Memo to Spitzer Observers regarding high precision photometry using dithered observations

Issued 18july2013

Summary: Using dithered observations may be an efficient alternative to staring mode observations if the required precision is greater than 0.01%. This method may enable more efficient searches for planetary transits and the ability to study other temporal phenomena such as spots and weather of brown dwarfs without continuous monitoring.

The SSC has performed an analysis of 17856 individual photometry measurements of one of the IRAC primary calibrators, HD 165459. The data are at 3.6 μm and were taken using 0.4s subarray observations with a 4 point Gaussian dither. The 70 AORs are distributed approximately every 14 days throughout the warm mission. The photometry from only one BCD was dropped due to problems processing that image.

Photometry was calculated for the star using the standard method used for the IRAC absolute flux density calibration. The centroid for the star was calculated on each subframe from the flux-weighted x and y moments in a 7x7 pixel box around the brightest pixel corresponding to the source. The background for centroid determination was estimated using a square annulus around the centroid box. Using the centroids, circular aperture photometry was performed using the aper.pro IDL astrolib routine with an aperture radius of 3 pixels, a background annulus of 3-7 pixels and the /EXACT and /FLUX keywords. The photometry has the location-dependent array photometric correction (section 3.5 of http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/warmfeatures/) and pixel-phase correction (http://irsa.ipac.caltech.edu/data/SPITZER/docs/irac/calibrationfiles/pixelphase/) appropriate for the warm mission applied. The photometry was aperture corrected by multiplying by 1.126.

We then compared the measured photometry to the predicted un-color corrected flux density expected (F*K*) based on the appropriate spectral template and fit to 2MASS and MSX photometry. F*K* = 649.5405 mJy for HD 165459. The expected signal-to-noise for a single 0.4 second measurement of HD 165459 is 433. Figure 1 compares the distribution of measured flux density offset from photometric truth for these observations. The distributions in flux density difference are shown for the ensemble as well as for each separate dither position for all the collected data. The distributions are fairly Gaussian with the mode of the aggregate and each individual dither position offset slightly from the expected flux density. The distributions of the individual dither positions are statistically offset from each other and the total. However, the offsets are within the expected error in the knowledge of the predicted flux density and the flux conversion factor used in scaling the IRAC data.

