



# The IRS Flats

Spitzer Science Center



# Table of Contents

## The IRS Flats 1

<b>Chapter 1. The Purpose of this Document.....</b>	<b>3</b>
<b>Chapter 2. IRS Procedure for Making a Flat .....</b>	<b>4</b>
2.1 Make a finely-spaced map of a star. ....	4
2.2 Simulate an extended source.....	6
2.3 Create a 2-D fits file as if the source were spatially extended and filled the slit.....	7
2.4 Divide the observed data by the modeled 2-D extended source. ....	8
2.5 Create an initial cmask.....	9
2.6 Divide the protoflat by the zodiacal background. ....	11
<b>Chapter 3. Individual Programs Used to Make the Flat .....</b>	<b>13</b>

## Chapter 1. The Purpose of this Document

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The goal of this document is to provide a detailed record of how the flats for the IRS instrument on *Spitzer* were made. In addition to describing the philosophy of the algorithm, we provide the IDL program used to create the flat for the LL module. *This program is provided for illustration only, and is not supported software.*

It is assumed that the reader is familiar with the IRS instrument and has obtained and reduced data with the spectrograph.

## Chapter 2. IRS Procedure for Making a Flat

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In order to make a flat we would ideally like to expose the IRS arrays to a monochromatic, spatially flat source. On the ground, we achieve this by exposing an array (or a CCD for optical observations) to a flat white screen inside the dome, or by taking observations of the sky at twilight. This is difficult in space because spectrally and spatially flat sources are rare. At the very least we would like to observe a source that is spatially uniform with a known spectral shape, free of sharp features and bright enough for good signal to noise but not so bright as to saturate the arrays. Although the zodiacal background, the moon, an elliptical galaxy or a nebula are amongst the plausible choices for making a flat for the IRS, each is impractical or ruled out for different reasons. The moon, for example, is too bright whereas the zodiacal background is typically too faint. And in nearly all cases, we do not know their spectrum a priori.

The best-studied objects with known spectra are stars. Therefore, the IRS team adopted a technique for making the flat by “filling” the slit with a star. The basic idea is to step a standard star through the slit to simulate an extended source. The non-uniform spatial response of a stepped star is later corrected for using observations of the zodiacal background. The remainder of this chapter outlines the steps for making the flat.

### 2.1 Make a finely-spaced map of a star.

Choose a star that is bright enough for a given module and make a finely spaced map of the star. For the flats currently in use, the following stars were used:

**Short-Low:**

HR 7341, AOR#19324416

(57 steps parallel to slit, 1.1” steps, 6s ramps x 3 cycles)

Corresponding zodiacal background: AOR#19324928

**Long-Low:**

In campaign 45, there was a bias change to mitigate the increasing number of rogue pixels in the LL module – hence two different flats for the pre- and post-bias change campaigns. In general, the bias changes introduced a slight tilt in the spectral slope but no spatial structure was introduced. Hence using an older flat before a bias change with newer data would work because the spectral shape could be removed by the fluxcon later on. However, the new bias did lead to fewer rogues which in turn allowed us to get cleaner, higher S/N data for the stars and zodiacal background. For Post-45 zodiacal background data, for

instance, we only used one zodiacal background observations and it was sufficient.

**LL-PRE45:**

HR6606 LL1 (AOR#13364480) + LL2 (AOR#13364736)  
(91 steps parallel to slit, 2.4" steps, 14s ramps x 4 cycles)  
Corresponding zodiacal background AORs #8243968, #9268992,  
#9530880, #10020352, #10020608.

**LL-POST45:**

HR6606, LL1 (AOR#24399872) + LL2 (AOR# 24400128)  
(91 steps parallel to slit, 2.4" steps, 14s ramps x 4 cycles)  
Corresponding zodiacal background AOR: #24426240.

**Short-High:**

HR 6688, (AOR# 13531136)  
(11 parallel steps of 1.1" x 5 perpendicular steps of 1.8", 30s ramps x 2 cycles)  
Dedicated sky data (AOR#13520384, #13515776).  
Corresponding Zodiacal background: AORs #12604416, #13782528,  
#16462848, #13782272, #13782784, #9859072

**Long-High:**

**LH-PRE25:**

HR6688 (AOR#13530368)  
(19 parallel steps of 1.3" x 3 perpendicular steps of 3.5", 60s ramps x 2  
cycles)  
Dedicated sky data (AOR#13530880).  
Corresponding zodiacal background Data: AOR# 11810304,  
#11810816, #9858560, #9859072, #11810560, #12604416, #9858816.

