

Results of the WFPC2 SM3a Lyman- α Throughput Check (proposals 8492, 8494, and 8515)

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ABSTRACT

The far-UV throughput of WFPC2 was monitored during December 1999 and January 2000 for any signs of unexpected throughput degradation following Servicing Mission 3a. No significant changes were detected.

1. Introduction

Servicing Mission 3a (SM3a) took place in December 1999, followed by the Servicing Mission Orbital Verification (SMOV), a period of intensive operations and calibration testing for all HST instruments and various other HST components. After successful completion of the appropriate tests and analysis of the data, science observations were reenabled. The SMOV3a for WFPC2, an instrument not directly being serviced, consisted of health and safety checks as well as calibration verifications.

A major concern for WFPC2 during any servicing mission is the possibility of contamination due to the servicing activities. For this reason, SMOVs for WFPC2 include a variety of controls and checks for contamination, such as special decontamination (decon) sequences, stepped cooldown procedures, intensive photometric monitoring, and contingency planning. An additional precaution taken during SMOV is to restrict HST's pointing (the BEA, or Bright Earth Avoidance epoch), to prevent high levels of UV flux on the telescope's optical surfaces, thereby minimizing damage by possible contaminants. The SMOV contamination rates and levels are determined from frequent monitoring observations taken in a variety of UV and visible filters; once the rates are found to be nominal, the BEA restrictions are lifted (Biretta et al., 1997; Casertano et al., 1999).

The CCD windows can, of course, be heated to remove any contaminant buildup; this is routinely and successfully accomplished with decon procedures about once a month

during normal science operations. However, during a servicing mission, contaminants could potentially settle on the pick-off mirror (POM) which is exposed in HST's hub area and can not be heated. The Lyman- α throughput tests, based upon observations taken with F160BW and F122M filters, are designed to monitor the far-UV throughput for any signs of degradation which may be due to a layer of contaminants on the pick-off mirror.

Much of the concern over the WFPC2 POM stems from the near total loss of Ly- α reflectivity of the WF/PC-1's pick-off mirror during its stay in orbit. During WFPC2's first year in orbit, the stability of the Lyman- α throughput was carefully monitored (MacKenty & Baggett, 1996); at that time, the throughput was found to be stable with an uncertainty of 10 to 20%. Additional Lyman- α monitoring was also done during SMOV2; no significant change in throughput was detected to within the 20% uncertainty (O'Dea et al., 1997). This report presents the Lyman- α monitoring results for SMOV3a.

2. Data

GRW+70D5824 is the preferred standard photometric monitoring target for WFPC2 and has been routinely used for monitoring observations since early 1994. However, due to BEA restrictions, which call for the avoidance of the bright Earth limb in early SMOV to protect the instruments from excessive UV flux, the GRW+70D5824 pointing was not permitted between Jan 3 and Jan 18, 2000. During this time period, the white dwarf star WD0710+741 served as an alternate standard; since this target had not been previously observed with WFPC2, pre-SMOV3a baseline measurements were taken in October 1999. The properties of the two stars are summarized in Table 1.

Table 1: Targets used for Lyman Alpha Throughput Monitoring^a

Property	Target	
	WD0710+741	GRW+70D5824
RA (J2000.0)	07:17:02.41	13:38:51.77
DEC (J2000.0)	74:00:42.52	70:17:08.5
spectral class	DA2	DA3
V	14.97	12.77
B-V	-0.06	-0.09
U-B	-0.75	-0.84
average count rate F122M in 10/99	2.9 dn/sec	28.1 dn/sec
observed redleak fraction in F122M	61%	60%
predicted redleak fraction (SYNPHOT)	--	65%
average count rate F160BW in 10/99	8.4 dn/s	78.9 dn/sec

Table 1: Targets used for Lyman Alpha Throughput Monitoring^a

Property	Target	
	WD0710+741	GRW+70D5824
observed redleak fraction in F160BW	73%	65%
predicted redleak fraction (SYNPHOT)	--	75%

a. Positions, spectral class, and UBV information for WD0710+741 and GRW+70D5824 from McCook & Sion (1987) and Turnshek et al. (1990), respectively. Average count rates are at -88C.

