

Description of Point Source Photometry Steps Used by GLIMPSE

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1 Overview

The Galactic Legacy Infrared Midplane Survey Extraordinaire (GLIMPSE) is an infrared survey of the inner Galactic plane using the Infrared Array Camera (IRAC) (Fazio et al. 2004) on board the *Spitzer* Space Telescope (SST) (Werner et al. 2004). IRAC has four detectors, centered at approximately 3.6, 4.5, 5.8 and 8.0 μm . GLIMPSE covered a latitude range of $\pm 1^\circ$, and a longitude range of $|l| = 10^\circ - 65^\circ$ (Benjamin et al. 2003). The GLIMPSE data products consist of a Point Source Catalog (GLMC), Point Source Archive (GLMA) and $1.1^\circ \times 0.8^\circ$ and $3.1^\circ \times 2.4^\circ$ mosaic images covering the survey area. See the GLIMPSE Data Products Document at www.astro.wisc.edu/glimpse/docs.html for more information. We use the DAOPHOT package (Stetson 1987) for point source photometry, modified to work with highly variable backgrounds. This document describes the steps used to produce the photometry for the GLIMPSE source lists. The GLIMPSE Quality Assurance Document (www.astro.wisc.edu/glimpse/docs.html) discusses the photometric accuracy along with other issues affecting data quality.

2 Photometry on Individual Frames

Photometry is performed on individual IRAC images using DAOPHOT. A source list for each frame is created giving total counts for each source and x-y pixel coordinates. These values are subsequently converted to flux units and world coordinate system (WCS) coordinates.

The GLIMPSE pipeline photometry process consists of three general steps; finding sources, photometering those found sources, and improving the photometry of sources which generally lie in complex background emission regions.

2.1 Finding Sources

Finding sources uses a modified version of DAOPHOT's FIND routine. The routine is modified to incorporate a local background determination when searching for sources at a specified sigma level above background. DAOPHOT's original FIND routine uses a mean/median background from the entire image. With the extreme background variability that can occur on GLIMPSE frames, a modification for local background determination is required. Initially, sources are found at a 3-sigma detection limit above the local background. Images are converted from flux units to counts. Knowledge of gain, read noise, and the amount of zodiacal light subtracted from the image are used to determine the 3-sigma detection level. See Appendix A.

2.2 Initial Photometry

The found sources are photometered using DAOPHOT's photometry routine ALLSTAR. ALLSTAR does iterative Point Source Function (PSF) fitting and source removal from the input image. As sources are removed, new background levels are calculated for sources that will be subsequently extracted. See Appendix B for a discussion of how DAOPHOT determines the background. Sources with low signal/error (<2.0) are removed from the source list. Once the initial list of found sources are extracted, a residual image (an image with the sources subtracted out) is produced. This image is then resubmitted to the modified DAOPHOT FIND routine to find additional sources which may have been hidden in the wings of the brighter sources. Because the residual image will have an added degree of noise (due to the imperfect subtraction of sources) the sigma level of detection on the second pass for finding sources is raised to 5. Additional sources found in this second pass are added to the list of sources extracted in the first pass. This new list is then submitted for extraction by ALLSTAR. Experience has shown that this second pass of photometry will produce a list of sources which can be further improved by resubmitting it to ALLSTAR for a third time. This is because ALLSTAR does iterative simultaneous fitting of multiple sources. Sources are allowed to migrate in position to improve the overall fit of all the associated sources; sources that do not converge are thrown out. By resubmitting the list to ALLSTAR a third time, often a few remaining poorly fit spurious sources are removed from the final source list. Because ALLSTAR is an iterative process, sources are PSF fitted and removed from the original image progressively making a residual image with fewer and fewer sources. Sources are allowed to migrate in position a small amount to optimize the PSF fit for the sources not yet extracted. This process can, on rare occasions, produce a source list that can have multiple sources within a very small radius of each other (a radius small enough that if ALLSTAR were processing just those close sources it would have merged them together into one source). Because of this rare situation, the above source list is checked for sources that are less than $0.375 * \text{FWHM}$ apart. Those sources are merged into one source.

