately, you can extract a sky in the off source subslit. So for example, if you are observing a source with both SL1 and SL2 in your AOR, when the source is in SL2, you can extract a sky from SL1 and vice-versa. Be sure to check that the off source subslit does not have serendipitous sources before extracting a sky.

10.2.3 Low Resolution Data: Extended Sources

11. If you have extended sources which fill most of your slit in LL/SL, it is strongly recommended that you have close in time sky observations built into your AORs.

12. You can obtain approximate background values for the date of your observations for a range of wavelengths using SPOT. These are in MJy/sr and you will have to multiply these by the solid angle of the slit width * extraction width and convert to Jy before subtracting them from your data in Step 10. This is the least accurate technique.

10.3 Data Reduction Steps

1. Be sure to have at least two cycles for staring mode observations: this will yield at least 4 sets of spectra and enable outlier rejection.

2. For long duration (>1 hour) integrations on very faint (<1-3 mJy) sources, the user should read "Report on ultradeep IRS spectroscopy of faint sources" (ssc.spitzer.caltech.edu/irs/imptnotes.html). You should

search for any charge accumulation (especially for high background and long integrations) by fitting ramps to the signal as a function of time. That is, take the median of each row (or 2-3 rows) within an order, in each BCD and see if the median of the same group of pixels increases with time. If so, fit a 1D polynomial to these median values and subtract the slope off. In LL, we have found that 1-2% of the charge persists on the detector between frames despite the resetting of the detector prior to each integration. This latent charge decays very slowly and is completely removed only by the anneals of the detector.

3. Subtract the 2D sky that you get either from your sky observations or calibration data from your 2D BCDs. If you have not found appropriate sky observations and are relying on the SPOT background values to do background subtraction, you will do the sky subtraction in step 10.

4. Use IRSCLEAN_MASK to mask known rogue pixels and flag any other pixels which look bad in your `bcd.fits` files. Rename the cleaned files as `clean_bcd.fits`

5. Create 2D sigma-clipped averages or medians of your 2D `clean_bcd.fits` files using IDL/IRAF for each nod position. You now have outlier cleaned, rogue pixel masked, background subtracted BCDs (`super_bcd.fits`). If you have only 2-3 cycles of staring mode data, you can skip this step and instead jump to step 8 using the `clean_bcd.fits` files as the `super_bcd.fits` files.

6. For SL and LL, subtract the average files from step 5 for each nod position from each other. This is the accepted procedure for sky subtraction if you observe point sources with low res. However, if you have an extended source which fills a significant fraction of the slit, skip this step and go to step 7.

7. For SH/LH, execute steps 2,3,4,5 on your sky observations. For extended sources observed with SL/LL, you will have to do steps 2,3,4,5 on your sky observations.

8. Run SPICE on your `super_bcd.fits` files, doing the basic steps of Profile, Ridge, Extract and Tune. Feel free to play around with extraction apertures to maximize signal to noise in your spectrum. But

pay careful attention to the fact that if you change the extraction apertures from the default, your flux calibration will need to be redone as outlined in step 11. In general, the default extraction apertures work well for point sources. For extended sources, you will probably have to do a full slit extraction. The S13 SPICE extended source calibration assumes that the source has a uniform surface brightness within the slit and has a flat spectrum with wavelength. It calculates the slit loss correction factor based on that assumption.

9. You now have two `spect.tbl` files (the output of Tune), one for each nod position which you can average together. If you ran step 8 directly after step 4, then you have spect.tbl files for each cycle. Average together all these `spect.tbl` files using some sigma clipping criterion to reject outliers.

10. If you have not yet done sky subtraction, subtract the sky background that you get from SPOT, from your spectrum.

11. If you have changed the extraction width from the default, you will have to apply a flux calibration correction. For a point source, this is essentially a ratio of the flux from a calibration star using the default extraction width to the flux from the same star using your extraction width. Multiply this ratio (which is wavelength dependent) to the spectrum from steps 9 or 10. Be sure that you have done exactly the same steps of rogue pixel masking, background subtraction and SPICE extraction on the calibration star as you have done for your target, before you estimate the flux calibration correction.

