IRAC/TM05-014

Simfit Report 52 Final

25 Position Model Pixel Response Functions (PRF)

Description and Quality

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1. Introduction

This report provides supporting information for a set of IRAC Pixel-Response-Functions (PRF) which have been determined for each of 25 standard positions from an optical model of IRAC and images observed with the Spitzer telescope. The model PRF's have been corrected by comparing PRF's obtained by the drizzle method from observed star images from IRAC Campaign Q with corresponding model PRF. Since in Campaign Q, 12 pixel-phase dithered images were obtained at each of the 25 positions, the resulting correction represents an average for the 25 positions.

The following sections include a description of the PRF image files, a discussion about how they were obtained, an assessment of their quality, and a prescription for their use.

The analysis depends on the Simfit program for analyzing observed images and comparing them with simulated images. This method is described in detail in:

Hoffmann, W.F. *et. al.* "Simfit and Focus Diversity: methods for determining the focus of the SIRTF telescope in space without a focus slew" SPIE 4850-69 IRAC/TM02-4003

Hoffmann, W.F. *et. al.* "Determination of Spitzer Space Telescope focus from IRAC images without a focus slew", Proc SPIE 5487 [88]

2. PRF file description and name conventions

The sirtfweb directory *FocusIPT/IRAC/prf_from_simfit/prf_25_positions/* contains 25 FITS images representing PRF for a 5x5 set of focal plane positions and one complex Fourier transform of a convolution correction function. The images are a grid of 128x128 32-bit floating-point numbers with a grid spacing 1/5 the IRAC pixel (0.24 arcsec). The full size is 25.6x25.6 IRAC pixels (31.2 arcsec). The images are normalized to a peak of unity. The FITS headers contain a minimum of information.

The PRF represent the response of the pixels of the IRAC array to images of a point source in the sky as they appear at the array with a standard orientation at the Spitzer focal plane. Since the IRAC pixels are of finite size and under-sample an image of a point-source in channels 1 and 2, the images are "pixel-response-functions" rather than "point-source-functions" (psf).

The file names are of the form:

prf_ch1_mdl55-34_setfocus_3.16_050709_pos00_z1_y5.fits

with the following information

ch1	IRAC channel number (1 to 4)
mdl55-34	Simfit model number for the corrected model appropriate for channel 1
setfocus_3.15	Secondary mirror focus position setting in microns from the model focus zero. Positive is away from the primary mirror
050709	Analysis date (yearmonthday)
pos00	Simfit focal plane position index (0 to 24)
z1_y5	Focal plane position designation (Goddard Space Flight Center [GSFC] terminology). *e.g.* z1_y1, z2_y1, *etc.*

The Fourier transform function name has the form:

drizconvfft_Q_ch1_mdl30-09_intp-yes_dbins11_shif_v456_050429_06fv_v041C_size128_thresh-0.0068.fits

with the following information

Q	IRAC Campaign designation for the observed images used for the correction
mdl30-09	Simfit model number for the uncorrected model
intp-yes	Switch on for interpolation of model image to position of observed image
dbins11	11x11 portion of the image used for the Fourier transform deconvolution
shif	Drizzle offsets determined by simfit shift, rather than centroids
v456	Version number for Simfit worksheet
050429	Date of Simfit version
06	Sequence number for PRF computation with given parameters
fv	PRF cropped appropriately for dbins
v041C	Version number for deconvolution/convolution worksheet ("makecheckmodel")
size128	Size of Fourier transform array (128x128 complex numbers)
thresh-0.0068	Threshold value for Fourier transform filter

3. Focal plane coordinates and locations and orientation of PRF's

Several coordinate frames have been used by different individuals to designate the position and orientation of IRAC images. Figure 1 shows those that I am aware of, each orientated to correspond to fits images prepared by the Spitzer Science Center (SSC). As confirmation that the image orientation shown in Figure 1 agrees with the current SSC and Focus IPT convention, Figure 2 presents a comparison of FitsView displays for the center position of the corrected model PRF and center position PRF distributed by Dave Elliott. For these images, the first data point is at the lower left corner and the data proceed toward the right.

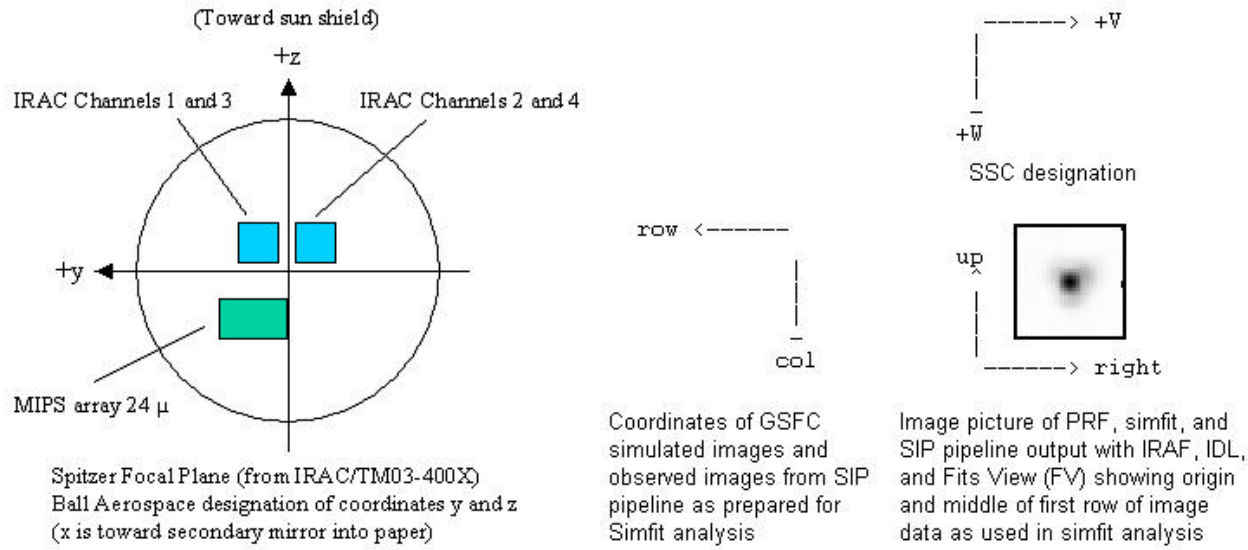
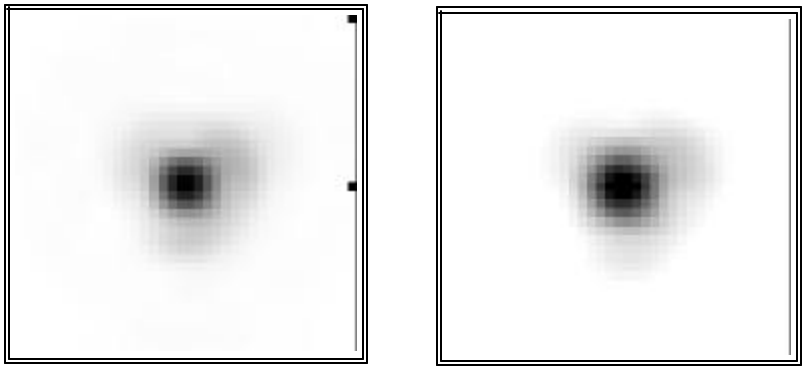