The initial cooldown of the WFPC2 cameras during SMOV3a was performed in two steps: cooling to -55C followed by a suite of monitoring observations, then, contingent upon nominal results from those observations, cooling to the normal operating temperature of -88C (Casertano et al., 1999). The Lyman- α observations were obtained at several epochs: pre-SMOV3a (baseline), SMOV3a at -55C, and finally, SMOV3a at -88C.

For GRW+70D5824, the most recent complete set of far-UV throughput data crossed with F130LP prior to SMOV3a are the November 1996 observations, which were taken 3 days after a decon. As discussed in more detail later, we also normalized the F160BW SMOV3a data to some more recent measurements (August 1997, no F122M data available).

The baseline images for WD0710+741 were taken in October 1999, unfortunately 26 days after a decontamination due to a scheduling error. An estimated contamination correction (0.6%/day, based on longterm F160BW photometric monitoring from Baggett & Gonzaga, 1998) was applied to the baseline data before using them to normalize the SMOV3a data. No contamination rates are available for F122M, so the F160BW correction was applied.

The images for the Lyman- α throughput check were taken with the far-UV filters F122M and F160BW: images were taken in single filters as well as crossed with the long-pass filter F130LP to provide an estimate of the redleak correction. Two images were taken with each of the four filter combinations. Due to scheduling restrictions during SMOV3a, only PC was observed in all filter combinations. During SMOV3a, WF3 was used only with the crossed filter configurations and has not been included in this study. Table 2 summarizes the observation timeline.

Table 2: Timeline of WFPC2 F160BW and F122M Observations^a

target	date	MJD	proposal	comment
GRW+70D5824	Nov 15, 1996 4:13PM	50402.676	7211	baseline set, 3 days after decon
	Aug 25, 1997 07:40AM	50685.32	6936	alternate baseline, ~5 days after decon
	Dec 29, 1999 5:49AM	51541.242	8492	cameras warm (-55C)
	Dec 29, 1999 12:27PM	51541.519	8492	cameras warm (-55C)
	Dec 29, 1999 5:04PM	51541.711	8492	cameras warm (-55C)
	Jan 18 2000 9:32PM	51561.897	8494	cameras at -88C
WD0710+741	Oct 4, 1999 8:13PM	51455.842	8515	baseline set, 26 days after decon
	Dec 29, 1999 9:41AM	51541.403	8492	cameras warm (-55C)
	Dec 29, 1999 2:18PM	51541.596	8492	cameras warm (-55C)
	Dec 29, 1999 7:07PM	51541.797	8492	cameras warm (-55C)
	Jan 3 2000 8:37AM	51546.359	8492	cameras at -88C
	Jan 3 2000 1:05PM	51546.545	8492	
	Jan 3 2000 5:56PM	51546.747	8492	

a. Date marks start time of observation set. Each set contains a pair of images in each filter combination except for Aug 1997, when only 1 image each of F160BW and F160BW+F130LP were taken (no images in F122M).

The images were calibrated using the standard STSDAS calwp2 task. The pre-SMOV3a dark reference files were used to correct for dark current in images taken after the cooldown to the normal operating temperature of -88C. During the -55C time period, when the dark current was expected to be 20-60 times higher than normal, no dark correction was applied; instead, the sky correction in the photometric reductions was relied upon to remove much of the dark level. Disregarding the dark at -55C appeared to work adequately for GRW+70D5824 but the WD0710+741 data at that temperature were unusable, due to the lower exposure levels (target is much fainter, see Table 1) and the large amount of dark current at -55C. The analysis of the -55C WD0710+741 data was postponed until an approximate dark reference could be generated from five contemporaneous dark frames taken at -55C.