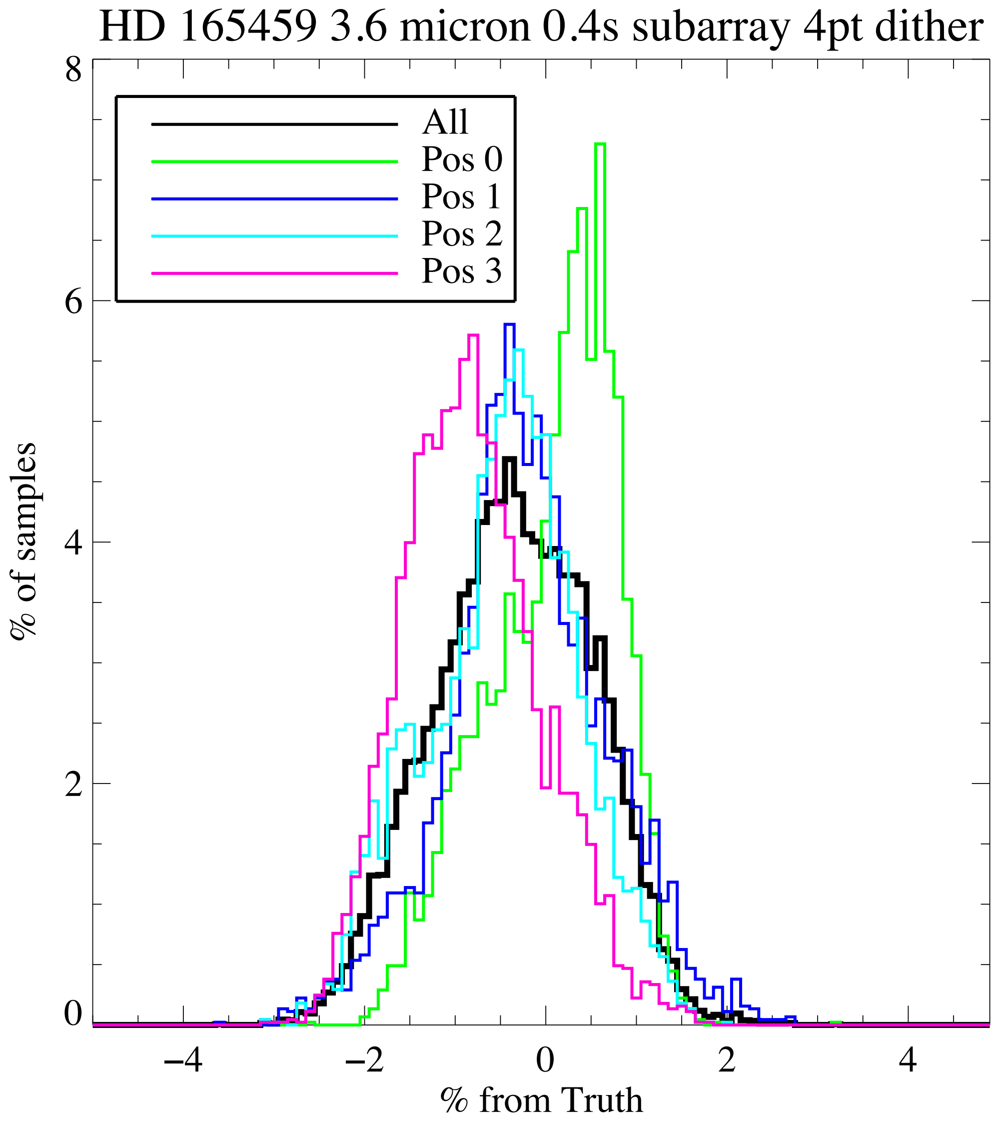

Figure 0: Distribution of percent difference of photometry from expected flux density as a function of the four dither positions (green, blue, cyan and magenta histograms) and for the entire data set (black histogram).

To assess the repeatability of dithered data and whether the uncertainty improves as $N^{0.5}$ where N is the number of independent photometric measurements, we measure the fractional uncertainty of ensembles of the data averaged over increasing numbers of measurements. The data in each bin in the ensemble is selected at random from the entire set of points to reduce the possibility of temporal or positional correlations.