Figure 1. **Spitzer focal plane coordinates and PRF image orientation.** Each of the coordinate systems is orientated consistent with the orientation of a Spitzer Science Center (SSC) image FITS file as displayed by IRAF, IDL or FitsView. An example of this is shown at the lower right. The small squares at the upper and middle right of the picture are the locations of the start and middle of the first row of data as given in the GSFC simulated images and in the observed images formatted for Simfit by SAO. These are the row-column coordinates used in the Simfit analysis program. They are shown immediately to the left of the picture. The coordinates above the picture are the V-W coordinates used by the SSC. The picture at the left shows the Spitzer focal plane with the locations of the IRAC arrays and MIPS 24 µm array and the Ball Aerospace y and z coordinate. These are the coordinates used by GSFC to designate the locations of the 25 standard positions in the focal plane for the simulated images. The position "z1_y1" is at the lower right in the picture, "z5_y1" at the upper right, and "z5_y5" at the upper left.



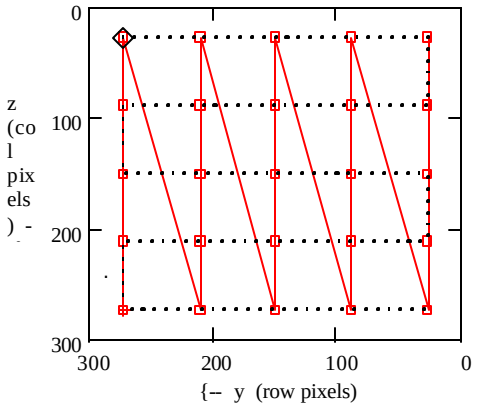
prf_ch1_mdl55-34_setfocus_3.16_-050709_center_pos12_z3_y3.fits

IRAC_ch1_PRF_cntr_jan05.fits

Figure 2. Center position PRF from Simfit and from Dave Elliott. The image on the left is from Simfit. The one on the right from the analysis of observed images by Dave Elliott in January, 2005. Although the images appear to be different, it is clear from their asymmetry that they have the same orientation. The two squares in the Simfit image show the start and middle of the first row as discussed in the caption to Figure 1.

Figure 3 shows the terminology for the positions on the focal plane, the Simfit position index number, and the sequence of the positions observed in Campaign Q. The 25 positions are a uniform grid starting 24 pixels from the edge and continuing with a spacing of 52 pixels.

$$pospic = \begin{pmatrix} "z5_y5" & "z5_y4" & "z5_y3" & "z5_y2" & "z5_y1" \\ "z4_y5" & "z4_y4" & "z4_y3" & "z4_y2" & "z4_y1" \\ "z3_y5" & "z3_y4" & "z3_y3" & "z3_y2" & "z3_y1" \\ "z2_y5" & "z2_y4" & "z2_y3" & "z2_y2" & "z2_y1" \\ "z1_y5" & "z1_y4" & "z1_y3" & "z1_y2" & "z1_y1" \end{pmatrix}$$



SIRTF CTA focal plane positions

Solid line shows the order for the simfit position index with + indicating the simfit 0 position. Dotted line shows order of observed image raster with diamond indicating start.

Campaign Q observing sequence

$$Qseq = \begin{pmatrix} 4 & 9 & 14 & 19 & 24 & 23 & 18 & 13 & 8 & 3 & 2 & 7 & 12 \\ 17 & 22 & 21 & 16 & 11 & 6 & 1 & 0 & 5 & 10 & 15 & 20 & "" \end{pmatrix}$$

Locations of 25 positions in pixels by Simfit position sequence index

$$loc = \begin{pmatrix} 232 & 232 & 232 & 232 & 232 & 180 & 180 & 180 & 180 & 180 & 128 & 128 & 128 & 128 & 128 & 76 & 76 & 76 & 76 & 76 & 24 & 24 & 24 & 24 & 24 \\ 232 & 180 & 128 & 76 & 24 & 232 & 180 & 128 & 76 & 24 & 232 & 180 & 128 & 76 & 24 & 232 & 180 & 128 & 76 & 24 & 232 & 180 & 128 & 76 & 24 \end{pmatrix}$$

Position names in order of observation in IRAC Campaign Q

$$pq = \begin{pmatrix} "z1_y5" & "z2_y5" & "z3_y5" & "z4_y5" & "z5_y5" & "z1_y4" & "z2_y4" & "z3_y4" & "z4_y4" & "z5_y4" & "z1_y3" & "z2_y3" & "z3_y3" \\ "z4_y3" & "z5_y3" & "z1_y2" & "z2_y2" & "z3_y2" & "z4_y2" & "z5_y2" & "z1_y1" & "z2_y1" & "z3_y1" & "z4_y1" & "z5_y1" & "" \end{pmatrix}$$

Figure 3. Terminology and location of 25 focal plane positions. The matrix at the upper left gives the position names with the orientation of Figure 1. The picture at the upper right shows the 25 positions with the Simfit row-column coordinates. The red squares and line show the sequence of positions specified by the Simfit position index from 0 to 24. The sequence begins at the lower left. The dashed black line starting at the upper left shows the sequence of positions as observed in IRAC Campaign Q. The matrix "Qseq" gives the Simfit position index for the observed sequence. The matrix labeled "loc" gives the location of each position in Simfit row-column coordinates in the Simfit position sequence. The positions start 24 pixels from the edge of the array and proceed with a spacing of 52 pixels. The matrix at the bottom called "pq" gives the position names in the sequence that they were observed in IRAC Campaign Q.

