# Determination of Spitzer Space Telescope focus from IRAC images without a focus slew

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## Abstract

Prior to launch, the Spitzer Space Telescope (SST) secondary focus mechanism was set to a predicted desired in-orbit focus value. This predicted setting, determined from double-pass cold chamber measurements and calculated ground-to-orbit corrections, had an uncertainty greater than the required on-orbit focus accuracy. Because of concern about the potential for failure in a cryogenic mechanism affecting all SST instruments, **it was required that any focus correction be made in a set of moves directly from the initial to the desired setting**. The task of determining the required focus moves fell to IRAC, the instrument most affected by and sensitive to defocus.

To determine the focus directly from examining images at a fixed focus, we developed two methods, "Simfit" and "Focus Diversity“ (Hoffmann W. F., et. al., 2003, SPIE, 4850, 428).

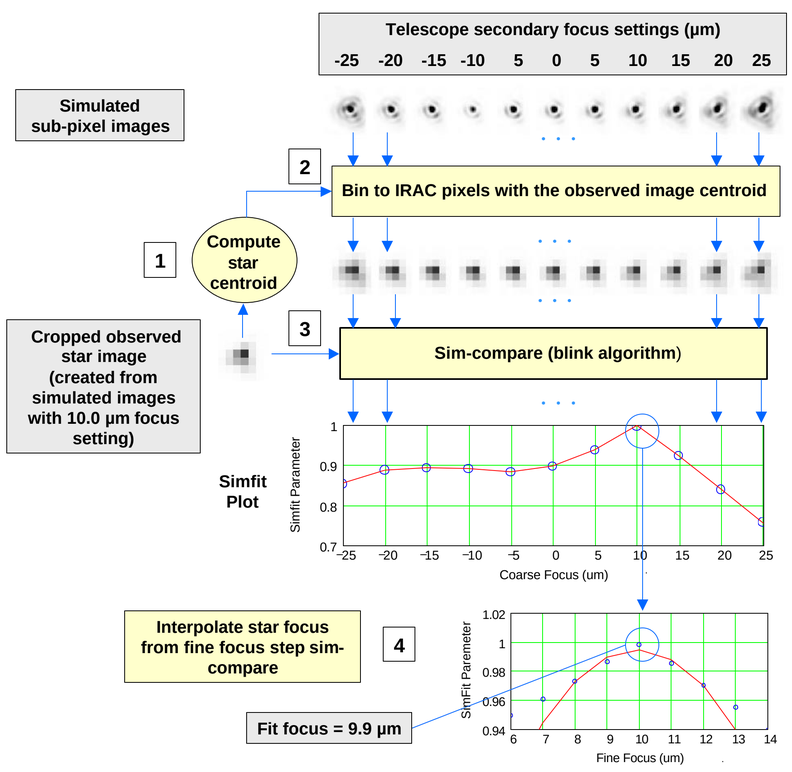
**Simfit** finds the focus by obtaining the best match between observed images and families of simulated images created for a range of focus settings.

**Focus Diversity** utilizes the focal plane curvature to find the best fit of the varied image blur over the focal plane to model defocus curves.

Observations of a single star at many field locations in each of the four IRAC bands were analyzed before and during the refocus activity. The resulting refocus moves brought the focus to close to the specified requirement of 0.3 mm from the desired IRAC optimum focus. This is less than a "Diffraction Focus Unit" (wavelength times focal ratio squared) of 0.48 mm at the shortest IRAC band (3.6 microns). The improvement in focus is apparent in both the appearance and the calculated noise-pixels of star images.

## The Methods

### Simfit




Both methods require a high quality optical model. Simfit requires simulated images which accurately match the observed images. Focus Diversity requires a defocus curve with focus setting and image size at best focus over the field, accurately accounting for focal plane curvature and tilt.

