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SMOV3B WFPC2 UV Contamination Monitoring and Throughput Check

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ABSTRACT

The throughput of the WFPC2 cameras in the UV is potentially susceptible to significant decreases as a result of contaminants deposited on the cold CCD windows, once the instrument has been cooled down to -88^o C. An important part of our SMOV3B checkout involved intensive monitoring of this contamination using the F170W filter, to ensure that the throughput never dropped below levels that can safely be removed by the regular decontamination procedures. We report here the results of these measurements, showing that the throughput remained at safe levels throughput SMOV3B, and in addition demonstrating that the decontamination procedures during SMOV3B returned the throughput to its nominal levels. We also find that the daily contamination rates have now returned to their pre-SMOV3B levels.

1. Introduction

A critical aspect of the initial cool-down and activation of WFPC2 after Servicing Mission 3B (SM3B) involved a period of intensive monitoring and verification of the throughput of the instrument at UV wavelengths, in order to ensure that the camera throughput was not permanently degraded by contamination deposited on the cold (-88^o C) CCD windows. In particular, the throughput in the F170W filter needed to be monitored to verify that the decrease in flux due to contamination never exceeded the safe limit of a 30% drop in total throughput, which corresponds to the maximum level that is known to be removed by the regular decontamination procedures.

Furthermore, we needed to verify whether the decontamination procedures scheduled during SMOV3B, which are aimed at removing contaminants by warming up the cameras for a period of several hours, were successful in returning the throughput to its nominal levels. Finally we needed to measure the daily contamination rate and carry out a comparison with pre-SMOV3B values.

2. Observations

The WFPC2 camera was cooled down to -88^o C on 23 March 2002, within a day after the end of the Bright Earth Avoidance (BEA) period which had lasted 12 days from the time that HST had been released from the space shuttle. The UV contamination monitoring plan for WFPC2 was based on observations of the WFPC2 primary standard star GRW+70d5824 through the F170W filter, in all 4 cameras of the instrument. The program consisted of two phases: an intensive period, beginning immediately after the cooldown to -88^o C and lasting for 6 days, until the first decontamination procedure took place one week after cooldown; and a second less intensive phase, lasting throughout the rest of SMOV3B for WFPC2, consisting of observations immediately before and after each of the subsequent decontamination procedures that occurred at intervals of 1-2 weeks.

The intensive phase began with a set of observations immediately after cool-down, consisting of two observations of GRW+70d5824 through the F170W filter in each of the four chips. This was subsequently repeated at 3, 6, 12, 18, 24, 36 hours, and 2, 3, 4, 5, 6 days after cooldown. At each epoch, the two observations for each chip consisted of a dither-pair where the second exposure was offset by 0.25" along both the x and y axes in a simple DITHER-LINE pattern. All exposures were 40s in length and obtained using GAIN=15. The timing of each set of observations varied slightly as a result of scheduling constraints and the fact that each visit required one to two orbits, but nevertheless all the observations were executed in accordance with the requirements of the program.

The data during the first 24 hours were all transferred using expedited delivery and were available for analysis within 2-3 hours of the observations being taken; the remainder of the data for the first week were generally available 12-24 hours within the time of the observations. In all cases the data were analyzed immediately upon receipt, typically within 1-2 hours, thereby maintaining a total turn-around time well within the 12 hours requirement. In all cases the resulting flux measurements showed that the contamination rate remained within the safety margin.

The remainder of the UV observations during the rest of SMOV3B, obtained before and after each subsequent decontamination procedure, were primarily intended to track the expected decrease in contamination rate as a function of time after HST release, and to afford a comparison with pre-SM3B values. These differed slightly from the intensive observations during the first week, in that only a single exposure was obtained for each chip, and in addition the observations were obtained as part of a photometric sweep that included several other filters in the UV and optical. The star was also placed on a different part of the chip, in order to provide consistency with other long-term photometric programs. However, all the exposures with the F170W were still 40s in length with GAIN=15, thus they afford a direct comparison with the more intensive observations from the first week after cooldown.

Table 1. WFPC2 Observations of GRW+70d5824 in F170W during SMOV3B.