2.3 Iteration

The final step in the photometry process is "tweaking". This step was found to be necessary due to the complex nature of the background emission seen in some GLIMPSE images. Again, experience has shown that sources extracted by ALLSTAR in complex background regions are often over-subtracted due to the difficult process of properly determining the background for multiple associated sources in a variable background region. ALLSTAR was designed and works well in flat background regions. The tweaking routine uses the residual image as a background image. First we median smooth the residual image (5 pixel box) and then subtract the smoothed image from the residual image itself; this produces a flattened residual image. Next we do aperture photometry on this flattened image. The ALLSTAR source list is used as the input list and a very small aperture (2 pixel radius) is chosen so only the very core of each source is measured. Because we are working with a flattened residual image, we can conclude that if the resultant aperture photometry at each source location is substantially negative or positive, then the source is respectively over or under subtracted from the original image. By comparing this aperture photometry to the original ALLSTAR photometry, we can determine if a correction is required, thus improving the residual image to show less evidence that a star was subtracted. For the Observation Strategy Validation (OSV) data, taken of the star formation region RCW49, the ratio of aperture photometry from the residual to ALLSTAR photometry was set at an aggressive level of only 5%. This was due to the

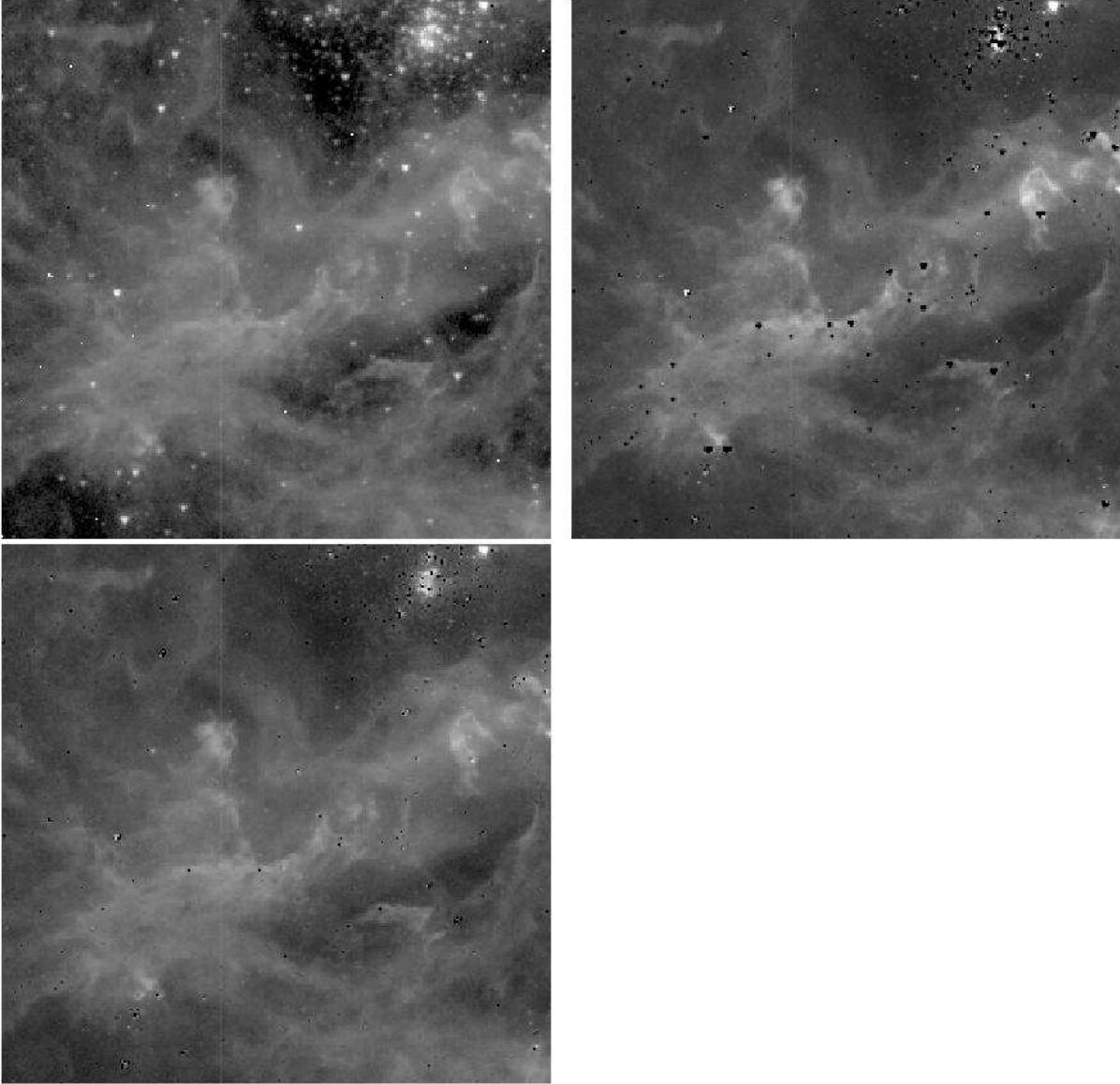


Figure 1: From left to right, top row: original channel 1 ($3.6 \mu\text{m}$) BCD image, residual image without tweaking applied, bottom row: residual image with tweaking.

