

# First-Order Test of WFC3/IR Imaging: from Phase 2 Proposal to MultiDrizzle Product

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## ABSTRACT

*We have run MultiDrizzle on a synthetically generated set of WFC3/IR central subarray images using headers produced and processed as they will be in on-orbit observations. The images consist of a few "stars" (point spread functions) which are dithered in a box pattern. We have measured the positions of the stars in the aligned distortion-corrected images by fitting a Gaussian to smoothed one-dimensional profiles along rows and columns, and show the accuracy of this method. We use the dispersion in the measured coordinates of each star as a first-order test of the end-to-end performance of the systems that specify target positioning and correct the images for geometric distortion. We find that the combined errors are comparable to the measuring errors,  $\sim 0.01$  pixel.*

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## Introduction

Many factors in several systems must be handled correctly to get from a submitted HST Phase 2 proposal to a successfully combined distortion-corrected set of exposures. Prior to obtaining on-orbit exposures of stellar fields with the WFC3 IR channel, we have conducted an end-to-end test of these systems by running MultiDrizzle on a synthetically generated set of dithered images designed to be consistent with headers created in a servicing mission ground test of the instrument. This test provides a "sanity check" that changes in the original pattern definitions and in the definition of the POSTARG frame relative to the V2-V3 frame propagated through all systems correctly. Some reprocessing was required to implement the POSTARG frame change.

We are testing the first association of IR exposures to be processed using the current definition of the POSTARG frame. It consists of a box pattern with small dither

steps using a small centrally located subarray on the IR detector, where non-linear distortion terms are very small. We are therefore approximating the dither steps as linear shifts of the target on the subarray. (Tests of the non-linear distortion terms will be made using simulated or real data covering the full detector.) The "target" consists of a few stars represented by simulated WFC3/IR PSFs (point spread functions). In the individually drizzled (*single\_sci*) images produced by MultiDrizzle, the PSFs in the four dither steps should be well aligned for each star if all systems have performed properly and if, as assumed, the non-linear distortion terms are negligible.

We have used the standard astrometric technique of measuring "marginal profiles" (one dimensional cross-cuts for *x* and *y*) for each PSF in the *single\_sci* images. The IR PSF is poorly sampled by the pixels (FWHM  $\sim 1$  pixel). We over-came artifacts in the measurements caused by pixelation of the PSF by smoothing the profiles before measuring them.

## Data

### *Image Headers*

The PyRAF/Python package MultiDrizzle is used to correct calibrated HST images for geometric distortion and to combine the distortion-corrected images. (For information on MultiDrizzle, see the MultiDrizzle Handbook, ed. Fruchter, A. and Sosey, M. et al. 2009, at [http://www.stsci.edu/hst/HST\\_overview/documents/multidrizzle](http://www.stsci.edu/hst/HST_overview/documents/multidrizzle).) As input, one needs datasets with image headers in the standard HST format that contain keywords that have been properly populated. We have used an associated set of files produced in the performance of the Servicing Mission 4 Ground Test (SMGT). The association was created by using a box pattern in the APT proposal generating software. The pattern parameters for this association (as described in the Phase II Proposal Instructions at <http://www.stsci.edu/hst/programs>) are P1\_NPTS: 4, P1\_PSPAC: 0.528", P1\_LSPAC: 0.382", P1\_ORINT: 23.348°, P1\_ANGLE: 95.036°, P1\_FRAME: POS-TARG. (This was one of the preliminary pattern definitions that is no longer included in the set of WFC3 convenience patterns.)

This pattern causes the target to be shifted on the detector relative to the defined target position as indicated in Table 1 for the 4 exposures. These shifts were computed using the linear terms of the distortion solution. The dither steps are small and the test is being performed on a subarray at the center of the detector, where the shifts due to the non-linear components of the geometric distortion are a small fraction of the linear shifts. For a step of several pixels in *X* or *Y* anywhere on the subarray, the neglected nonlinear component is less than 0.1% or 0.2% of the linear component in *X* or *Y*, respectively.