The flatfields used were the pre-SMOV3a pipeline flats for F122M and F160BW (i5515213u and i5515214u, respectively). Flatfields are not available for the crossed filter combinations, so the flatfields for the uncrossed filter were used. Finally, since the flat for F160BW is known to be somewhat noisy (~20% RMS in PC, see, e.g., STAN 33, Aug. 1998), we tried using a sigma-clipped version of the flatfield. One set of images for each target was reduced using the pipeline flat and using the clipped flat; since the resulting

photometry differed by less than 0.5%, all SMOV3a data were processed with the standard pipeline flatfield.

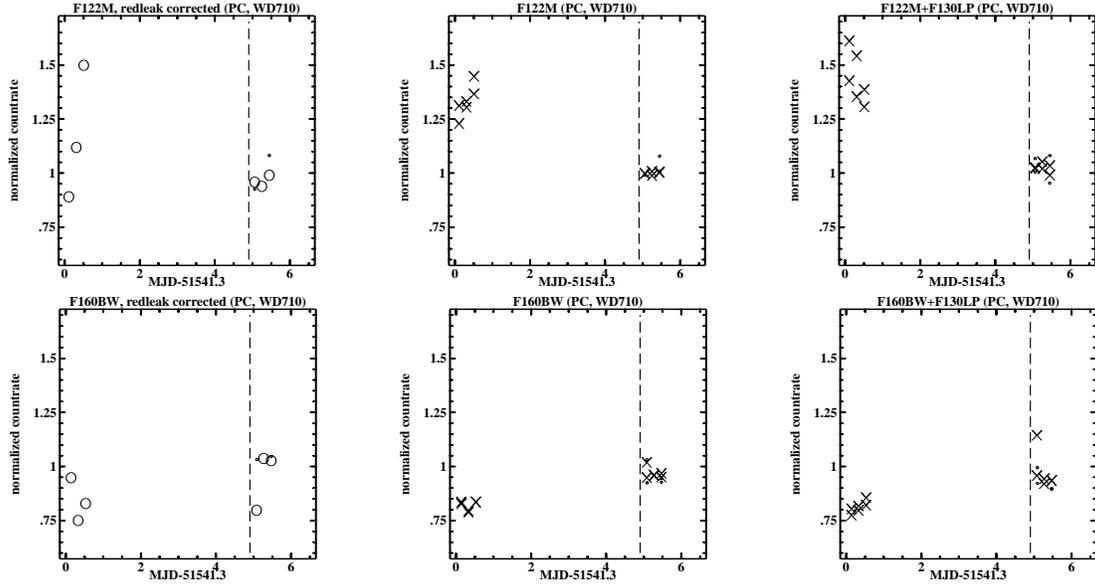
After calibration, cosmic rays and hot pixels within the region of interest were removed manually with the IRAF imedit task; typically, 4-20 edits were necessary. Centering of the stars was done with the imcntr task and refined manually for cases where the PSF was very asymmetric. Photometry was obtained using the STSDAS digiphot.apphot phot task, with aperture radius of 0.5'' (5 pixels in WF chips, 11 pixels in PC) and sky subtraction annulus from 1.4''-1.9''. The pairs of observations were reduced and analyzed individually; an approximate redleak correction was obtained by subtracting count rates measured on the crossed filter images from the count rates measured on the uncrossed filter images. To check repeatability, some datasets were reduced and analyzed by both authors individually; for the final analysis, results from the same person are used although the second set of results are included in the WD710+741 plots as small dots.

3. Results

The normalized count rate ratios are presented in Figures 1 and 2 for WD710+741 and GRW+70D5824, respectively. The final redleak-corrected values are presented and for completeness, the results of the individual observations are included as well.