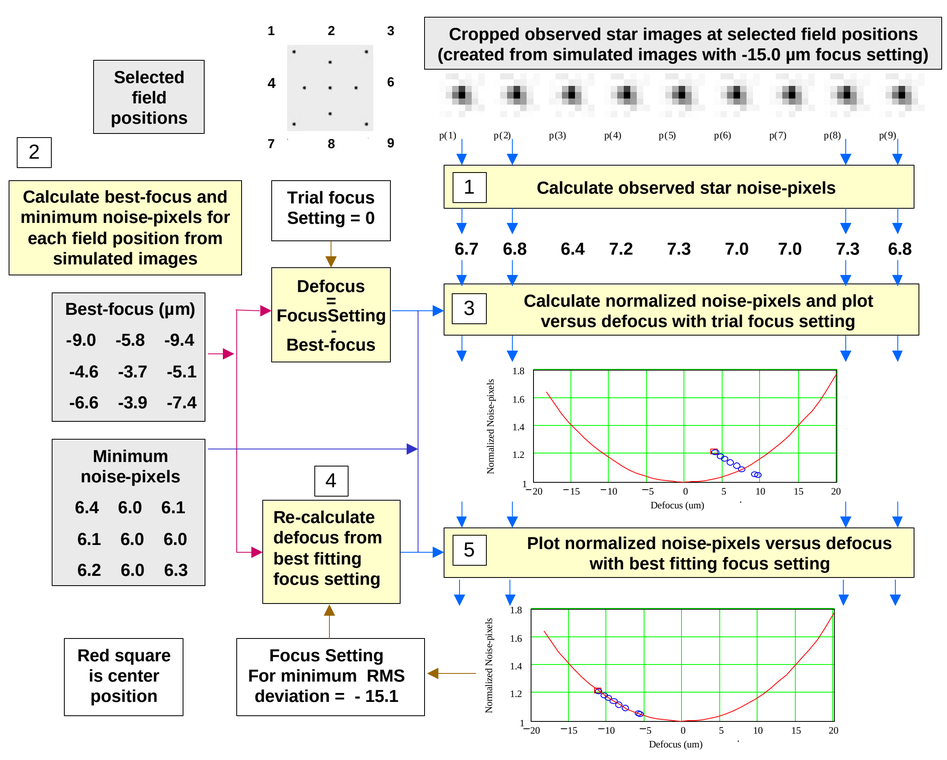
The focus determination is given as the setting of the secondary position in μm. 1 μm at the secondary corresponds to 0.1 mm at the SST focal plane.

The measure of the blur, or area, of the images used in Focus Diversity is noise-pixels. Noise-pixels (NP) are proportional to the integration time required for a point source to reach background limited noise.

For $Star_{i,j}$ equal to the intensity in pixel i,j of an image:

$$NoisePixels(Star) = \frac{\left(\sum_{i,j} Star_{ij}\right)^2}{\sum_{i,j}\left(Star_{ij}\right)^2}$$

### Focus Diversity




## The Results

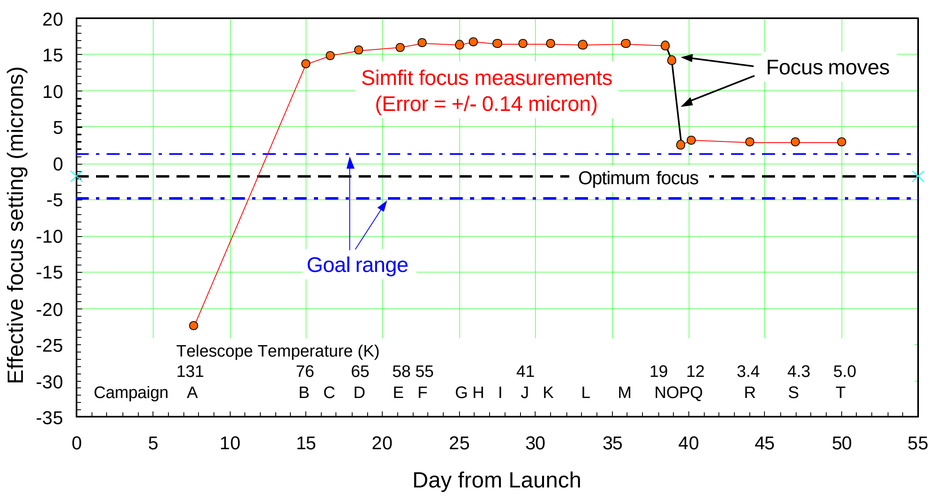
The Simfit Focus Plot to the right gives the secondary focus position in μm versus Day-from-Launch during the initial orbital checkout while the telescope was cooling. The IRAC Campaign letters and associated telescope temperatures are given at the bottom of the graph. The optimum focus and goal range are shown. The first measurement is negative because of transient temperature differences in the telescope. By the time the telescope reached a temperature of 55 K, the focus had settled to a value of 16.5, 18.3 μm greater than the optimum focus. At day 38 an initial "exploratory" move of -2 μm followed by a main move of -12.3 μm was carried out. A planned third move of -4 μm was not made because of ambiguity in interpretation of the focus diversity results at the time due to model error in the focal plane tilt and curvature.