**Table 1.** Target Shifts Produced by Box Pattern

Exposure	POSTARGX (arcsec)	POSTARGY (arcsec)	X (pixels)	Y (pixels)
1	+0.000	+0.000	+0.00	+0.00
2	+0.485	+0.209	+3.58	+1.73
3	+0.365	+0.572	+2.69	+4.72
4	-0.120	+0.363	-0.89	+2.99

**Table 2.** Specified PSF Centers in the First Exposure

PSF	X	Y
A	10.58	38.54
B	21.65	9.15
C	35.76	25.38
D	52.48	51.83

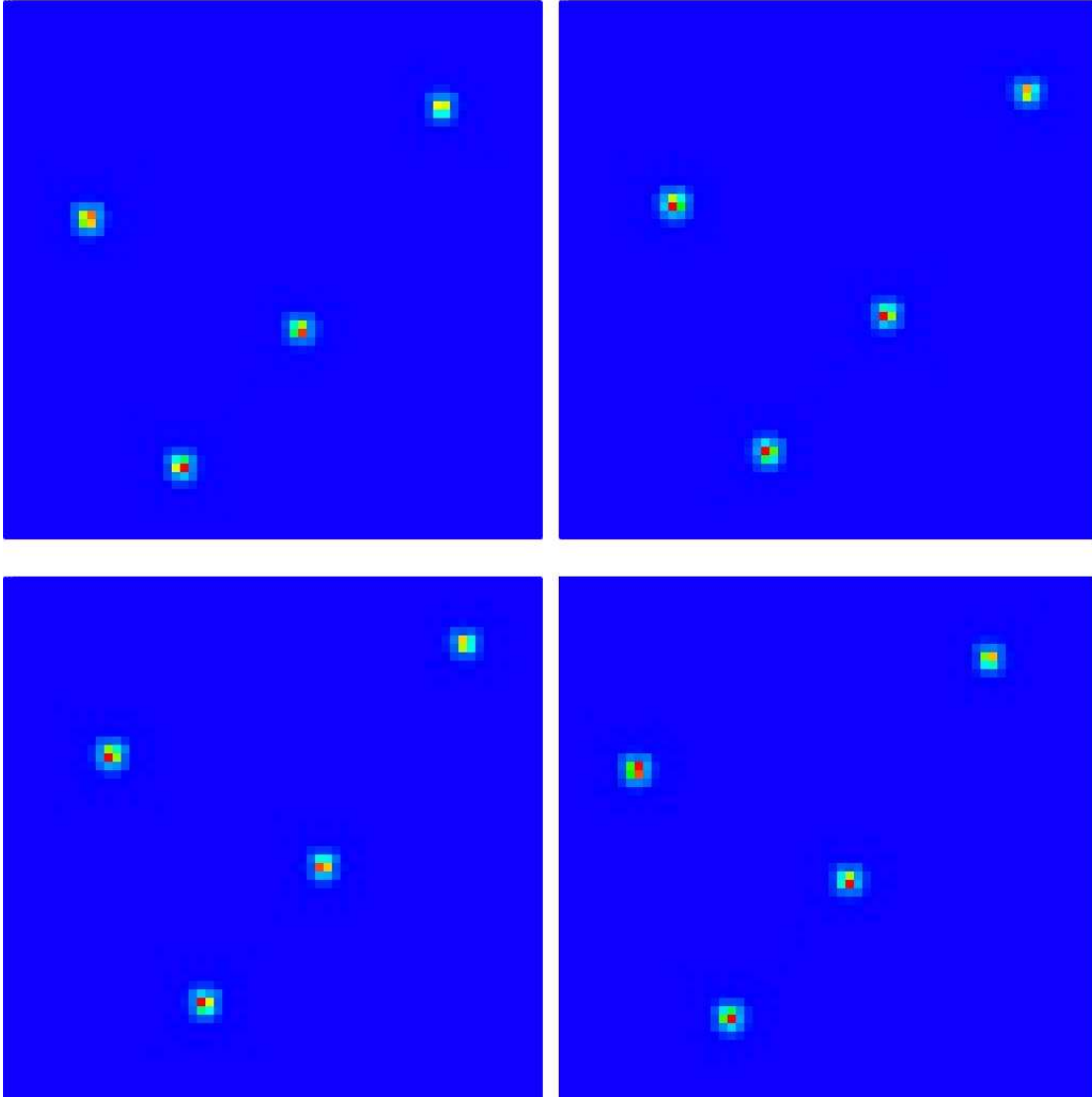
### *Images*

The SMGT datasets do not have useful data in the image extensions. We replaced the science data in the calibrated exposures (flt.fits[1]) with