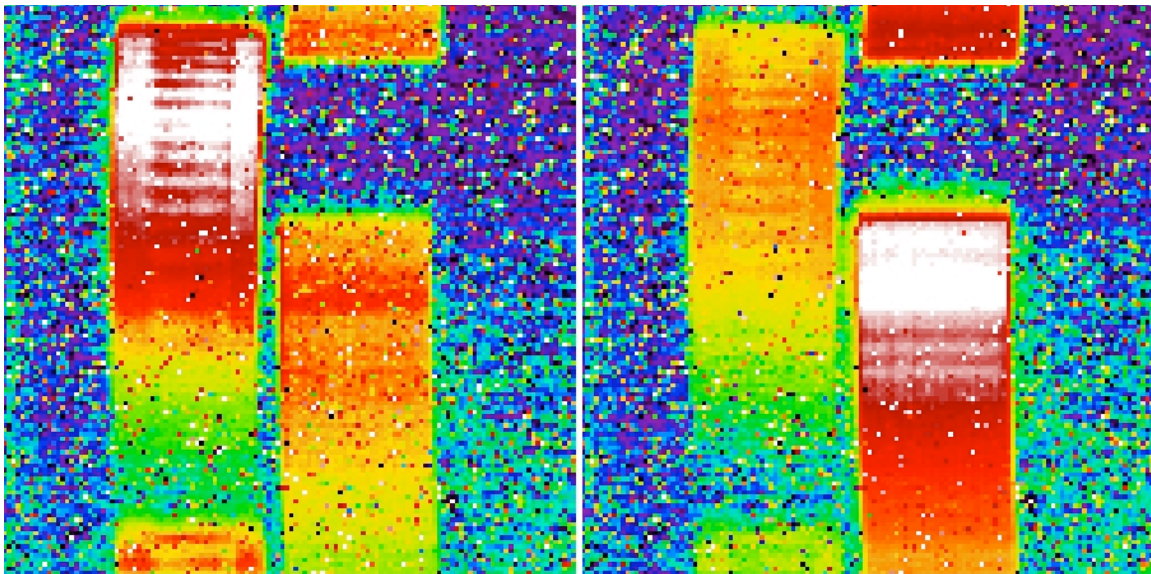
**LH-POST25:**

HR2491, (AOR#16101888)  
(21 parallel steps of 1.7" x 15 perpendicular steps of 1.7", 6s ramps x 3  
cycles)  
Dedicated sky (AORs #16088320. #16087296).  
Corresponding zodiacal background AORs #16097792, #16098048,  
#16098304, #16462848

For the high-res modules you need dedicated sky observations to remove the background and rogue pixels. Also one needs a lot of zodiacal background data for good S/N.

**One must use the pre-flatfielded (*\*rsc.fits*) files to make the flat.** We take the *\*rsc.fits* files for the star data and co-add them using an IDL program called *comb.nl*. This is included in the tar ball of the flat making code provided and is called from within the parent *makeflat.pro* routine. The IDL program *comb.nl* is very straightforward and simply combines a list of files to create a median and a mean of all the finite values (i.e. ignoring NaNs) in the fits files provided. The program produces a mean and a median file.

These files can still contain a lot of rogues. Note that for the low resolution modules the individual orders are combined separately. So there is a SL1 (LL1) and SL2 (LL2) star mean flat. Figure 2.1 shows one example of such images from the example code and data for LL.



**Figure 2.1** An example of the co-added data for a star in LL1 (left panel) and LL2 & LL3 (right panel) modules. This is before the sky subtraction and combining of the two orders. Combining orders means taking each of individual orders and pasting them together to make an initial 2-d image of a “extended star” – this would be equivalent to stepping the star through all three orders.

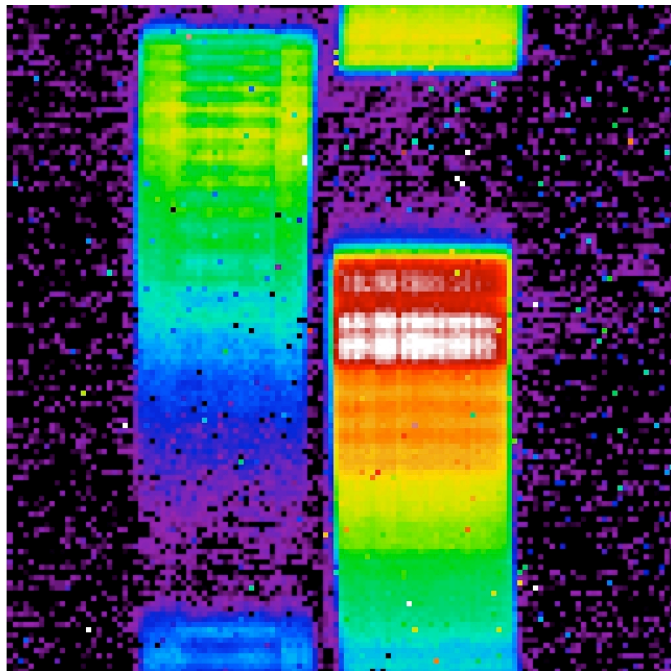
## 2.2 Simulate an extended source.