**The final focus is 0.96 diffraction focus units ($\lambda f^2$) from optimum (best compromise focus for Bands 1 and 2) and meets IRAC image requirements.**

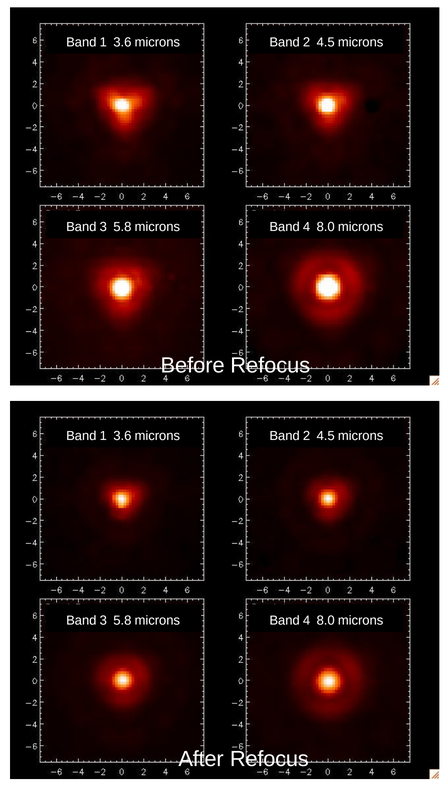
The plots below give Simfit and Focus Diversity for Bands 1 and 2 before and after refocus. Simfit is shown for one of the grid of 25 field positions used. The double peaks are on either side of best focus with the higher peak showing be best fit between the observed and simulated images. The focus diversity diagram plots normalized NP versus focus for all 25 positions. The shift in the defocus curves between bands 1 and 2 is due to the non-confocality of their focal planes. At best-focus for the given field position the normalized NP value is 1.0. The dashed line at 1.10 is the maximum acceptable mean normalized NP. At the optimum focus, the mean normalized NP for Bands 1 and 2 are the same.

The pictures show point-spread-functions in all four bands before and after refocus. The box size is 16 IRAC pixels (18.3 arc-seconds). The triangular appearance of the images, particularly prominent in the out-of-focus images, was first identified in an early cold test of the telescope assembly. It is attributed to the method of secondary mirror support.

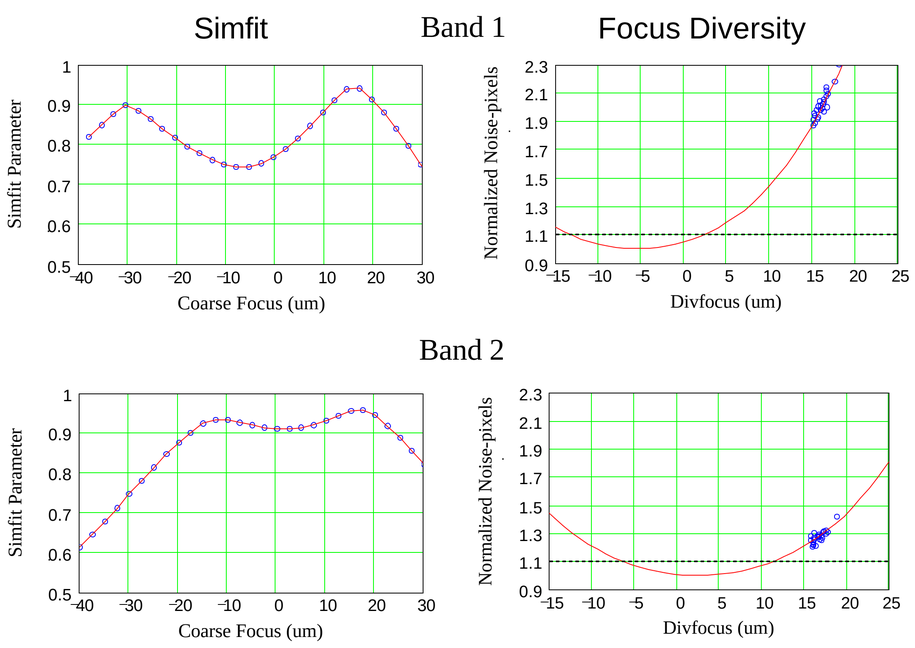
### 20 Simfit Focus Measurements (Mean of Bands 1, 2)




### PSF in 4 Bands




### Before Refocus Secondary focus position = 16.5 microns




### After Refocus Secondary focus position = 2.8 microns