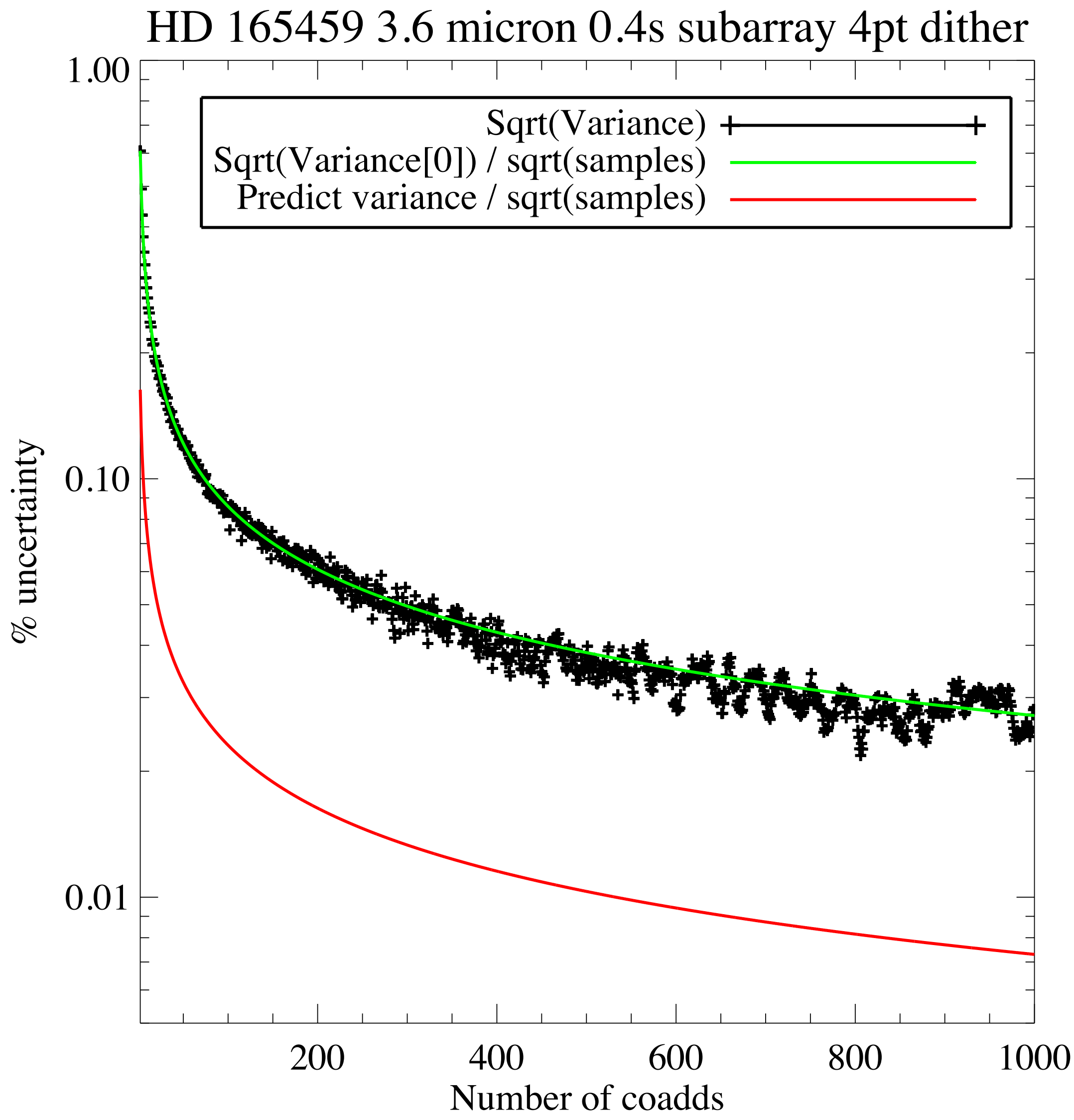

Figure 0: Variation in uncertainty as a function of averaging. The green curve is the N-0.5 trend scaled to the first data point. The red line is the expected uncertainty estimated from the readnoise and photon noise contributions.

Figure 2 displays the variation in measured uncertainty as a function of coadding data points. For each point on the plot representing a different number of photometric measurements coadded, the percent uncertainty is the measured standard deviation of the bin-averaged photometry over all the bins. For the largest bin size of 1000 coadded measurements, there are 17 bins of data. The uncertainty in the standard deviation is of order the localized scatter in the plot.

The uncertainty follows the expected $N^{-0.5}$ trend (green curve) for all bin sizes examined indicating that there is no red noise for the photometry at the 0.01% level. Note that the noise is about 3.7 times higher than what is predicted from the root-sum-square of the photon noise and readnoise in the aperture photometry. The increased noise is likely due to imperfect correction of the location dependent photometric effects including intra-pixel gain variation as well as residual flat-field error and variations in photometry due to the residual bias pattern. While we have not performed a comprehensive study of how much larger the actual uncertainty is over predictions for high signal-to-noise (SNR > 100) observations, it is likely a factor of 2-5 for most cases and will vary from observation to observation depending on positions and pixel-phases sampled.

