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WFPC2 Photometry from Subtraction of Observed PSFs

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Abstract. Based on observed PSFs from the WFPC2 calibration programs, a series of PSF subtraction tests have been performed and the resulting photometry analyzed. We find that using a composite observed PSF, constructed from optimally selected PSFs based on location and breathing values, yields single photometric values affected by an RMS dispersion of about 0.01–0.02 mag. While resampling does not appear to have much of an effect on the photometric results, the color of the PSF employed is important.

1. Introduction

Subtraction of scaled PSFs from direct CCD images of quasars (or stars) not only offers the possibility of detecting the presence of host or foreground galaxies (or companions like brown dwarfs or planets) but also provides a means of deriving accurate photometry of the primary objects.

The observations used for the tests described here were taken from the WFPC2 photometric monitoring programs; primarily F555W in the PC was used, although separate independent tests were also done with a subset of the F814W and F439W, in PC and WF3, images. The target in all cases was the spectrophotometric standard GRW+70D5824, a DA3 white dwarf ($V = 12.77$, $B - V = -0.09$ mag). Details of the F555W images are provided in the table in Appendix A; tabulated are the image rootname, the PSF positions on the original chip, the row and column position of the PSF in the mosaic frame (see Figure in Appendix A), the date and MJD for the start of the observations, the exposure time (in seconds), the relative defocus of the secondary mirror (in μm) and finally, the X,Y components of coma (in μm) of wavefront error. The relative focus was determined using the phase retrieval code of Krist & Burrows (1995) to reproduce the detailed shape of the observed PSFs; the derived focus positions are illustrated in Figure 1 as a function of Modified Julian Date (MJD). Appendix A, Figure 4, provides a greyscale mosaic of the 43 observed PSFs.

In the MIDAS environment, Remy (1996) has developed a general, automatic procedure to derive optimal photometric measurements of (multiple) point sources. A composite PSF is determined by summation of the selected images of the spectrophotometric standard regularly observed with WFPC2, after recentering at the same position by bi-quadratic interpolations. Photometric measurements of single observations are then determined by fitting in flux and position the above composite PSF, using a χ^2 minimization method. A description of this automatic procedure may also be found in Remy et al. (1997).

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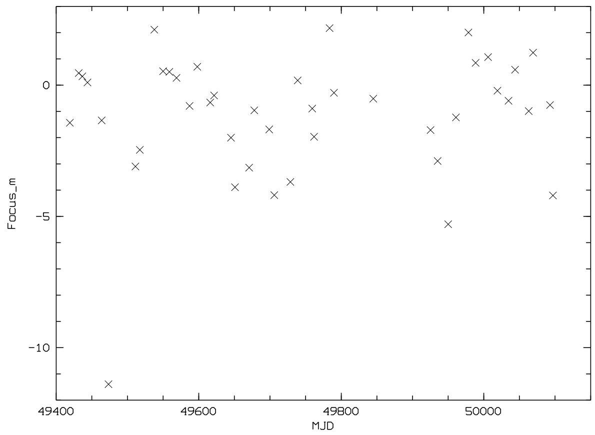

Figure 1. Relative focus positions (in μm) as a function of Modified Julian Date (MJD).

2. The Photometry

2.1. Single Star—F555W, PC

As a baseline for comparison, photometry using a single PSF star (characterized by various defocussing values) was performed on the 43 individual F555W images. Depending upon the precise focus value of the observed PSF used, the final average magnitudes ranged from 12.79 to 12.85 mag, with scatter typically around 0.02 mag (somewhat higher, 0.04 mag, for the highest focus PSF, about 0.5μm). These tests indicate that using a single PSF leads to adequate results provided that it is close in location and focus to the target. However, the use of an observed PSF whose relative focus position differs by 6 μm or more may result in a systematic photometric error that exceeds 0.1 mag.