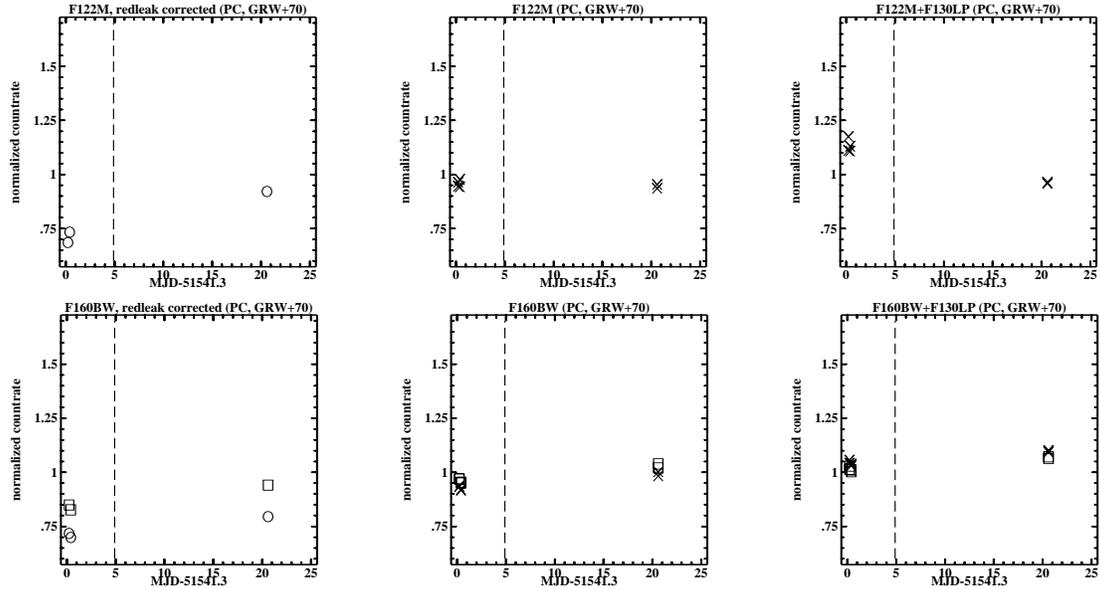
Each figure illustrates the results from F122M (top row of plots) and F160BW (bottom row of plots). Leftmost plots show the redleak-corrected normalized count rates, middle plots the normalized count rates for the single filter images, and rightmost plots the normalized count rates for the crossed filter images. The dashed line marks the date of the cooldown to -88C. As mentioned earlier, the images were taken in pairs. In Figures 1 and 2, the middle and right plots (containing crosses) are the results from individual images, while the left plots (containing circles) represent the redleak-corrected value for each pair of images (the average of the crossed filter count rates subtracted from the average of the single filter count rates). The small symbols (dots) in Figure 1 are independent measurements of some of the same data presented by the large symbols (circles and crosses), to test repeatability. The independent measurements were found to agree to within at least 10% and usually better than that; the difference was attributed to variations in the cosmic-ray and hot pixel manual editing.

Figure 1: SMOV3a Lyman- α throughput check results for WD710+741. Top row of plots are for F122M, bottom row plots are for F160BW. Plots from left to right are the normalized count rates for: redleak-corrected, single filter, and crossed filter data as a function of Modified Julian date. count rates were normalized to the contamination-corrected October 1999 measurements; dashed line marks the date of the SMOV3a cooldown from -55C to -88C. The smallest dots are independent measurements of some of the data represented by the large symbols.



In F122M, the redleak-corrected values for WD710+741 (top left plot in Figure 1) show a large amount of scatter at -55C ($\sim\pm 30\%$) while the values at -88C are better behaved ($\sim\pm 5\%$). A large scatter at -55C was not entirely unexpected, due to the faintness of the target and the high level of dark current at the warmer temperature. The absolute F122M photometry level at -88C is within 5% of the baseline measurements. In F160BW at -55C, the redleak-corrected data show less scatter ($<\pm 10\%$) than in F122M and at -88C, excluding the one outlier, the measurement scatter is only $\sim\pm 5\%$, with the absolute level within 5% of the baseline value.