Remove a background and combine the *\*rsc.fits* (pre-flatfielded) data so that we “simulate” an extended source that fills the slit by co-adding all the *\*rsc.fits*. Moreover if the star is stepped through the different orders separately as is the case for SL and LL, each of these orders then need to be cut and pasted together to make a combined image as if the “extended” star is filling the slit.

For the SL and LL data, we mapped the star in such a way that several of the slit positions were far enough from the star. We used these “edge”-steps in the map to estimate the background. The mean of these data was subtracted from the mean of the co-added star data.

For the SH and LH data we use the dedicated background AORs to estimate a mean and median background. Depending on the quality of the data, the mean or the median is adopted to give us a background image, which is then subtracted from the mean star-only data.

After the background is subtracted and the orders combined, the LL product from above is shown in Figure 2.2.



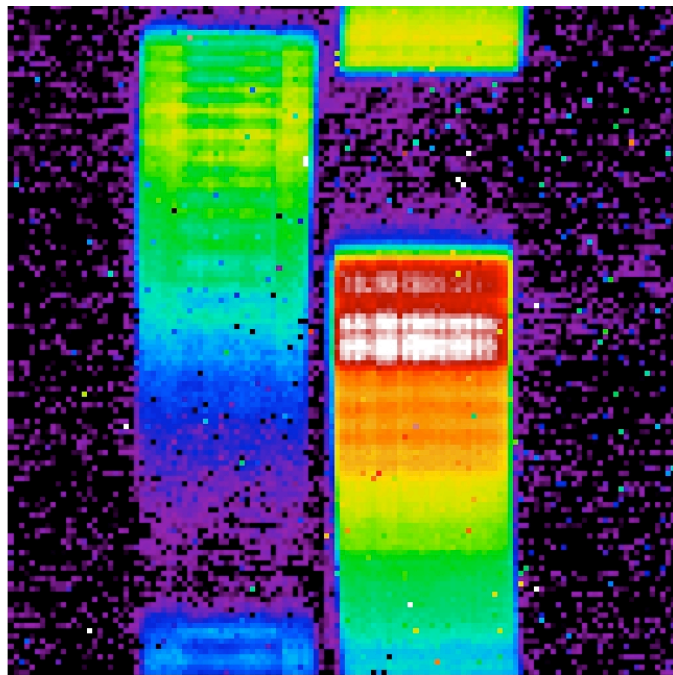
**Figure 2.2** Mean background has been subtracted after the orders were combined as described earlier. This is our observation of a flat, extended source created by stepping a star everywhere in a slit.

### 2.3 Create a 2-D fits file as if the source were spatially extended and filled the slit.

The next step is to take a 1-D model spectrum of the star and create a 2-D fits file as if the source were spatially extended and filled the slit. The 1-d models for all the standard stars are available at:

<http://ssc.spitzer.caltech.edu/irs/calib/templ/>

Here we use the latest wavsamp and omask to get the correct model. The wavsamp table contains the translation from the pixel coordinates to wavelength. A given wavelength for IRS is indicated by a tilted rectangle, often called a “pseudo“-rectangle in other IRS documentation. There is also a wavsamp.fits file which shows the 2-D translation of the wavsamp.tbl file for the different modules. The omask file shows where the orders of a given module are present in the 2-D data. It is usually used to mask out the inter-order regions. In the makeflat process, the conversion from the model spectrum to a 2-D file is achieved with step 2.2 where we call on the routines *conwavlr.pro* (*conwavhr.pro* for high res), and the routine *de\_extract.pro*. The 2-D model file looks is illustrated in Figure 2.3.



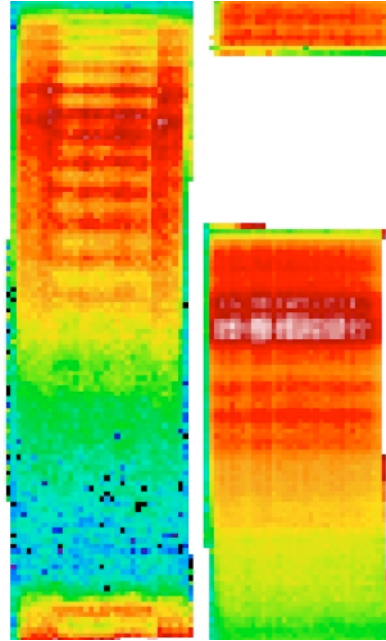
**Figure 2.3** This is the model of a stellar spectrum in 2-D created by interpolating the 1-D spectrum over the wavsamp file.