4. Creation and optimization of the model PRF's

4.1 Introduction to Point-Spread-Function (PSF) and Pixel Response Function (PRF)

A PSF is a function which represents the intensity pattern image of an external point source produced by an optical system at a focal plane of the system. A PRF is a PSF convolved with a detector pixel at that focal plane. It has been called a "superimage formed by uniformly sampled pixel phases" (Tod R. Lauer). Both are normally expressed in numerical form as a set of values over a two-dimensional grid. The grid spacing should be small compared with the structure of either function. If the detector pixel size for the PRF is sufficiently small so that the PSF can be closely approximated by a tilted plane over the pixel, then the PRF and PSF are very nearly the same.

The IRAC library of simulated images are produced at Goddard Space Flight Center (GSFC) by summing rays from an optical model over grid boxes with a spacing 1/5 the IRAC pixel size. Hence they are PRF with a "pixel" size 1/5 that of IRAC. Since this grid spacing is sufficiently small to approximate the condition given in the previous paragraph, I choose, for convenience, to call the simulated images "PSF" to distinguish them for the PRF convolved with the full IRAC pixel. The Simfit analyses described in this and the previous sections are carried out with the GSFC PSF model images. The corrected PSF are converted to PRF for general use at the end of the process.

An IRAC pixel image can be obtained from either a PSF or a PRF. In both cases, the IRAC pixel pattern is overlaid on the higher resolution grid. For the PSF, the values on the grid within each pixel area are added to provide the value in that pixel. For the PRF, the value on the grid at the center of the IRAC pixel is taken for the pixel value. In both cases, if the IRAC pattern is not registered exactly with the grid, the values must be interpolated between grid points.

4.2. The model PSF image library

The starting point for the model psf image library is simulated model images created at GSFC from the Ball Aerospace-GSFC optical model of Spitzer and IRAC using the Optical Research Associates ray-trace program, CodeV. The wavefront deformations, properties, and positions of the optical elements in the model were taken from measurements of individual components and subassemblies obtained at the operating temperatures. The IRAC component properties include variation with wavelength. The model was verified and refined by comparing model images to measured images obtained during end-to-end tests at Ball Aerospace & Technologies Corporation using their largest thermal vacuum chamber, known as the "Brutus" chamber. During these tests a wavefront correction for each IRAC channel was determined by the method of Phase Retrieval. Since it could not be determined whether this correction just applied to the Brutus test optics or at least partially to the system to be orbited, model images were obtained both with and without the correction.

The images used in the analysis reported here and identified by the date 20020719 were created by Eric Mentzell by the following steps.

1. For each image, create a set of rays from a point source at infinity to the focal plane array, uniformly covering the SST aperture and sampling the wavelength range of the array. This is done for a particular telescope secondary focus setting, secondary decenter, position on the array, and presence or absence of the phase-retrieval correction.

2. Use the ray-trace data to compute the wavefront aberration of the system. Apply the phase-retrieval wavefront correction, if this is specified. Then by Fast Fourier Transform, compute from the corrected wavefront the diffraction image distribution at the plane of the array for each wavelength sampled.
3. Sum these intensity distributions over wavelength, weighting for the spectral response of the array and filter and for the source spectrum (Rayleigh-Jeans for a star).
4. Sum the previously summed wavelength intensity data into a grid of 128x128 "sub-pixels" each one-fifth the size of an IRAC pixel. This grid is centered on the source..
5. Format the results as a FITS image file.

For each IRAC channel this process is repeated to create at total of 6250 images for the parameters:

Focal plane positions: 25 position in a grid of IRAC pixel coordinates on each axis of 24, 76, 128, 180, and 232

Focus settings: secondary focus mechanism 25 settings -30 to +30 μm in steps of 2.5 μm

Phase-retrieval correction: absent (component model); present (phase-retrieval model)

Secondary decenter 5 settings

4.3. Optimization of the model secondary focus, secondary decenter, and phase retrieval correction by comparison to Spitzer Images

Optimization was carried out using Simfit to determine the values of the parameters which give the best fit between the observed and model images. This was done for the observed images from Campaign Q, the first full data set after refocus which contains 300 images (12 dithered images from each of the 25 positions). It was assumed that the same secondary decenter applies to all IRAC channels and focal plane positions and that the same phase retrieval correction applies to all 25 positions for each channel. It was found that the same secondary focus setting does not apply to the four IRAC channels or even to the 25 positions for one channel. The best focus settings for each position for Channel 1 have been fit to a quadratic surface (tilted ellipsoid) to determine a smoothed focus correction over the field. With this correction applied, a single model focus setting is determined by an overall best fit to the 300 observed images.

The optimization of all parameters was determined by interpolation between set values by interpolating the model images between the parameter settings. Because the calculations were all carried out in row-column coordinates, these will be used for the description of focus correction over the focal plane. The relation between row-column and other coordinates is given in Section3.

The optimization results for Channel 1 are:

1. Focus. The focus curvature correction best fitting quadratic fit is given by

$$f(r,c) := a_0 + a_1 \cdot r + a_2 \cdot c + a_3 \cdot r \cdot c + a_4 \cdot r^2 + a_5 \cdot c^2$$

where r and c are row and column numbers, f is in μm, and

$$\begin{array}{cccccc} a_0 & a_1 & a_2 & a_3 & a_4 & a_5 \end{array}$$
$$a = \begin{pmatrix} -1.291 & 0.012 & 1.802 \times 10^{-3} & -3.267 \times 10^{-5} & 1.263 \times 10^{-4} & 1.121 \times 10^{-4} \end{pmatrix}.$$

The fit offset values for the 25 focal plane positions in μm secondary motion are;

fit =

	column 0	1	2	3	4
row 0	-0.5	-1.1	-1.2	-0.6	0.6
1	-0.7	-1.5	-1.6	-1.1	0.0
2	-0.3	-1.1	-1.3	-0.9	0.1
3	0.9	-0.0	-0.3	-0.0	0.9
4	2.7	1.7	1.3	1.5	2.4

Secondary focus shift in μm

The mean value of the focus (to be added to these corrections) is 3.16 μm

The mean values of the Simfit focus for each position agree very closely with this quadratic fit as seen in Figure 4.