2.2. Composite of 42 Observed PSFs—F555W, PC

A composite PSF image constructed from 42 of the observed F555W PSFs was subtracted from each of the 43 original observations; a greyscale representation of the subtraction results is illustrated in Figure 4 in Appendix A. Because of the PC image undersampling, concentric rings are indicative that the centering may be slightly different from the center of the composite; fainter features around the periphery are probably due to focus differences (breathing, i.e., the PSF variations seen over the timescale of an HST orbit). The photometry results achievable when using this 42-image composite PSF are plotted in Figure 2 in the form of magnitudes obtained as a function of focus. The scatter affecting the photometric results of the 34 reliable (see below) observations of GRW+70D5824 is 0.014 mag. Note that no systematic dependence of the derived V magnitude as a function of the relative focus position is noticeable. These good photometric results are certainly due to the high S/N of the composite PSF constructed from the 42 single observations.

2.3. Composite of 34 Observed PSFs—F555W, PC

Immediately apparent in the photometric results of the previous test (Figure 2, using the composite of 42) are eight outliers; five of these appear to be due to PSFs with larger coma or PSFs which are in a substantially different location on the chip, while three of the PSFs were taken under different conditions: CLOCKS=ON, and therefore the exposure time was slightly shortened (two in Dec 94), or at a warmer operating temperature (one in Feb 94). For these reasons, a second observed composite was constructed, omitting these questionable PSFs as well as the one PSF dropped earlier (very far from the average focus).

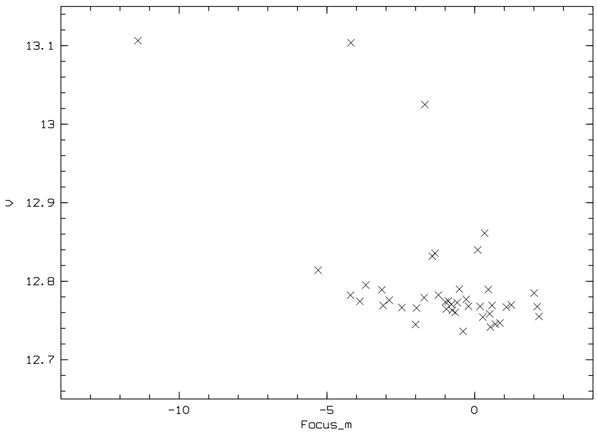

Figure 2. Magnitudes, obtained via PSF subtraction of the 42-image composite, as a function of focus (in μm).

The photometry results using this composite of 34 images are also listed in Table 1. The photometric results derived from the 34 composite PSF are comparable (0.014 mag scatter) to those based on the 42 composite PSF.

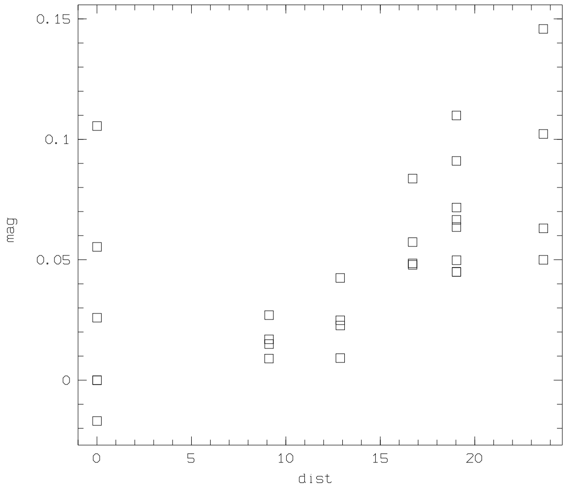

Figure 3. Changes in photometry as a function of radial distance from center (in arcsec). Additional data points at dist = 0 are the results of using TinyTim PSFs of various spectral types ($B - V = -0.297$, -0.155, 0.126, 0.619, and 1.590; note: for dist > 0, magnitudes were computed using $B - V = -0.155$ mag).