12. Finally, trim the edges of the orders: they are noisy and you need to reject the first few and last few pixels. You should have a nicely matched spectrum with orders matched and properly flux calibrated (this is less certain if you obtained the sky background from SPOT rather than from real observations).

13. Check flux calibration by comparing the flux in the spectrum with broadband imaging observations. It is also useful to extract a spectrum from a blank part of the slit in your reduced 2D spectrum (`super_bcd.fits`) from step 8 to check if there is any residual sky or latent charge remaining.

10.4 Line Fits

1. Use IDEA, the line fitting tool which is a part of SMART to fit lines, obtain equivalent widths etc. Or use your favorite IRAF or IDL package.

2. Be sure that lines are present in both nod positions (or multiple bcd files) for reliability.

3. Be sure that the line is not the 13 micron teardrop known to exist in the data.

4. Be sure that the FWHM of the lines are reasonable i.e at least the spectral resolution of the instrument.

5. Do not mistake rogue pixels/cosmic rays for lines by carefully inspecting the time history of pixels. When doing full slit extraction for SH/LH, the rogue pixels (since they only decay slowly with time) can appear in both nod positions in the spectrum while cosmic rays will appear only in one nod.

6. If you have undertaken all these steps, you can write your paper !

Appendix A

Example BCD.FITS Header

```
SIMPLE  =                    T / Fits standard
BITPIX  =                  -32 / FOUR-BYTE SINGLE PRECISION FLOATING POINT
NAXIS   =                    2 / STANDARD FITS FORMAT
NAXIS1  =                  128 /
NAXIS2  =                  128 /
ORIGIN  = 'Spitzer Science Center' / Organization generating this FITS file
CREATOR = 'S13.2.0 '           / SW version used to create this FITS file
TELESCOP= 'Spitzer '
INSTRUME= 'IRSX    '
CAL_SET = 'C13.0PRE25.A'       / ID for the set of CAL files used
CHNLNUM =                    2 / 0=SL, 1=SH, 2=LL, 3=LH
FILENAME= 'IRSX.2.0015333376.0008.0000.01.mipl.fits' / File name
EXPTYPE = 'sfx     '           / Exposure Type
REQTYPE = 'AOR     '           / Request type (AOR,IER, or SER)
AOT_TYPE= 'IrsStare'           / Observation Template Type
AORLABEL= 'calsfx-22A-HR7341'  / AOR Label
FOVID   =                   44 / Field of View ID
FOVNAME = 'IRS_Long-Lo_2nd_Order_1st_Position' / Field of View Name
READMODE= 'RAW     '           / Readout Mode

          / PROPOSAL INFORMATION

OBSRVR  = 'YOUR NAME HERE'          / Observer Name
OBSRVRID=                   21 / Observer ID of Principal Investigator
PROCYCL =                    3 / Proposal Cycle
PROGID  =                 1422 / Program ID
PROTITLE= 'SIRTF IRS Calibration Program' / Program Title
PROGCAT =                   32 / Program Category

          / TIME AND EXPOSURE INFORMATION
```

```
DATE_OBS= '2005-06-30T00:36:32.011' / Date & time at DCE start
MJD_OBS =            53551.025 / [days] MJD at DCE start (JD-2400000.5)
UTCS_OBS=        173363792.011 / [sec] J2000 ephem. time at DCE start
SCLK_OBS=        804559191.925 / [sec] SCLK time (since 1/1/1980) at DCE start
SAMPTIME=               1.0486 / [sec] Sample integration time
REQMODE =                    5 / ID for mode or type of request
EXPSTRTC=            804559184 / Exposure Start Timestamp Coarse
EXPSTRTF=                36993 / Exposure Start Timestamp Fine
GRPARVTC=            804559207 / [sec] Coarse Spacecraft Group Time
GRPARVTF=                    0 / [sec] Fine Spacecraft Group Time
AIRSCMDN=                    2 / Commanded number of DCEs for IRS
AIRS_DET=                    2 / Selected IRS detector for exposure command
AIRSEXPM=                    1 / Current Mode of the IRS Exp Manager
GRPTIME =               2.0972 / [sec] Group (w/ spin) integration time
DEADTIME=               6.2916 / [sec] Reset + boost(s) time
RAMPTIME=                31.46 / [sec] Ramp (total DCE) integration time
EXPTOT_T=                62.92 / [sec] Integr. time for all DCEs in exposure
AIRSERCT=                    0 / Number of IRS exposure errors

          / TARGET AND POINTING INFORMATION