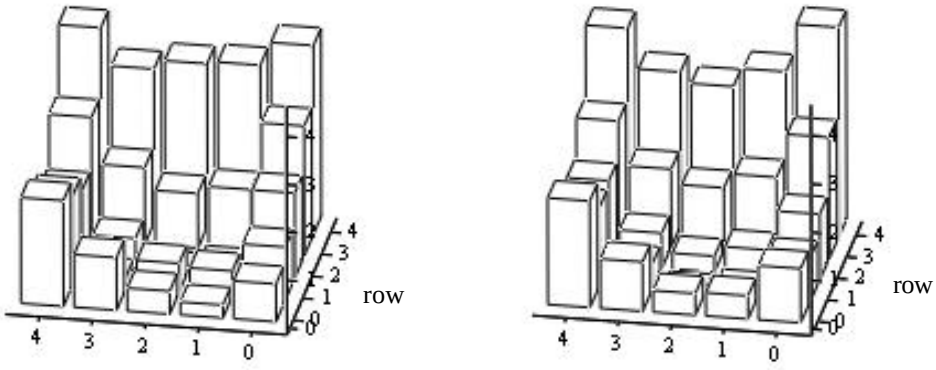


Figure 4. Comparison of three dimensional bar plots for the observed means (left) and the fit values (right) in row-column coordinates. The vertical scale has been offset to make all values positive for clarity on the plot. The fit values are calculated from a quadratic surface best fitting the observed values. The correction is primarily a tilt with some curvature. The curvature is nearly the same in both axis indicating that it is largely spherical. The excellent fit between the two plots indicates that the Simfit focus determinations over the focal plane are accurate with little noise and that the model focal surface error is largely that of a tilted sphere.

2. Secondary decenter: z-decenter +0.004 mm; y-decenter -0.049 mm

3. Phase retrieval correction: Interpolate images with 0.75 phase retrieval corrected model and 0.25 uncorrected model

4. Gaussian blur. It was found that convolving the images with a Gaussian blur function improved the fit considerably. However, this step was not carried out for this analysis but instead incorporated into the convolution correction described in the next section.

4.4. Creating observed and model PRF with the drizzle technique

In order to correct the model PRF by comparing it with an observed PRF, it is necessary to create an observed PRF from the data and a corresponding model PRF from the model PSF. For this I have chosen to us the "drizzle" technique. The following discussion is based on my understanding and use of the drizzle technique.

The classical method for combining dithered, or mosaiced, images is to shift the images to a common center and add individual pixels into the nearest point on a grid with the observing instrument pixel spacing. This has the effect of smoothing, or smearing, the data and results in the loss of spatial structure information. Drizzle is a method for combining the images retaining the structure information. In the drizzle method, the fractional position shift is retained and used to place the data from the individual images onto a finer grid than the instrument pixel scale. When the object in the images is a point source, the result is a point-spread-function convolved with the array pixel response of the observations to give a pixel-response-function (PRF).

Application of the method requires resolving two issues:

1) Determination of the appropriate shift of each image to a common enter
2) Creating an image with regular grid (sub-pixel) spacing from the data with random fractional pixel spacing.

Solutions commonly used for the first issue are to determine the shifts from the telescope coordinate offsets, from a calculation of the image centroids, or from cross-correlation of images. For Spitzer, the telescope coordinates are not known with sufficient precision for this purpose. For IRAC channels 1 and 2, because of image under-sampling, the centroid does not correspond closely enough to the position shift. Finally, the dithered images are too widely separated for cross-correlation. Instead, I have chosen to a use best fit to the model images to determine the shift, using the tools of Simfit.

For the second issue, I assign each of the pixel values to the nearest PRF grid box, retaining the exact coordinate of the pixel. For Campaign Q with 300 images, the mean number of values per box are 12. A quadratic surface is then best-fit to these values in order to obtain a single value for the center of the box utilizing all the data equally.

4.5. Details of using the drizzle method for creating observed and simulated PRF

1. Place the observed images for Campaign Q Channel 1 into a single directory. There are 300 images (25 positions, 12 dithers per position). The following steps are carried out with the worksheet "Simfit" run under Mathcad.
2. Identify, locate, and calculate basic properties of the brightest point source in each image. Properties are obtained for both a minimum cropped image (7x7 pixels) and an extended size (11x11 pixels or larger).
3. Reject flawed detections by the following criterion. Typically about 12 images are rejected.
    a. Source is too close to edge of array
    b. Minimum or maximum of source is out of range
    c. The sum of the source (flux) is out of range
    d. Ratio of peak to sum of source is out of range
    e. A pixel, other than the peak, is higher than all its neighbors
    f. Source noise-pixels deviates from the median by more than 2.2 σ
4. Obtain simulated IRAC pixel sized images best-fit to each of the observed images. In this process, the simulated sub-pixel library images are shifted by fractional subpixel values to exactly match the centroids of the simulated images to those of the observed images. These shifts are saved to be used in Item 5.
5. Start the drizzle process by establishing a drizzle grid for the observed and the for the simulated images each with spacing 1/5 IRAC pixel size. Using the pixel position in the image and the shifts from the image center determined in Item 4, assign the value of each pixel in all the cropped images to a grid box, retaining with each value the fractional grid spacing shift. For the 1/5 IRAC pixel grid spacing, 25 positions, and 12 dither there are typically 12 pixel values per drizzle grid box.
6. Use all the pixel values in each grid box to determine the best-value for the center of the box. This is done with the following iterated procedure.
    a. If the number of values > or = 8, find the best fitting quadratic surface to the set of pixel values with their position shifts.
    b. If the number of values is < 8 and > or = 5, find the best fitting linear surface (plane) to the set of pixel values with their position shifts
    c. If the number of values is < 5 and > or = 3, obtain the mean of the values.
    d. If the number of values is < 3, set the result to zero
    e. Mark as rejected any values with more than 3 sigma deviation from the surface or mean.
    f. If any values have been rejected, repeat a ..d at most twice
    g. Select as the value for the grid box the value on the surface at the center of the box..