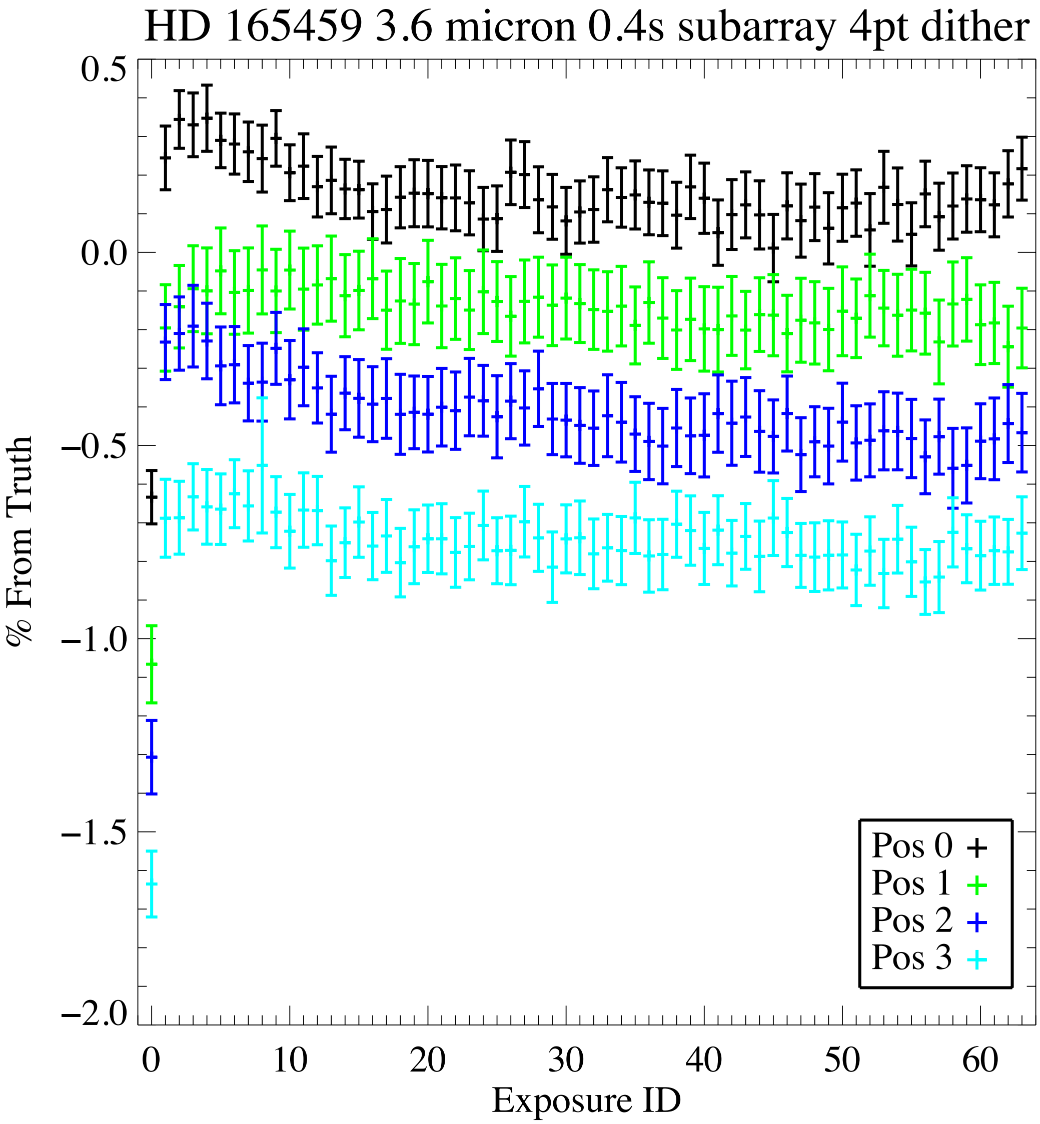

Figure 0: Variation of measured photometry compared to truth estimate as a function of subframe in each BCD and dither position.

The available data suggest that dithered observations can produce repeatable and fairly precise photometry for high signal-to-noise sources. Precisions of ~0.01% can be achieved using dithered observations to average down the photometric noise. The first advantage of this strategy is that dithering averages over array systematics permitting comparison of multiple epochs in a much more straightforward fashion than staring mode observations. Staring mode observations can produce extremely precise data (~30 ppm) but can have definite systematic offsets in measured flux from epoch to epoch. A sample set of systematics due to different dithered positions are illustrated in Figure 3. With judicious selection of array locations to observe with and using archival photometry to better understand the variation of photometry with position for those regions, it should be possible to improve the precision of dithered photometry for some applications. As dithered observations average over systematics, there is a better possibility of comparing different epochs directly and sparsely sampling light curves to a decent precision for sources with high enough signal-to-noise. The last point can result in a non-trivial throughput advantage for science objectives that would be satisfied with sparser than continuous sampling precisions that are a fraction of a percent instead of 100 ppm.

Calibration data are available for download via the Spitzer Heritage Archive for interested observers to explore this concept. The IRAC primary calibrators have been observed throughout the course of the warm mission and there is ample data to investigate. Reach et al. (2005, PASP, 117, 978) lists the calibrators which span a range of brightness and frame times used.