Figure 2: SMOV3a Lyman- α throughput check results for GRW+70D5824. Top row of plots are for F122M, bottom row plots are for F160BW. Plots from left to right are the normalized count rates for: redleak-corrected, single filter, and crossed filter data, as a function of Modified Julian date. Dashed line marks the date of the cooldown from -55C to -88C. For both far-UV filters, count rates normalized to Nov. 1996 measurements are denoted with crosses (single and crossed filter images) and circles (redleak-corrected averages of each image pair). count rates for F160BW were also normalized to Aug. 1997 (squares).



The scatter in the GRW+70D5824 data at -55C is much smaller than for the fainter WD701+741, only $\sim\pm 5\%$. However, the absolute level of the redleak-corrected values at -88C are below the pre-SMOV3a values. When normalized to the November 1996 baseline data, the data are $\sim 5\text{-}10\%$ low in F122M and $\sim 20\%$ low in F160BW. The data were also normalized to a baseline set taken closer in time to SMOV3a, though only the F160BW data were available; these data are shown as squares in Figure 2. In this case, the -88C data fall only $\sim 5\%$ below the pre-SMOV3a data.

For GRW+70D5824, the formal errors are $\sim 1\text{-}3\%$ for the individual measurements and $3\text{-}4\%$ for the redleak-corrected results; for WD710+741, those formal errors are $\sim 5\text{-}7\%$ and $8\text{-}9\%$, respectively. However, we estimate the errors are closer to $10\text{-}20\%$ due to the following factors.

- No contamination rate estimates exist for F122M; the rate for F160BW ($\sim 0.6\%$ /day) was used for both F122M and F160BW. This could be particularly significant for the baseline WD710+741 measurements since they required a large correction (26 days).

- The flatfields for F122M and F160BW are based on ground thermal vacuum test data; no on-orbit updates have been made. The F160BW flatfield is known to be somewhat noisy (see, e.g., STAN 33, Aug. 1998): the RMS noise near the center of the PC is nearly ~20% and there are a few individual pixel errors nearly a factor of 6 larger. Note, however, that any individual pixel outliers, at least, would have been removed in the manual cosmic ray and hot pixel cleanup.
- There are no flatfields for the crossed filter combinations; as noted in the data section, the uncrossed flatfields were used for all images.
- The redleak for these stars is appreciable (more than 60% in F122M and ~70% in F160BW). Any errors in either the single or crossed filter data propagate into the redleak-corrected results. In addition, the redleak correction was a very simple one: subtraction of the crossed filter results from the single filter results. No correction was made to account for less than perfect throughput in F130LP (~0.95 beyond 4000Å).
- There is a considerable amount of scatter in the normal F160BW routine monitoring observations of GRW+70D5824 (images crossed with F130LP are not routinely taken). For example, since 1996, the contamination-corrected PC F160BW observations taken less than 5 days after a decon have fluctuated by about 8% (based on data from Gonzaga et al., WWW memo).
- In addition, a small longterm increase in post-decon measurements of GRW+70D5824 has been observed in F160BW in PC (Baggett & Gonzaga, 1998). The effect is ~5% between late 1996 and early 2000. This particular effect would, of course, move the redleak-corrected values higher (Figure 2, lower left plot).
- The target faintness made it extremely difficult to find WD710+741 in some of the datasets at -55C and center the target in the aperture, even after recalibrating using a post-SM3a dark generated from five dark frames taken at -55C. The WD710+741 count rates are a factor of 10 lower than those for GRW+70D5824; at the same time, scheduling restrictions prohibited increasing exposure times to match the GRW+70D5824 total counts. Within the aperture, total counts for the two stars were typically ~4500 DN vs 870 DN (F122M) and 3160 DN vs 1350 DN (F160BW).

For these reasons, the results for SMOV3a are considered to be within the measurement error and we conclude that the Lyman- α throughput measurements for SMOV3a in PC did not show any significant changes compared to pre-SM3a. The WFPC2 pick-off mirror appears to have been protected from any significant contamination.

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