7. This results in two PRF, one for the observed and one for the corresponding best fitting simulated images. In each the data are all used most affectively with deviant points rejected. If the model accurately represented the telescope and instrument, the two PRF would be identical.

4.6. Comparing the model and observed PRF to obtain and apply a convolution correction function

The model is further improved with a convolution correction function by the following steps:

1. Deconvolve the observed PRF with the simulated PRF using Fast Fourier Transform (fft) to create a convolution function. This is done by dividing term-by-term the complex fft of the observed PRF with that of the simulated PRF. The values are unity for terms which are the same for the observed and simulated PRF.
2. Apply a filter to the convolution fft to remove artifacts caused by noise and very small Fourier components in the denominator (simulated fft). The form of the filter causes terms in the convolution fft for which the simulated fft values are much smaller than the threshold to be 1.00. The filter is given in the equation below The filtered fft is provided on in the sirtfweb site as:

drizconvfft_Q_ch1_mdl30-09_intp-yes_dbins11_shif_v456_050429_06fv_v041C_size128_thresh-0.0068.fits

The filter function is given below for

fftconv = the Fourier transform of the convolution function

fftsim = the Fourier transform of the simulated PRF

fftthreshold = the filter threshold value, taken to be 0.01

$$\text{filteredfftconv}_{i,j} := \frac{\text{fftconv}_{i,j}\left[\left|\left(\text{fftsim}_{i,j}\right)\right|\right]^2 + \text{fftthreshold}^2}{\left[\left|\left(\text{fftsim}_{i,j}\right)\right|\right]^2 + \text{fftthreshold}^2}$$

3. Convolve each image in the library of simulated images (PRF or PSF) with the filtered convolution function to obtain a corrected set of simulated images. This is done by multiplying term-by-term the fft of the simulated image by the filtered convolution fft.
4. Obtain the inverse transformation of the fft to obtain corrected PRF (or PSF)
5. If the corrected function is a PSF, calculate the associated PRF by replacing each value with the sum of the values in a 5x5 box centered at that value.

Figure 5 shows the absolute value of the filtered convolution fft.

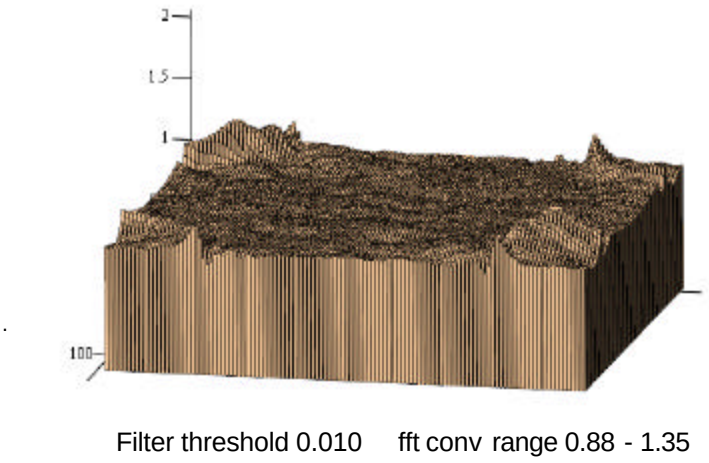


Figure 5. Absolute value of filtered convolution fft. This is a 128x128 array of values plotted as a function of row and column spatial frequency. There is no correction for values equal to 1.

While the convolution function is obtained by comparing PRF's, it is appropriate to apply it to either the simulated PSF or PRF because the processes of summing a PSF into IRAC sized pixels for a PRF or an IRAC image are both linear and are interchangeable in order. Corrected PRF are formed by summing the PSF grid points over IRAC sized pixels.

The results as described in Section 5 show a remarkable improvement in the fit between the observed and simulated images. The simfit parameter increased from 0.965 to 0.982. This is a greater improvement than obtained with previous optimizations. The standard deviation of the differences between the observed and best-fit simulated images decreased by a factor of two.

5. PRF characteristics and quality

The quality of the model PRF can be assessed by comparing the model PRF with an observed PRF or by comparing IRAC observed images with ones obtained from a model PRF with suitable shifting to match the pixel phase. This section describes the results of comparing the observed and model images. A comparison of the observed and model PRF is present in Section 6. All the results were obtained with the model corrected as described in Section 4.

5.1 Comparison of observed and model images.

Figure 6 is a histogram of the Simfit focus values for each of the observed images of IRAC Campaign Q. Out of the 300 observed images, 12 dithers for each of the 25 focal plane positions, 287 passed the set of validity tests and were used for this analysis. The analysis also used a library of point-spread-functions created from the optical model at GSFC with the corrections described in Section 4 with a range of secondary focus settings. These settings have been corrected for each

focal plane position as described in Section 4.3. For each observed image, the psf images were shifted with interpolation in pixel phase and interpolated in focus to provide the best fit to the corresponding observed image. The histogram shows the resulting focus values to be closely bunched. The mean focus is near 3.16 µm, the value of the model focus used for the remainder of the analysis and the figures in this report.

Figure 7 is a histogram of the Simfit parameter for the best fit for each of the observed images using the mean focus value of 3.16 µm. The Simfit parameter is similar to a correlation coefficient with 0.0 for no correlation and 1.0 for a perfect fit. The values in the histogram cluster around 0.98 indicating a good fit with little scatter. The conclusion from these histograms is that the model images are a good representation of the observed images.