a uniform background and 4 point spread functions (PSFs) to represent stars. The PSFs were generated with the PSF modelling code written by George Hartig (WFC3 ISR 2008-31), using the mean Zernike terms listed in line 17 of table 3 in his ISR. Jitter of 34 milliarcsec was included to simulate the smearing that would be seen in an on orbit exposure.

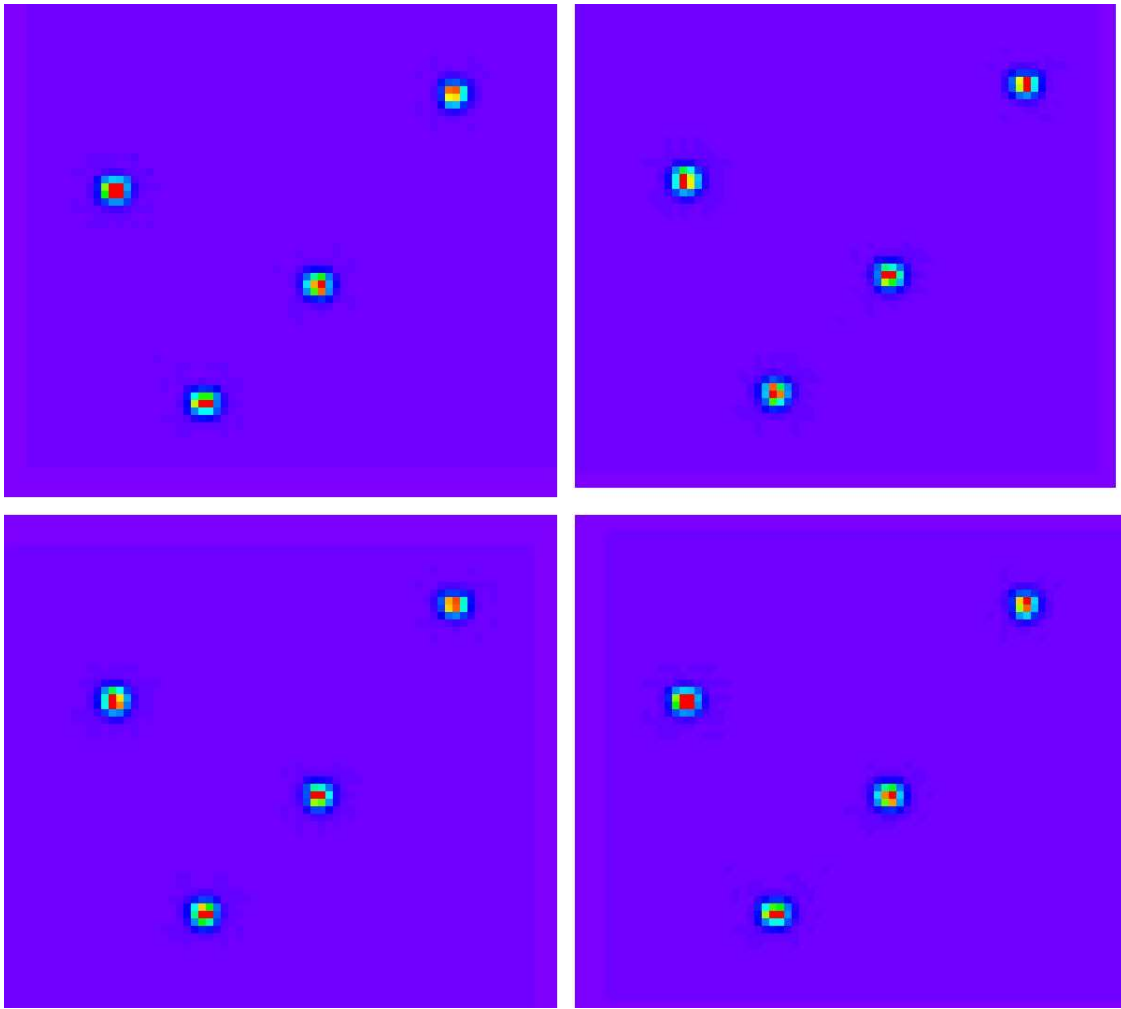
The association that we are analyzing uses the IRSUB64 subarray, with dimensions 64x64. The specified centers of the PSFs in the first exposure on this subarray are shown in Table 2. The PSFs were distributed over the subarray with sufficient separation in X and Y to prevent the position measurement of one star from being affected by the other stars. The subpixel portions of the PSF coordinates in the first exposure were chosen at random to sample the PSF with pixels in different ways. The shifts in Table 1 were added to the centers in Table 2 to find the centers to specify as input to the PSF modelling code to generate the PSFs for the remaining 3 exposures. The exposures are illustrated in Figure 1.