OBJECT  = 'HR 7341 '           / Target Name
OBJTYPE = 'TargetFixedSingle'  / Target Type
RA_HMS  = '19h18m36.8s'        / [hh:mm:ss.s] RA_SLT or CRVAL1 in sexagesimal
DEC_DMS = '+49d33m45s'         / [dd:mm:ss] DEC_SLT or CRVAL2 in sexagesimal
RA_RQST =     289.657841111111 / [deg] Commanded RA referenced to commanded FOV
DEC_RQST=     49.5695133333334 / [deg] Commanded Dec referenced to commanded FOV
PA_RQST =     20.6751479983268 / [deg] Requested pos. angle of axis 2 (E of N)
PM_RA   =                0.021 / [arcsec/yr] Proper Motion in RA (J2000)
PM_DEC  =                0.045 / [arcsec/yr] Proper Motion in Dec (J2000)
CRDER1  = 0.000301188438205456 / [deg] Uncertainty in RA of SI boresight
CRDER2  = 0.000301342495149151 / [deg] Uncertainty in DEC of SI boresight
SIGRA   =   0.0163623362235713 / [arcsec] RMS dispersion of RA over DCE
SIGDEC  =   0.0157579332698576 / [arcsec] RMS dispersion of DEC over DCE
SIGPA   =   0.0707856579751057 / [arcsec] RMS dispersion of PA over DCE
PTGDIFF =    0.169410034412867 / [arcsec] offset btwn actual and rqsted pntng
PTGDIFFX=    0.142544256798727 / [arcsec] requested - actual pntg along axis 1
PTGDIFFY=  -0.0915884819061654 / [arcsec] requested - actual pntg along axis 2
RA_REF  =         289.65784111 / [deg] Commanded RA (J2000) of ref. position
DEC_REF =          49.56951333 / [deg] Commanded Dec (J2000) of ref. position
USEDBPHF=                    T / T if Boresight Pointing History File was used.
RMS_JIT =   0.0148661606969589 / [arcsec] RMS jitter during DCE
RMS_JITY=   0.0126887900940979 / [arcsec] RMS jitter during DCE along Y
RMS_JITZ=  0.00774579497635506 / [arcsec] RMS jitter during DCE along Z
```

```
RA_FOV  =     289.657854765625 / [deg] RA at FOVID averaged over DCE
DEC_FOV =     49.5694671093752 / [deg] DEC at FOVID averaged over DCE
PA_FOV  =     21.8768490624992 / [deg] PA at FOVID averaged over DCE
RA_SLT  =     289.653479765625 / [deg] RA at slit center averaged over DCE
DEC_SLT =     49.5624004843752 / [deg] DEC at slit center averaged over DCE
PA_SLT  =     21.8735190624991 / [deg] PA at slit center averaged over DCE
CSDRADEC= 8.12185305643438E-06 / [deg] Costandard deviation in RA and Dec
CSD_JTYZ=  0.00275422466464332 / [arcsec] Costandard deviation of jitter in YZ
BPHFNAME= 'BPHF.0804556800.02.pntg' / Boresight Pointing History Filename
FOVVERSN= 'BodyFrames_FTU_20b.xls' / FOV/BodyFrames file version used

          / PHOTOMETRY (IRS IMAGING)

BUNIT   = 'e-/sec  '           / Units of image data

          / SPECTROPHOTOMETRY IRS SL, LL (CHNLNUM 0, 2)

FLXCON01=            5347.4346 / [electrons/sec/Jy] Flux conversion Order 1
FLXERR01=                124.5 / Flux conversion uncertainties Order 1
FLXCON02=            5188.8115 / [electrons/sec/Jy] Flux conversion Order 2
FLXERR02=                124.5 / Flux conversion uncertainties Order 2
FLXCON03=            5350.0703 / [electrons/sec/Jy] Flux conversion Bonus Order
FLXERR03=                124.5 / Flux conversion uncertainties Order 3

          / GENERAL MAPPING KEYWORDS

DBEXPOID=              2931395 / Currnet Exposure ID

          / IRS PEAKUP KEYWORDS

PKUPMODE= 'IRS     '           / Peakup mode (none, IRS, or PCRS)
PKUPACCU= 'High    '           / Peakup Accuracy (high, moderate,low)
PKUPFILT= 'BLUE    '           / Peakup filter (blue or red)
PKUPFLUX=                 51.9 / Flux density of peakup target for IRS [mJy] or
PKUPXTND=                    F / Extended source (T/F)
ISPUPOS =                    T / PU target given in absolute positions (T) or re
PKUPRA  =          289.32712004 / [deg] RA peakup position
PKUPDEC =           49.85022773 / [deg] Dec peakup position
PM_PKRA =                0.036 / [''/yr]Proper motion for RA peakup position
PM_PKDEC=               -0.062 / [''/yr]Proper motion for Dec peakup position
HP_CENQ =                    0 / Peakup centroid quality code
APKUPCEN=                    1 / Status of the peakup centroid
AXCNTRD1=                10804 / [centipixels] X value of the brightest centroid
AYCNTRD1=                 2792 / [centipixels] Y value of the brightest centroid
AXCNTRD2=                    0 / [centipixels] X value of the second brightest c
```