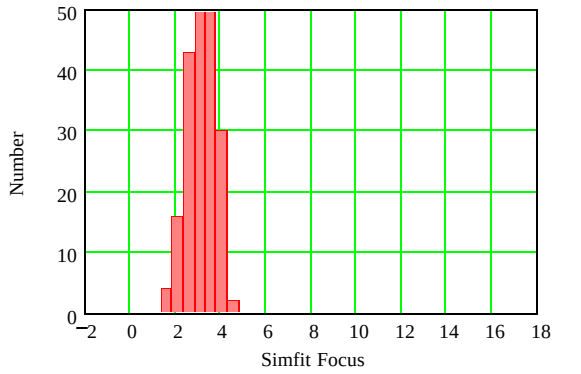


Figure 6. Histogram of Simfit focus. This histogram plots the best-fit focus for the 287 acceptable images of IRAC Campaign Q. The best-fit focus is determined by Simfit to be the secondary setting for each image which gives the best Simfit parameter over 7x7 pixels centered on the star. The optimization uses a library of simulated PRF covering a range of focus settings, interpolating between these settings. The PRF are also interpolated in position for sub-pixel shifts to match the simulated image centroid to that of the observed image. The resulting focus values cluster around 3.16, the value used for all model PRF in all the remaining figures.

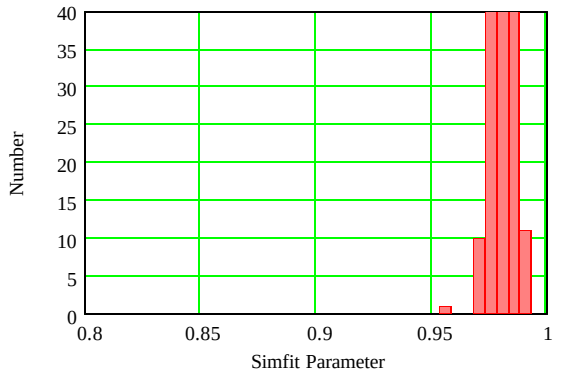


Figure 7. Histogram of Simfit parameter. The Simfit parameter shows the quality of the fit between an observed and a simulated image for the central 7x7 pixels. The model PRF are all obtained at a focus setting of 3.16, the mean setting shown in the histogram in Figure 4. The model PRF are shifted in pixel phase with interpolation so that the model image has the same centroid as the corresponding observed image. The Simfit parameter is similar to a correlation coefficient. For the 287 acceptable images of Campaign Q, the simfit parameter clusters around the value of 0.98 indicating very good fit

Figure 8 displays the errors in the fit between the model and observed images in another way. The difference between each pixel of the observed and the model images are plotted versus the distance of the pixel from the star's peak pixel. Each observed image is normalized to have a maximum of 1.00. The model images are normalized to have the same total flux as the corresponding observed image. The largest errors occur near the peak of the star image and are typically less than 0.06 of the image peak. The differences beyond a radius of 4 pixels are dominated by noise in the observed images.

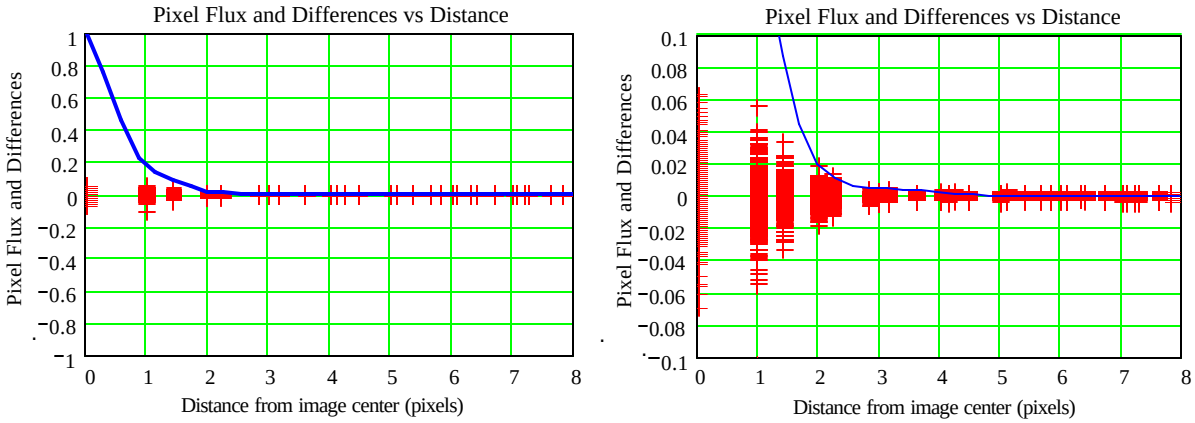


Figure 8. Pixel differences between observed and model images as a function of distance from center of star. The "+" give the difference of the corresponding pixels for the observed and model images taken over a 21x21 IRAC pixel square centered on the star. The total number of pixels displayed is 287x21x21 = 126567. Each observed image is normalized to a peak pixel of unity. Each model image is normalized to have the same total flux as the observed image. The blue line gives the mean flux as a function of radius. The difference scale on the right hand plot is 0.1 that of the left hand plot. The plots show that the maximum difference, which occurs for the center pixel, is +/- 0.06 of the peak. The difference beyond a radius of 5 pixels is largely noise in the observed images.

Figures 9 and 10 are a histograms of the pixel differences, Figure 9 for the inner 3x3 pixels and Figure 10 for the remaining pixels in a 21x21 pixel box. The right hand histogram in each figure has an expanded scale to show the low level numbers more clearly. The standard deviation of the errors for the inner 3x3 box is 0.0071 of the image peak and for the remaining pixels 0.0007. The latter is mainly noise in the observed image.