### *Processing*

We used MultiDrizzle version 3.3.1dev to process the association of "calibrated" (flt.fits) images. The reference file sau19319i\_mdz.fits was used to specify the default parameters for MultiDrizzle. The image distortion coefficient table wfc3irfinal\_idc.fits (to be



**Figure 1.** *Input flt.fits images. Top tier: image 1 (unshifted) and image 2. Bottom tier: image 3 and image 4*



**Figure 2.** Output *single\_sci.fits* images. Top tier: image 1 and image 2. Bottom tier: image 3 and image 4

renamed upon delivery to CDBS), which was based on an optical model, was used to define the geometric distortion. The *single\_sci.fits* images produced for the four exposures by MultiDrizzle are illustrated in Figure 2. These images contain data that has been transformed to the same undistorted frame. Ideally, a given "star" will have the same coordinates in all four *single\_sci.fits* images.

## Analysis

### *Measurement Techniques*

In order to gauge how well MultiDrizzle is working, we measured the X and Y positions of the center of each PSF in each of the *single\_sci.fits* images. We determined the X and

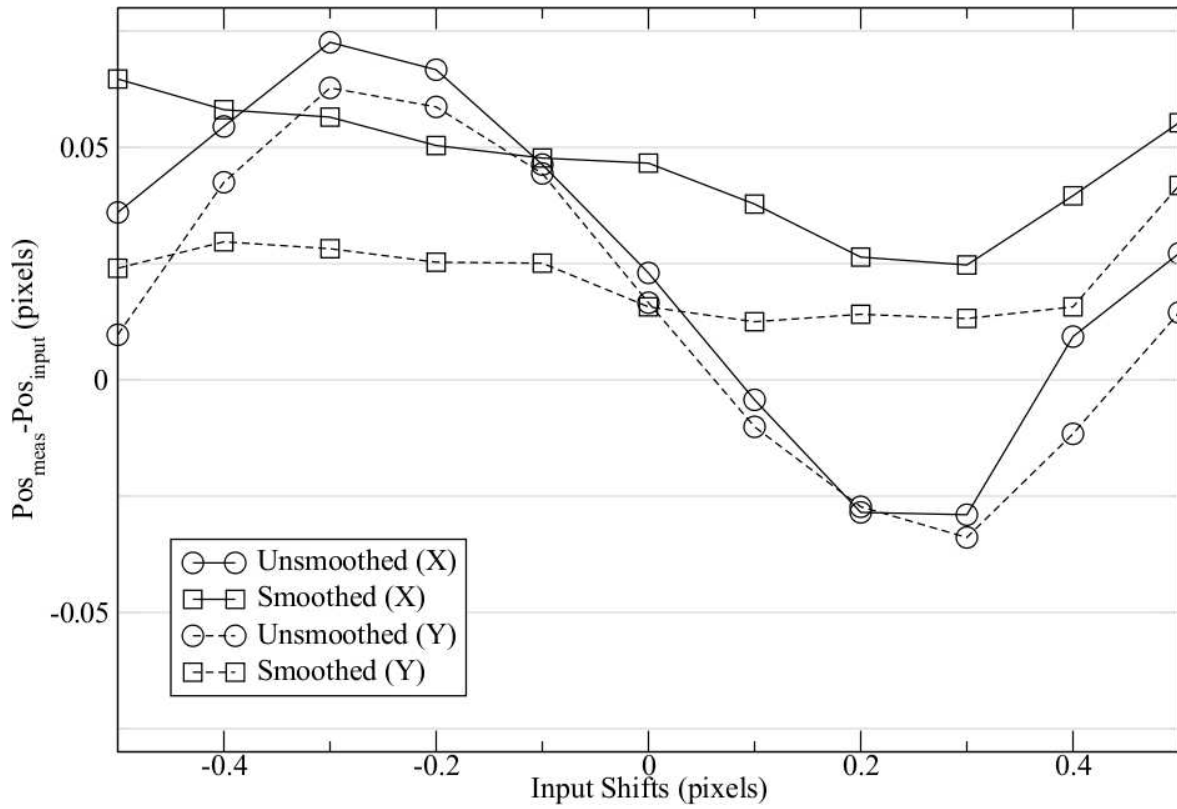
Y centers separately by analyzing a flux profile along each axis. We summed 7 rows centered on a PSF to form a profile along X, and summed 7 columns centered on the PSF to form a profile along Y. The IDL function GAUSSFIT was called to fit a gaussian and a uniform background to each profile, thus providing us with Gaussian-fit centers. We made a second set of measurements by smoothing the X and Y profiles with a 3-point sliding boxcar prior to performing the Gaussian fit. This choice of smoothing was based on our experience with measuring the spatial center of the trace of a stellar spectrum in STIS spectral images (Dressel, STIS ISR 2007-03). A Gaussian is not a good fit to a PSF that has been undersampled by the pixels. Boxcar-smoothing the PSF along the slit in a spectral image convincingly removes artifacts from the Gaussian-fit center of the trace as it crosses the detector.