extremely high and variable background seen in much of the OSV region. For our first segment of the survey data and subsequent segments, a less aggressive threshold value of 20% was used because most of the images are flatter with lower backgrounds. If the backgrounds are low and flat, ALLSTAR should do a good job and tweaking should not be required. Understanding the conditions requiring a tweaking correction is still an on-going process. Figure 1 shows an example of tweaking for a band 1 IRAC frame.

An additional positive outcome from this tweaking step is the identification of possible cosmic rays (CRs). Sources that appear to be excessively undersubtracted are characteristically CRs. This is because to fit a stellar PSF to a bright CR will result in a residual bright core with an oversubtracted wing region. The tweaking routine is designed to look for these and flag them as CRs. These false

sources are then removed from the source list. This process will find many CRs but certainly not all of them. The others are handled in our source selection criteria during catalog production, as described in the Data Products Document.

2.4 Photometry Summary

For each image, we now have a final source list. The photometric steps have found and excluded egregious CRs and merged any sources within $0.375 \times \text{FWHM}$ of each other; it has tweaked sources determined to be over or under-subtracted from the original image; it has found sources both at a 3 sigma local background level and sources at a 5-sigma level that may have been hidden in the wings of bright sources. These sources are then removed from the original image to produce a final residual image. The photometry for each source has an associated error that is a result of four components: photon-statistical error, psf-determination error, flat-fielding error and readout noise. The error is also adjusted to reflect the accuracy of the PSF fit determined from the associated chi value of the PSF fit. PSFs for each band are determined by DAOPHOT's PSF command. Select IRAC frames with multiple bright stellar sources are used to determine the PSFs.

REFERENCES

- Benjamin, R.A., et al, 2003, PASP, 115, 953.
Fazio et al., 2004, ApJS, 154, 10.
Stetson, P. 1987, PASP, 99, 191.
Werner et al. 2004, ApJS, 154, 1.

APPENDIX A - Determination of FIND Threshold

A one-sigma detection level for finding sources (§2.1) is given by:

$$\sigma = \sqrt{S/P + R^2}$$

where

- σ = sigma level (threshold for FIND)
S = sky brightness in Data Numbers (DN)
= image sky + subtracted zodiacal light
P = gain factor (photons per DN)
R = read noise in DN

APPENDIX B - How DAOPHOT II determines the Background

Summarizing from the June 5, 2000 version of the DAOPHOT II Manual (<http://www.astro.wisc.edu/glimpse/daophot2.pdf>) within the section describing ALLSTAR (page 58):

ALLSTAR II is empowered to redetermine sky values for the stars in the frame. This is done as follows: the user sets the optional parameters OS = “Outer sky radius” > 0 and IS = “Inner sky radius” $< OS$. Here OS should be large compared to the FITTING RADIUS - if possible, comparable to or somewhat larger than the PSF RADIUS - but definitely smaller than the spatial scales of any significant variations in the sky background. The inner sky radius, IS, can be quite small: comparable to or less than the FITTING RADIUS, or even zero. It is probably best to set IS to at least one or two pixels, to keep the enhanced photon noise and the uncertain PSF near the center of a star image from overly influencing the derived sky values. As long as $OS > IS$, before every third iteration (starting with iteration 3), after all the stars have been subtracted from the working copy of the image, the program will redetermine the median brightness value in the annulus bounded by these two radii. This is used as the sky estimate for the star for the next three iterations. This is discussed at some length in Stetson, 1987 PASP, 99, 101, Sect. III.D.2.a.

The GLIMPSE pipeline uses the following parameters (in pixels):

PSF RADIUS = 15

FITTING RADIUS = 3

IS = 3

OS = 8

Because spatial variations in GLIMPSE images can be less than 15 pixels, a compromise OS (which is desired to be large compared to the FITTING RADIUS but smaller than the spatial scales of any significant variations) was chosen. In general, more than 90% of the flux is within an 8 pixel radius for all 4 IRAC channels; thus the $OS = 8$ is comparable to the PSF RADIUS.