## 2.4 Divide the observed data by the modeled 2-D extended source.

The next step is to simply divide the observed data by the modeled 2-D extended source. This resulting file is then normalized by dividing it by the median value calculated from all the finite data in the fits file. The result is a fairly decent proto-flat. We run this initial proto-flat through



IRSCLEAN to remove and replace rogue pixels because the flat should be a smooth 2-D file. Figure 2.4 illustrates the results.



**Figure 2.4** The prot-flat created by dividing the mean star flat by the modeled 2-D image and then run once through IRSCLEAN to remove many of the rogue pixels.

## 2.5 Create an initial cmask.

The purpose of the cmask is to indicate where the flat is valid, uncertain or invalid. All the regions outside the wavsamp are obviously invalid but in general the wavsamps created by the SSC are conservative. The actual spatial area that is imaged by the spectrograph is slightly larger, especially for the high-res modules. Of course, the sensitivity of the spectrograph falls off from the center of each order so the edges are highly uncertain. In making the flat, especially for the high-res modules, we took the approach of maximizing the amount of information collected by the IRS. Since the area exposed to the sky by the array is larger (by ~5%) than the wavsamps, we created and used slightly larger wavsamps than the ones used by SPICE and other programs. These were interpolated to be ~5-10% wider than the narrower wavsamps from which the spectra are extracted. Then as a first step in making the cmask, we set all the area outside this wavsamp to be invalid (bit 7). In other words, all the inter-order regions are set to bit 128. All the pixels within the order are then set to 0.

The next step is to determine the “uncertain” flat pixels. We first take the maximum value in each order. Then all pixels that are less than 0.001 of maximum in the flat are assumed to be regions

where the flat is uncertain. In general this should pick up most of the edges of the wavsamps. But in the case of LL and LH, the array efficiency drops sharply at the longer wavelengths and hence these modules have many more uncertain flat pixels towards longer wavelengths. The (peculiar) cmask for the LL module shown in Figure 5 highlights these low S/N pixels at long wavelengths.

After an initial automated masking, the next step is to interactively go through the cmask and mask out pixels that the automated procedure did not pick out. This is perhaps the trickiest part of the flat making process. Narrowing the cmask too much will mean less signal and can also introduce tilts in the spectrum especially in extended sources. However keeping the cmask too broad, i.e. allowing many edge pixels to be counted as valid, can lead to noisier spectra. So this step is in fact iterative. For the peculiar case of LL where the uncertain pixels form a band towards the long wavelengths, we usually declare most pixels longwards of 37 microns as uncertain. Once a cmask and a flat are available we run some regular observations of stars or other standard objects through the pipeline and determine if any obviously bad pixels have made it through (i.e. spikes in the final spectrum that are being introduced by the flat – and have not been flagged by the cmask). We would flag such pixels in the cmask. We also study the noise and try to minimize the noise while narrowing or widening the cmask. For the high resolution modules, this step needs to be done carefully for each of the 10 orders. Figure 2.5 shows the typical cmask from this extensive process.

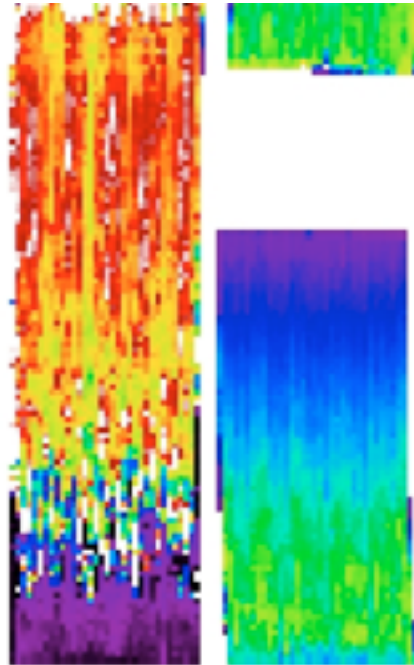


**Figure 2.5 A cmask for the LL-PRE25 data. The pixels marked white are the ones labeled uncertain by our process.**

## 2.6 Divide the protoflat by the zodiacal background.

Finally, since there are likely real (endemic to the array) and artificial (introduced by the discrete stepping of the star through the slit) spatial variations in the protoflat, we need to remove these variations by using a truly extended flat source - i.e. the zodiacal background. Our basic process involves co-adding a large number of zodiacal background observations, cleaning this product with IRSCLEAN and dividing out the protoflat by the zodiacal background. Here all we are interested in doing is removing the spatial variations and the ratio of the protoflat to the zodiacal background is giving us a measure of these variations. We need to flatten this image. To do this, we take a running 5-row average for each order and calculate a spatial correction to the data.