### *Measuring Errors*

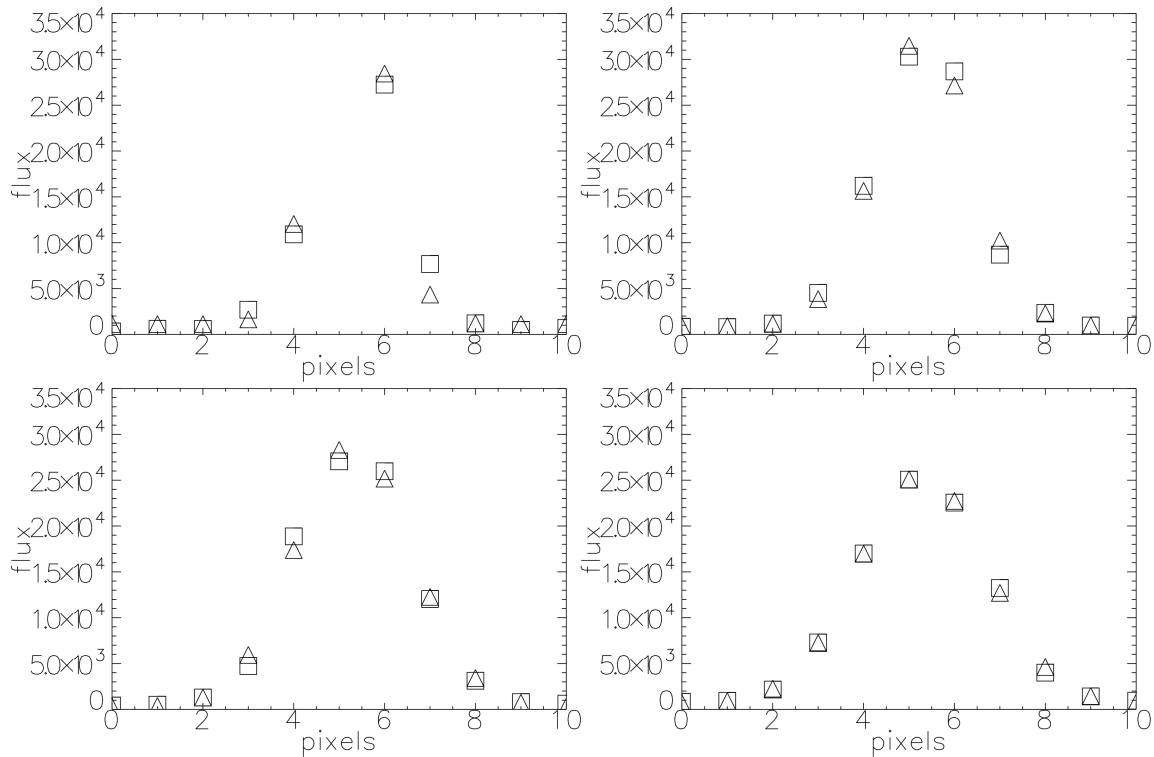
To demonstrate the signature of PSF-undersampling in Gaussian-fit centers, we used the modelling code to produce a series of WFC3/IR PSFs stepped along X in increments of 0.1 pixel, and stepped along Y in increments of 0.1 pixel. The steps ranged from -0.5 pixel to +0.5 pixel in each coordinate relative to the center of the detector field of view. We found the Gaussian-fit centers of the PSFs in X and Y as described above, with and without boxcar smoothing of the profiles. The Gaussian-fit center minus the center that was input to the PSF modelling code is plotted as a function of input step position in Figure 3 for each set of measurements.

The curves in Figure 3 made without profile smoothing are sinusoidal, with a peak-to-peak amplitude of 0.12 pixel on the vertical axis for both the X and the Y step sequences. For each curve, the deviation from the mean is smallest where the PSF is centered on a pixel or centered between two pixels. In each of those cases, the profile is nearly symmetric, and the center of the Gaussian fit is least affected by the undersampling. The further away from those positions the PSF is centered, the more asymmetric the pixel-quantized profile becomes, and the less well a Gaussian fits the profile.

The curves in Figure 3 made with profile smoothing are much flatter than those made without profile smoothing. The rms about the mean is 0.033 and 0.032 pixels in X and Y, respectively, for the PSFs measured without profile smoothing, and 0.012 and 0.009 pixels in X and Y, respectively, for the PSFs measured with profile smoothing. Smoothing has thus reduced the subpixel position dependent variations by a factor of 3. There is an offset between the means in the different systems, but for a set of PSFs with a well determined mean coordinate, it is the dispersion relative to that mean that describes the error in the measurement due to the positioning of the PSF on a pixel. The pixel quantization error clearly dominates the measurement error for the unsmoothed profiles. Departures of the PSF from a true Gaussian contribute to the systematic offsets between measurements made with different techniques.



**Figure 3.** Measured PSF centers for sequences of model PSFs stepped across a pixel in X and in Y, as a function of input position on the pixel. PSF profiles along X and Y were not smoothed (squares) or boxcar smoothed (circles) before Gaussian fitting.



**Figure 4.** Gaussian fits (triangles) to PSF profiles along the X axis (squares). Left panels: PSF in the fit image; right panels: PSF in the single\_sci image. Upper panels: unsmoothed profile; lower panels: boxcar-smoothed profile.