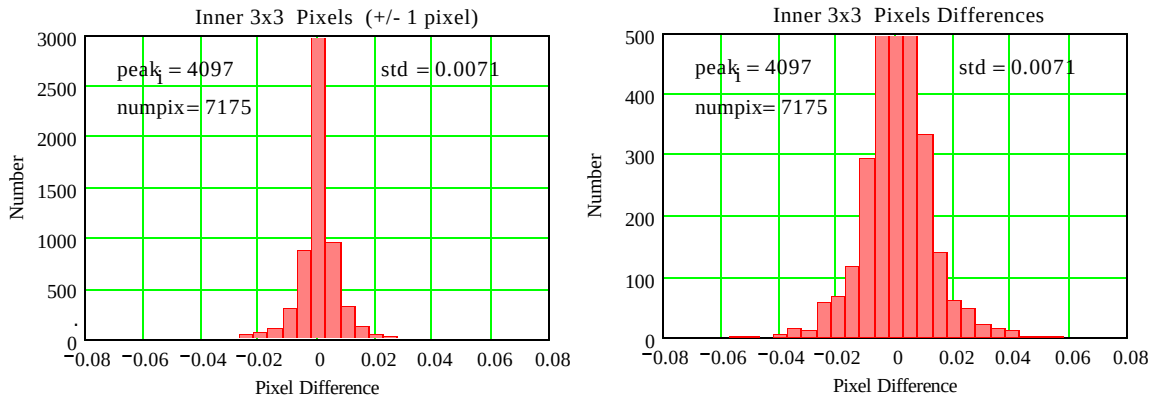


Figure 9. Histogram of the pixel differences for the central 3x3 pixels of the observed and model images. The left plot shows a histogram of the differences within the central 3x3 pixels, where most of the flux is. The right plot shows the same histogram with an expanded number scale to show the low numbers better. There are 7175 pixels in this group with a standard deviation of 0.0071.

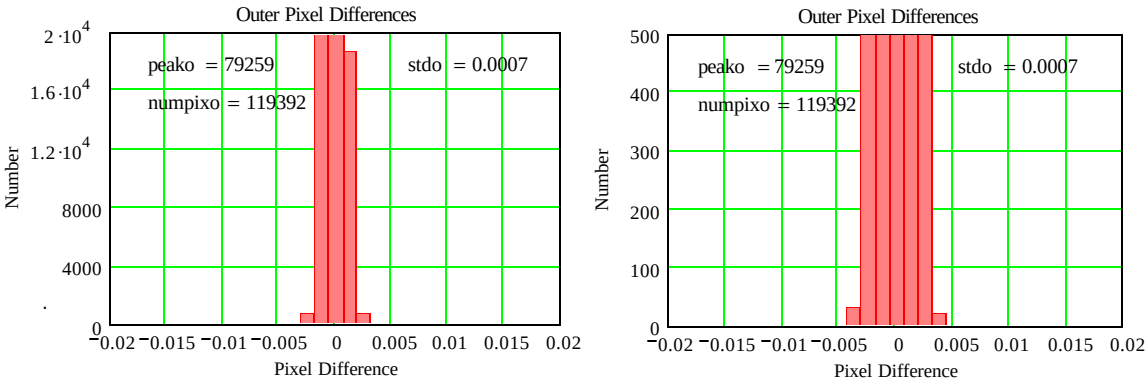
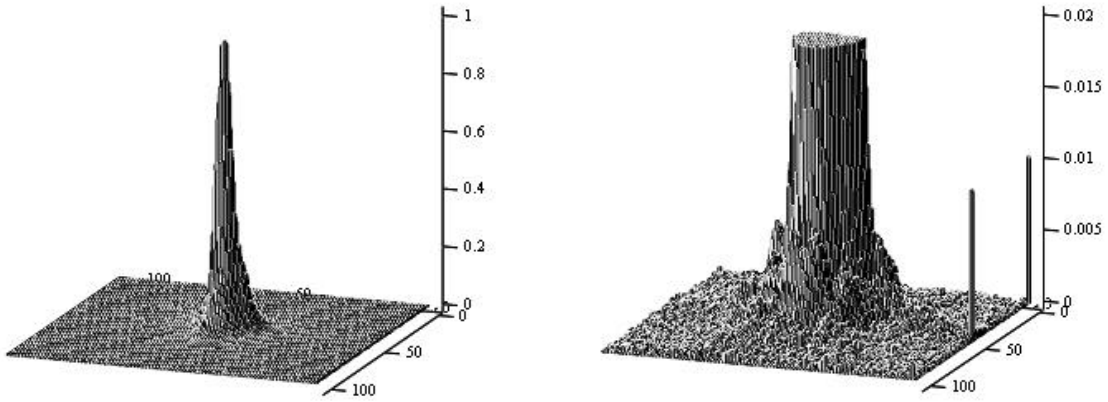


Figure 10. Histogram of the pixel differences for outer 21x21 pixels of the observed and model images. The left plot shows a histogram of the differences of all but the central 3x3 pixels of the 21x21 pixel images. The right plot shows the same histogram with an expanded number scale to show the low numbers better. There are 119392 pixels in this group with a standard deviation of 0.0007.

6. Conclusion - comparison of observed and model PRF

It is dramatic how well the corrected model PRF correspond to the observed PRF including the detailed features, while at the same time suppressing the noise of the observed PRF. This approach is effectively a method for filtering noise and artifacts from the observed PRF.

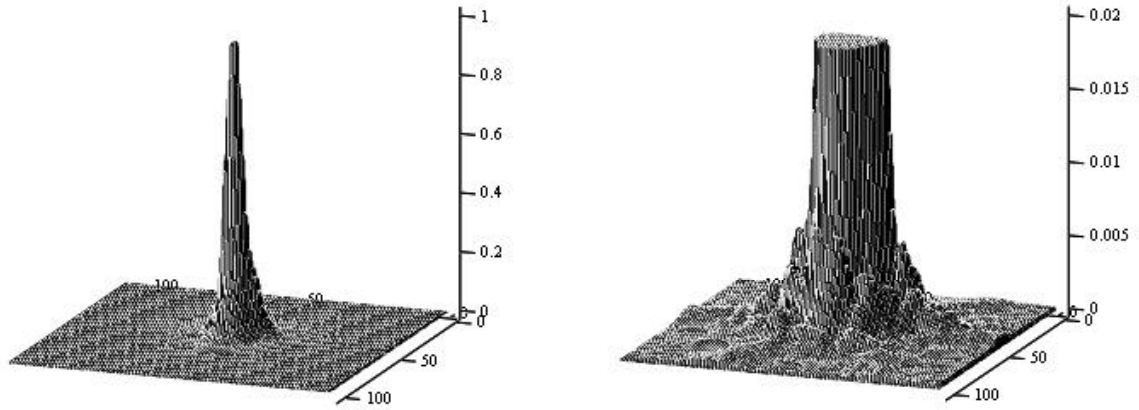
Figures 11 and 12 are three dimensional bar plots of the observed the model mean PRF obtained by a drizzle method over a 105x105 grid. The plots on the right have an expanded scale to show the low level flux more clearly. The inner part of the two plots are very similar. For the outer part, the model PRF shows the structure clearly, whereas the observed PRF is obscured by noise. Figure 13 displays the model mean PRF with a still higher scale expansion. Figure 14 shows a drizzle image at the same scale for a region of the observed images away from a star. It is dramatic how well the corrected model images suppress the noise compared with the observed PRF. Figure 15 displays the difference between the observed and model mean PRF with maximum difference 0.02 of the peak and the difference outside the central region dominated by observed noise.