2.4. Position and Spectral Type Dependence

Figure 3 demonstrates the scatter in the resulting photometry when TinyTim (Krist 1993, 1996) model PSFs at a range of angular distances away from the target are used. Also in the same figure (at distance = 0) are the results when using TinyTim PSFs of various spectral types. As can be seen, a mismatch in spectral type can result in nearly as much error as when using a PSF about 15–20$''$ away from the target.

3. Conclusions

Table 1 summarizes the average magnitude and scatter obtained from the PSF subtraction photometry of GRW+70D5824 when using the noted (composite or single) PSF type and focus range. These results indicate that the best PSF subtraction photometry is obtained when using a composite PSF close in relative focus to the target, originating from a location on the chip as close as possible to the target (typically less than 10″) and having a spectral type as similar to the target's type as possible, in that order of importance. Owing to the better S/N, a composite PSF fared better than a single PSF, however, the specific number of PSFs used in the composite was found to be relatively unimportant. In addition, resampling did not improve the resulting photometry. Additional tests were also done with a subset of F814W and F439W PC and WF3 images, corroborating the F555W PC results. A WFPC2 PSF Library has been established to enable users to carry out more experiments (see WWW page, under WFPC2 Software Tools). An investigation of photometric measurements based upon subtraction of TinyTim model PSFs has been performed by Remy et al. (1997).

Table 1. Summary of the F555W PSF subtraction photometry results. The average magnitudes and scatters were calculated from the 34 reliable observations (see text); columns 3 and 4 are results for a composite PSF, columns 5 and 6 are results using a resampled composite PSF. Focus (in μm) is that of the composite PSF.

test case	relative focus	mag	scatter	mag	scatter
observed PSF, single	$F \geq 0.492$	12.806	0.042	12.826	0.087
	$0.492 > F \geq -0.820$	12.809	0.022	12.750	0.065
	$-0.820 > F \geq -2.459$	12.849	0.024	12.826	0.050
	$-2.459 > F$	12.792	0.024	12.746	0.049
observed PSF, composite of 42	$2.295 > F > -11.311$	12.736	0.014	12.770	0.016
observed PSF, composite of 34	$2.295 > F > -11.311$	12.769	0.014	12.767	0.021

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4. Appendix A: Table and Figure of Images

Table 2. Log of PC1 F555W images used for tests described in this paper.