### Profile Fitting

Figure 4 illustrates the breadth of the PSF and the goodness of fit of a Gaussian for several profiles. The profile along rows (squares) and the Gaussian fit (triangles) is shown for the single\_sci image of PSF A in exposure 1 in the right hand panels, with the unsmoothed profile in the upper panel and the boxcar smoothed profile in the lower panel. A model PSF with the same placement on a pixel was generated to represent the PSF in a fit.fits image with the same phase in the undersampling sinusoid. The profile along rows (squares) and the Gaussian fit (triangles) is shown for that PSF in the left hand panels, with the unsmoothed profile in the upper panel and the boxcar smoothed profile in the lower panel. It can be seen that the goodness of fit improves as the profile is broadened both by the boxcar smoothing and by the redistribution of flux performed by MultiDrizzle.

**Table 3.** Centers of PSFs measured in single\_sci images using Gaussian fits to unsmoothed profiles

Exposure	PSF A		PSF B		PSF C		PSF D	
	X	Y	X	Y	X	Y	X	Y
1	15.32	41.61	27.33	13.12	42.66	28.85	60.62	54.53
2	15.17	41.56	27.20	13.13	42.46	28.88	60.72	54.51
3	15.21	41.56	27.26	13.13	42.50	28.87	60.67	54.50
4	15.30	41.60	27.30	13.11	42.63	28.84	60.68	54.53
Mean	15.25	41.59	27.27	13.12	42.56	28.86	60.67	54.52
RMS	0.07	0.03	0.06	0.01	0.10	0.02	0.04	0.01

**Table 4.** Centers of PSFs measured in single\_sci images using Gaussian fits to boxcar-smoothed profiles

Exposure	PSF A		PSF B		PSF C		PSF D	
	X	Y	X	Y	X	Y	X	Y
1	15.30	41.59	27.30	13.14	42.60	28.86	60.67	54.49
2	15.26	41.59	27.27	13.14	42.53	28.86	60.72	54.49
3	15.26	41.60	27.27	13.13	42.55	28.85	60.69	54.48
4	15.28	41.59	27.29	13.14	42.59	28.85	60.70	54.49
Mean	15.27	41.59	27.28	13.14	42.57	28.86	60.70	54.49
RMS	0.020	0.005	0.016	0.004	0.032	0.007	0.022	0.005

## Results

The measured positions of the PSFs in the single\_sci.fits images are tabulated in Tables 3 and 4. As expected, measurement of the smoothed profiles produces more consistent results ( $X_{rms} \sim 0.02$  pixels,  $Y_{rms} \sim 0.005$  pixels) than measurement of the unsmoothed profiles ( $X_{rms} \sim 0.07$  pixels,  $Y_{rms} \sim 0.02$  pixels). The dispersion is somewhat greater in X than in Y. (Simulated dithered full frame images will be used to investigate this further.) For both X and Y, the dispersion is sufficiently small for MultiDrizzle to produce excellent stellar images; in fact, the dispersions in Y are so small in Table 4 (less than 0.01 pixel) that an extra significant figure was used to represent them. (The mean was computed using a precision of 0.001 pixel, and the rms was computed relative to that mean.) The use of precision 0.01 instead of 0.001 pixels in the dither shifts introduces an rms error of 0.003 pixels, which is insignificant when added in quadrature to the other errors. The analysis presented above indicates that the error in measuring the PSF center using smoothed profiles is  $\sim 0.01$  pixel, so the error in the relative placement of dithered PSFs onto the drizzled image must be of the same order.

## Conclusions

From the above tests on simulated 64x64 subarray images at the center of the WFC3/IR detector, we can draw the following conclusions. Applying a simple smoothing algorithm to PSF profiles significantly improves the accuracy of position measurement via Gaussian fitting. The measured dispersion in the position of a dithered star in the aligned distortion-corrected MultiDrizzle images is comparable to the measurement error,  $\sim 0.01$  pixel. The combined errors in the computation or application of the SIAF file (used to position the target on the aperture), the WCS Parameters (see the MultiDrizzle Handbook), the pattern-driven dither shifts, the distortion model in the IDCTAB, and the MultiDrizzle code are also of this order.

## References

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