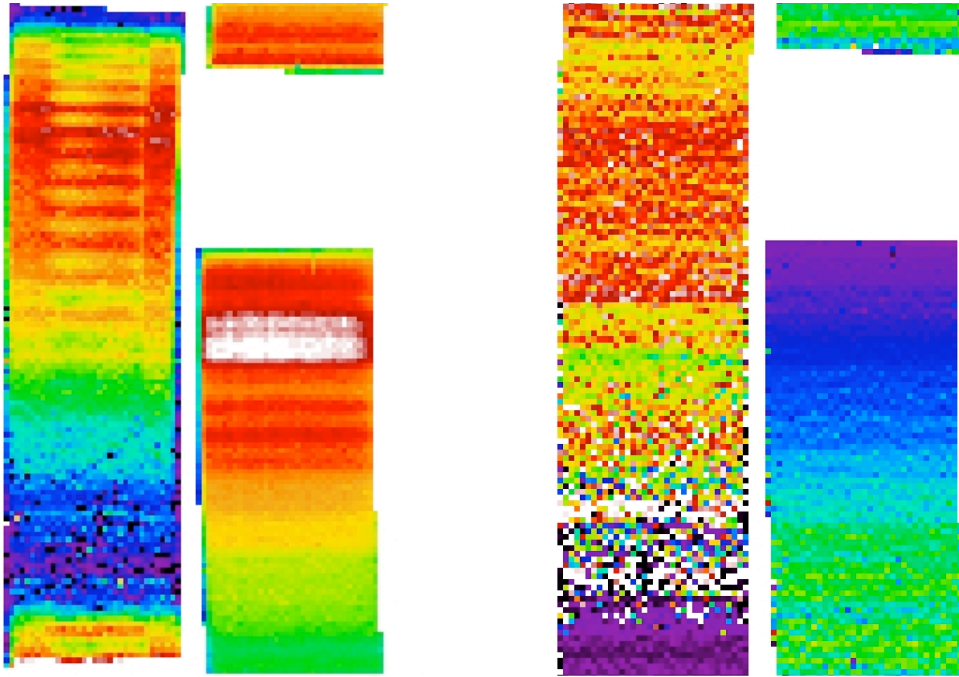
This is accomplished by a routine included in the flatmaking tar ball called *flattenit\*\*.pro* where \*\* stands for low and high res versions. This spatial correction is then multiplied back into the data and this is the final flat. The spatial correction for the LL data in this example is shown in Figure 2.6.



**Figure 2.6** The spatial correction for the LL example generated by taking a running 5-row average of the protoflat / zodiacal background file. Multiplying this back into the flat gives us the final flat.

This spatial correction step does introduce a slight spectral slope (which was previously taken out by the model) but we ignore it and take out whatever residual slopes there may be at the fluxcon step later on in the pipeline.

The final flat shown in Figure 2.7 then looks like this. The right hand figure shows our final check to make sure we have a spatially flat image, which is done by again dividing the zodiacal background by the final flat.



**Figure 2.7** *Left:* The final flat. *Right:* The zodiacal background divided by the final flat, as a check to make sure that we have a spatially flat image.

## Chapter 3. Individual Programs Used to Make the Flat

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All of the programs used to make the flat were written in IDL. Below is a list of the individual programs, along with a brief description.

1. *makeflat.pro* – This is the main program.
2. *comb\_nl.pro* – Combines the data and makes a median and a mean file.
3. *conwavlr.pro* (*conwavhr.pro*) – Interpolates the model spectrum onto the wavsamp in 1-D.
4. *de\_extract.pro* – Converts the 1-D spectrum into a 2-D file. The program *de\_extract.pro* lives within a package called *poly\_mask\_new* which contains the program *de\_extract.pro*, *read\_tbl.pro* and *poly\_mask.pro*.
5. *irsclean\_mask.pro* – this is within the IRSCLEAN package distributed by the SSC.
6. *flattenitir.pro* – example of low res version of program that removes the spectral variation. The high res version simply goes through orders 11-20 instead of 1-3.

These programs are available for download on the SSC website to serve as examples for those users who wish to create their own flats. They are not supported tools.