rootname	x	y	ix	iy	obsdate	MJD	expt	focus	x-coma	y-coma
u2a70305t	472	458	1	1	8/03/94	49419.1328	1.6	-1.4333	0.0029	-0.0029
u2a70605t	417	428	2	1	20/03/94	49431.6602	1.6	0.4610	0.0054	0.0005
u2a70905t	402	444	3	1	25/03/94	49436.6875	1.6	0.3345	0.0023	-0.0023
u2a70c05p	431	477	4	1	1/04/94	49443.8555	1.6	0.1025	0.0043	-0.0044
u2a70i05t	355	496	5	1	21/04/94	49463.7852	1.6	-1.3445	0.0055	-0.0066
u2a70l05t	345	486	6	1	1/05/94	49473.3750	1.6	-11.3925	0.0017	-0.0103
u2a70o05t	331	420	7	1	8/06/94	49511.1367	1.6	-3.0977	0.0149	-0.0104
u2a70r05t	329	432	1	2	14/06/94	49517.3555	1.6	-2.4649	0.0088	-0.0061
u2a70u05t	357	385	2	2	4/07/94	49537.6523	1.6	2.1136	0.0045	-0.0047
u2a70x05t	369	372	3	2	16/07/94	49549.9766	1.6	0.5301	0.0078	-0.0072
u2a71005p	381	363	4	2	25/07/94	49558.8164	1.6	0.5056	0.0093	-0.0056
u2a71305t	367	340	5	2	4/08/94	49568.8477	1.6	0.2755	0.0090	-0.0070
u2a71605t	395	361	6	2	23/08/94	49587.1289	1.6	-0.7914	0.0091	-0.0048
u2a71905t	412	356	7	2	2/09/94	49597.9805	1.6	0.7010	0.0099	-0.0080
u2a71c05t	452	325	1	3	21/09/94	49616.0547	1.6	-0.6605	0.0035	-0.0048
u2a71f05t	458	328	2	3	26/09/94	49621.5391	1.6	-0.3941	0.0056	-0.0066
u2a71i05t	483	345	3	3	20/10/94	49645.2461	1.6	-2.0015	0.0084	-0.0069
u2a71l05t	489	352	4	3	25/10/94	49650.8750	1.6	-3.8875	0.0087	-0.0050
u2a71o05t	504	379	5	3	14/11/94	49670.7617	1.6	-3.1423	0.0045	-0.0063
u2a71r05t	507	388	6	3	21/11/94	49677.9805	1.6	-0.9612	0.0077	-0.0052
u2a71u05t	511	423	7	3	12/12/94	49698.8633	1.0	-1.6872	0.0080	-0.0078
u2a71x05t	522	462	1	4	20/12/94	49706.0312	1.0	-4.1893	0.0168	-0.0088
u2a72605t	509	497	2	4	11/01/95	49728.6172	1.6	-3.6870	0.0051	-0.0096
u2a72905t	498	513	3	4	21/01/95	49738.8750	1.6	0.1799	0.0119	-0.0085
u2a72c05t	465	504	4	4	11/02/95	49759.3242	1.6	-0.8905	0.0060	-0.0070
u2a72f05t	459	505	5	4	13/02/95	49761.8711	1.6	-1.9657	0.0086	-0.0097
u2n10203p	409	593	6	4	7/03/95	49783.5586	3.5	2.1728	0.0133	-0.0083
u2n10403t	392	590	7	4	13/03/95	49789.7695	3.5	-0.2908	0.0122	-0.0092
u2o00501t	332	504	1	5	7/05/95	49844.9141	1.2	-0.5168	0.0113	-0.0087
u2s61101t	406	419	2	5	27/07/95	49925.2930	3.5	-1.7113	0.0098	-0.0053
u2s61201t	405	419	3	5	6/08/95	49935.1953	3.5	-2.8893	0.0115	-0.0067
u2s61301t	427	436	4	5	21/08/95	49950.0586	3.5	-5.2985	0.0132	-0.0122
u2s61401t	408	451	5	5	31/08/95	49960.9609	3.5	-1.2288	0.0092	-0.0082
u2s61501t	418	410	6	5	18/09/95	49978.4453	3.5	2.0072	0.0126	-0.0066
u2s61601t	419	411	7	5	28/09/95	49988.5430	3.5	0.8492	0.0123	-0.0071
u2s61701t	418	415	1	6	16/10/95	50006.0664	3.5	1.0692	0.0094	-0.0096
u2s61801t	417	417	2	6	29/10/95	50019.1992	3.5	-0.2110	0.0108	-0.0049
u2s62101t	416	410	3	6	13/11/95	50034.7266	3.5	-0.5944	0.0133	-0.0050
u2s62201t	416	412	4	6	22/11/95	50043.9023	3.5	0.5878	0.0116	-0.0050
u2s62301t	416	413	5	6	12/12/95	50063.0547	3.5	-0.9875	0.0126	-0.0053
u2s62401t	416	415	6	6	18/12/95	50069.2031	3.5	1.2373	0.0098	-0.0060
u2s62501t	417	416	7	6	10/01/96	50092.9648	3.5	-0.7580	0.0132	-0.0024
u2s62601t	448	429	1	7	15/01/96	50097.0508	3.5	-4.2018	0.0084	-0.0054