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AYCNTRD2=                    0 / [centipixels] Y value of the second brightest c
AINTENS1=               199917 / [counts] Intensity value of the brightest centr
AINTENS2=                    0 / [counts] Intensity value of the second brightes
APKUPXCE=                10804 / [centipixels] X value of the centroid to be ret
APKUPYCE=                 2792 / [centipixels] Y value of the centroid to be ret

          / DATA FLOW KEYWORDS

DATE    = '2005-12-28T07:00:05' / [YYYY-MM-DDThh:mm:ss UTC] file creation date
AORKEY  = '15333376'           / AOR or EIR key. Astrnmy Obs Req/Instr Eng Req
EXPID   =                    8 / Exposure ID (0-9999)
DCENUM  =                    0 / DCE number (0-9999)
TLMGRPS =                   16 / Number of expected telemetry groups
FILE_VER=                    1 / Version of the raw file made by SIS
RAWNAME = 'IRSX.2.0015333376.0008.0000.01.mipl.fits' / Raw data file name
SIS_SVER= 'J5.3    '           / SIS SW VERsion
CPT_VER = '3.1.11  '           / Channel Param Table FOS version
CTD_VER = '3.0.94S '           / Cmded telemetry data version
EXPDFLAG=                    T / (T/F) expedited DCE
MISS_LCT=                    0 / Total Missed Line Cnt in this FITS
MANCPKT =                    F / T if this FITS is Missing Ancillary Data
MISSDATA=                    F / T if this FITS is Missing Image Data
PAONUM  =                 1298 / PAO Number
CAMPAIGN= 'IRSX005200'         / Campaign
DCEID   =             36810105 / Data-Collection-Event ID
DCEINSID=              7574623 / DCE Instance ID
DPID    =             64674041 / Data Product Instance ID
PIPENUM =                  201 / Pipeline Script Number
SOS_VER =                   1. / Data-Product Version
PLVID   =                   10 / Pipeline Version ID
CALID   =                    4 / CalTrans Version ID
ORIGIN0 = 'JPL_FOS '           / site where RAW FITS files was written
CREATOR0= 'J5.3    '           / SW system that created RAW FITS

GAIN1   =                  4.6 / e/DN conversion (readout channel 1)
GAIN2   =                  4.6 / e/DN conversion (readout channel 2)
GAIN3   =                  4.6 / e/DN conversion (readout channel 3)
GAIN4   =                  4.6 / e/DN conversion (readout channel 4)
BASECH1 =             36944.66 / Trimmed mean channel 1 signal in reference unil
BASECH2 =             39515.05 / Trimmed mean channel 2 signal in reference unil
BASECH3 =             37933.77 / Trimmed mean channel 3 signal in reference unil
BASECH4 =             34622.29 / Trimmed mean channel 4 signal in reference unil