drizzleobsfv

mark(drizzleobsfv, 1, 0.01)

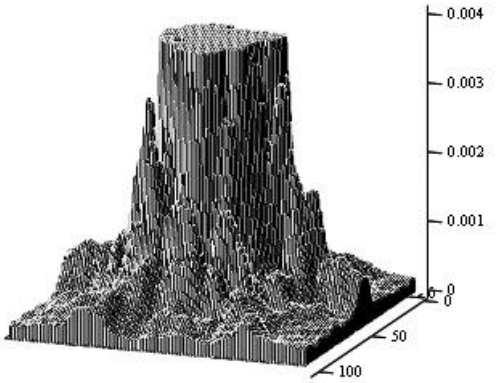
Figure 11. Observed PRF obtained by a drizzle method from the IRAC Campaign Q images. The drizzle was carried out for a 21x21 pixel portion of the IRAC images yielding a PRF at a resolution of 1/5 IRAC pixel over a 105x105 grid. The PRF is normalized to a maximum of unity. It represents a mean observed PRF over the 25 focal plane positions of the data of Campaign Q. Obtaining a PRF for each of the positions observed is not possible because only 12 images were obtained at each position. The right hand plot has a vertical scale expanded by a factor of 50 to show the low level flux. The two posts along the right edge in the right plot are at the start and middle of the first row of the Simfit row-column coordinates. They are shown this and other plots to provide for tracking and checking the orientations.



drizzlesimfv

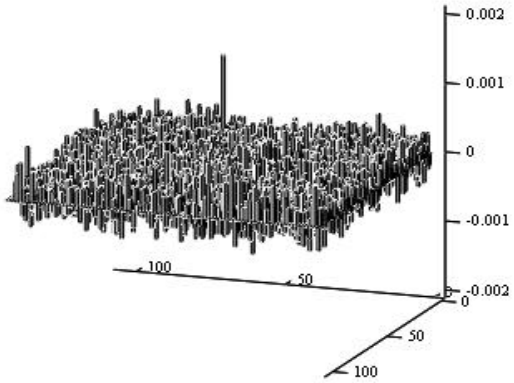
drizzlesimfv

Figure 12. Model PRF obtained by a drizzle method from the IRAC Campaign Q images. The drizzle was carried out for model images with the PRF shifted to exactly match the centroids of the observed images. This PRF is shown over the same 105x105 grid as the observed PRF. This model PRF is a mean for the 25 focal plane positions and is not the same as the 25 individual model PRF's associated with this explanation. The right hand plot has a vertical scale expanded by a factor of 50 to show the low level flux. The mean model PRF clearly shows structure out to the edge of the image which is obscured by noise in the observed PRF shown in Figure 9. For the region not obscured by noise, the model PRF appears very nearly the same as the observed PRF.



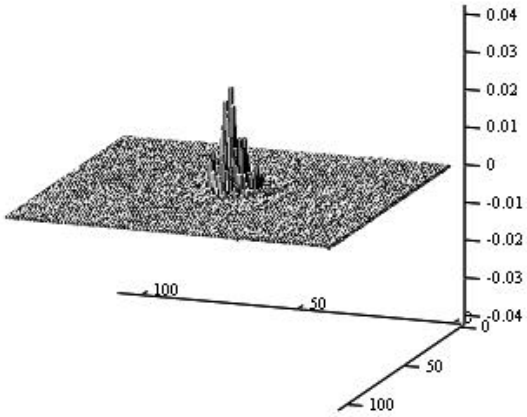
drizzlesimfv

Figure 13. The model PRF shown in Figure 10 with the vertical scale expanded by a factor of 5. This shows clearly the low level flux pattern with very little effect of noise out to +/- 52 grid spacings (10.4 IRAC pixels) from the center

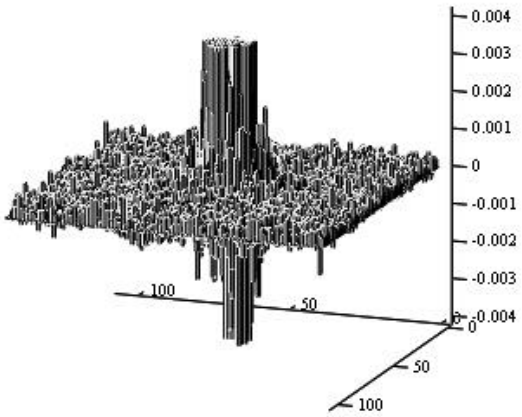


drizzlenoisefv

Figure 14. Observed image drizzle noise. This is a drizzled image obtained from the observed images at a location with no star but with the exact same pixel offsets used in making the observed and model PRF's. It is dramatic how effectively the model PRF supresses this noise.



drizzledifffv



drizzledifffv

Figure 15. Difference between observed and model drizzle image (PRF). The left hand plot shows that the maximum difference is about 0.02 of the peak. The right hand image with the expanded scale shows that outside the central region, the difference is mostly noise in the observed PRF.

7. Appendix - how to use the PRF

Procedures for using the PRF are being developed by the Spitzer Science Center and Focus IPT. An essential step in the process is to interpolate the nearest PRF to the position of interest and to interpret within the resulting PRF to the exact pixel phase of interest.