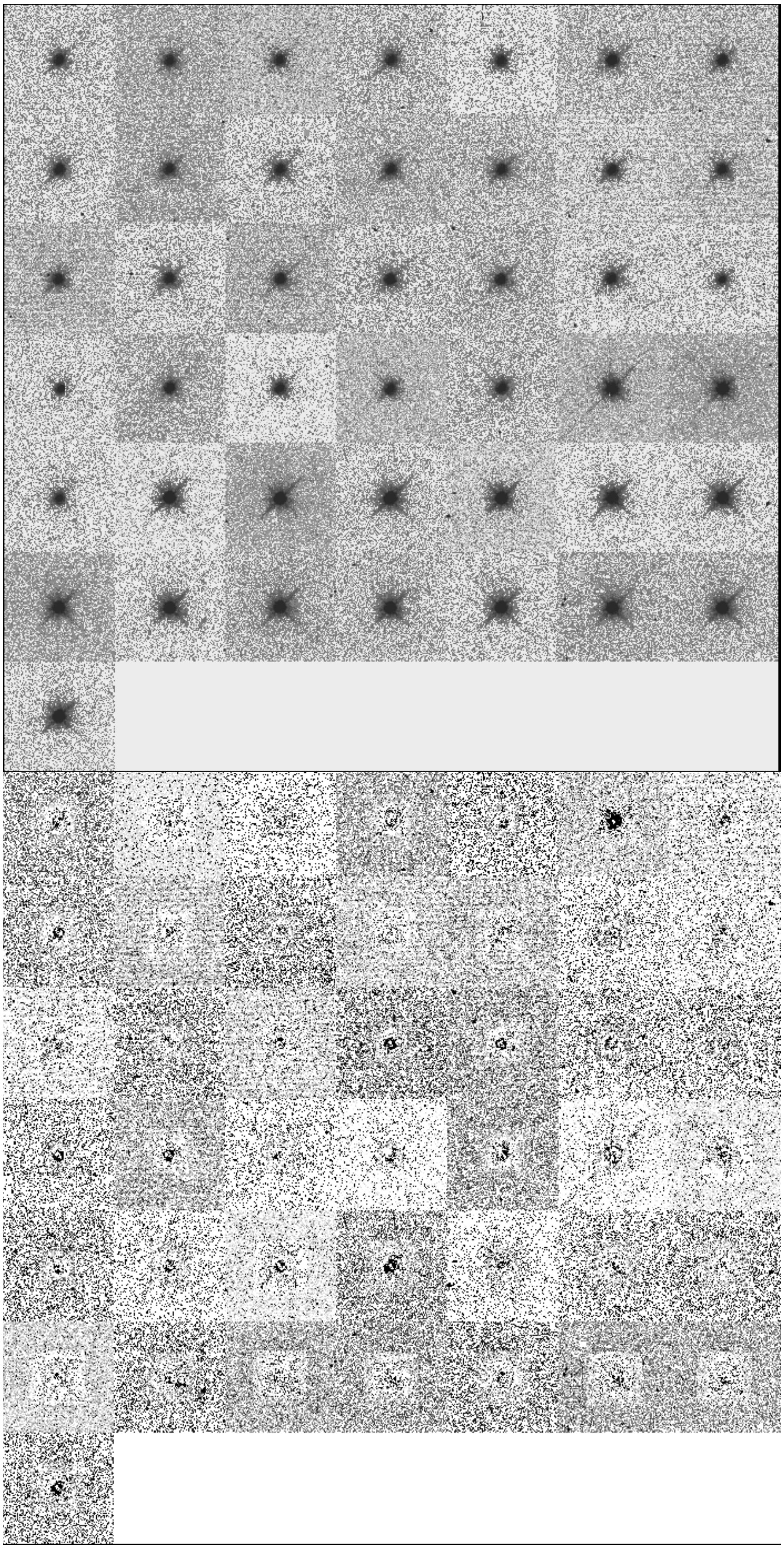

Figure 4. Greyscale representation of the 43 GRW+70D5824 observed PSFs (top) and residuals after subtraction of the composite observed PSF (bottom).