HISTORY job.c ver: 1.50
HISTORY TRANHEAD                  v.          12.6, ran Tue Dec 27 22:59:04 2005
```

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HISTORY CALTRANS                 v.        4.0, ran Tue Dec 27 22:59:07 2005
HISTORY cvti2r4          v.  1.30 A50506, generated 12/27/05 at 22:59:12
HISTORY DNTOFLUX                  v.          4.1, ran Tue Dec 27 22:59:18 2005
HISTORY imagest          v.  1.78 A50512, generated 12/27/05 at 22:59:25
HISTORY  input: cvte.fits
HISTORY  unc.: cvte_unc.fits
HISTORY DROOPOP                   v.     3.700000, ran Tue Dec 27 22:59:28 2005
HISTORY DARKBASE                  v.     2.200000, ran Tue Dec 27 22:59:34 2005
HISTORY CUBESUB                   v.     3.200000, ran Tue Dec 27 22:59:36 2005
HISTORY lineariz         v.  1.39 A40318, generated 12/27/05 at 22:59:37
HISTORY  input: cubesub.fits
HISTORY  model: ./cal/lincal.fits
HISTORY DARKDRIFT                 v.          4.0, ran Tue Dec 27 23:00:05 2005
HISTORY imagest          v.  1.78 A50512, generated 12/27/05 at 23:00:08
HISTORY  input: darkdrift.fits
HISTORY DROOPRES                  v.     2.200000, ran Tue Dec 27 23:00:12 2005
HISTORY FLATAP                    v. 1.500   Tue Dec 27 23:00:18 2005
HISTORY CALTRANS                 v.        4.0, ran Tue Dec 27 23:01:11 2005
HISTORY PTNTRAN                   v.          1.3, ran Tue Dec 27 23:01:12 2005
HISTORY PTNTRAN                   v.          1.3, ran Tue Dec 27 23:01:13 2005
HISTORY FPGen                     v.         1.25, ran Tue Dec 27 23:01:14 2005
FBIDDARK=                   243
FBIDFLAT=                   397
FBIDLNCR=                    24
FBIDLNMD=                   238
FBIDOMSK=                    31
FBIDPMSK=                   109
FBIDWSMP=                   412
FBIDUMSK=                    68
FBIDWSOF=                   416
FBIDWSOM=                   419
FBIDWSWA=                   409
FBIDFLXC=                   401
FBIDFMSK=                    73
FBIDNMSK=                    79
FBIDCALS=                   440
HISTORY CALTRANS                 v.        4.0, ran Tue Dec 27 23:05:13 2005
END
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Appendix B

Acronyms

Acronym:	Stands For:
ACQ	ACQuisition
AOR	Astronomical Observation Request
AOT	Astronomical Observation Template
ASCII	American Standard Code for Information Interchange
BCD	Basic Calibrated Data
DCE	Data Collection Event
DCS	Double Correlated Sampling
DN	Data Number
FITS	Flexible Image Transport System
IDL	Interactive Data Language
IRS	InfraRed Spectrograph
LH	Long-High (module)
LL	Long-Low (module)
MIPL	Multimission Image Processing Laboratory
NaN	Not-a-Number
PB	Peak-up Only Blue
PBI	Peak-up Imaging Blue
PCRS	Pointing Control Reference Sensor
PR	Peak-up Only Red
PRI	Peak-up Imaging Red
PSF	Point Spread Function
RSRF	Relative Spectral Response Function
SH	Short-High (module)
SL	Short-Low (module)

SOM	Spitzer Observer's Manual
SPICE	SPitzer IRS Custom Extractor
SPOT	Spitzer Planning Observations Tool
SS	Sweet Spot
SSC	Spitzer Science Center
SUR	Sample Up the Ramp
WCS	World Coordinate System