Time since Cooldown	PC	WF2	WF3	WF4
0h	u8cz1301 u8cz1302	u8cz1303 u8cz1304	u8cz1305 u8cz1306	u8cz1307 u8cz1308
3h	u8cz1501 u8cz1502	u8cz1503 u8cz1504	u8cz1505 u8cz1506	u8cz1507 u8cz1508
6h	u8cz1601 u8cz1602	u8cz1603 u8cz1604	u8cz1605 u8cz1606	u8cz1607 u8cz1608
12h	u8cz1701 u8cz1702	u8cz1703 u8cz1704	u8cz1705 u8cz1706	u8cz1707 u8cz1708
18h	u8cz1801 u8cz1802	u8cz1803 u8cz1804	u8cz1805 u8cz1806	u8cz1807 u8cz1808
24h	u8cz2001 u8cz2002	u8cz2003 u8cz2004	u8cz2005 u8cz2006	u8cz2007 u8cz2008
36h	u8cz2301 u8cz2302	u8cz2303 u8cz2304	u8cz2305 u8cz2306	u8cz2307 u8cz2308
48h (2d)	u8cz2401 u8cz2402	u8cz2403 u8cz2404	u8cz2405 u8cz2406	u8cz2407 u8cz2408
3d	u8cz2601 u8cz2602	u8cz2603 u8cz2604	u8cz2605 u8cz2606	u8cz2607 u8cz2608
4d	u8cz2801 u8cz2802	u8cz2803 u8cz2804	u8cz2805 u8cz2806	u8cz2807 u8cz2808
5d	u8cz2901 u8cz2902	u8cz2903 u8cz2904	u8cz2905 u8cz2906	u8cz2907 u8cz2908
6d	u8cz3001 u8cz3002	u8cz3003 u8cz3004	u8cz3005 u8cz3006	u8cz3007 u8cz3008
7d pre-decon	u8cz4107	u8cz4108	u8cz4109	u8cz410a
7d post-decon	u8cz4807	u8cz4808	u8cz4809	u8cz480a
14d pre-decon	u8cz5107	u8cz5108	u8cz5109	u8cz510a
14d post-decon	u8cz5407	u8cz5408	u8cz5409	u8cz540a
26d pre-decon[a]	u8cz7107	u8cz7108	u8cz7109	u8cz710a
26d post-decon	u8cz7407	u8cz7408	u8cz7409	u8cz740a

a. Due to guide star problems, this observation did not execute successfully.

3. Analysis

The data were first calibrated using the normal WFPC2 pipeline, which included applying standard flatfields, A-to-D conversion, and bias subtraction. For each camera, the pair of CR-split images were *not* combined using cosmic-ray rejection algorithms but were instead treated as separate images, and the flux of the star measured independently on each image. This was considered to provide more robust identification of outlier flux measurements that may be affected by cosmic rays, warm pixels or other effects. In addition, this allows a direct comparison with the later photometric points from the remainder of SMOV3B, where only a single exposure in F170W was obtained for each chip.

In each image, cosmic rays were identified and removed by hand, and standard aperture photometry was carried out on the resulting image. In general cosmic rays were not a serious problem, due to the relatively short exposure times that were used (40s); only about 10% of the images had cosmic rays sufficiently close to the star, and of sufficient intensity, that editing was necessary. During the first 24 hours, which was the most critical part of the monitoring, the editing and photometry was carried out independently by all five members of the team, in order to verify consistency in terms of cosmic ray removal as well as photometry. In general, extremely good consistency was achieved (typically to well within the formal measurement errors associated with the photometry, which were generally in the range 0.3 - 0.5%). The measurements from all the team members were collected into a single database and the points were then input into a regression routine to obtain a fit to the contamination rate as a function of time; the database and the regression fit were updated immediately upon receipt of each new set of measurements.

4. Results

In Figure 1 we show the rate of throughput decrease as a function of time, resulting from the growth of contaminants on the CCD windows of the four detectors. The dashed line in each case shows the nominal count-rate based on measurements of the star before SMOV3B; here we describe several features apparent in the plots.

Firstly, the initial throughput in all four cameras measured during the first few hours after cooldown was ~ 1 - 2% below the nominal expected throughput, even though the instrument had just come out of a decontamination period that had lasted almost two weeks. Analysis of the PSF revealed that the telescope was substantially out of focus during the first day or so after the end of BEA, therefore some flux was lost from the aperture surrounding the star, thereby reducing the apparent count rate. This effect is verified by the fact that the throughput only began to show a clear downward trend after the first 2-3 days, when the focus had recovered to its nominal values and the measured count rates were no longer being substantially affected by the quality of the PSF. The effect was also verified by showing that for smaller apertures, even more light was lost during the first few measurements; larger apertures retained more light but were not used due to the increased effects contamination from low-level cosmic rays and other defects.

It can be seen that for all four cameras, the overall decrease in flux by the time of the first decontamination at 7 days after cooldown was no more than 10-15% below the nominal 100% throughput value, thereby remaining safely above the 30% decrease limit.

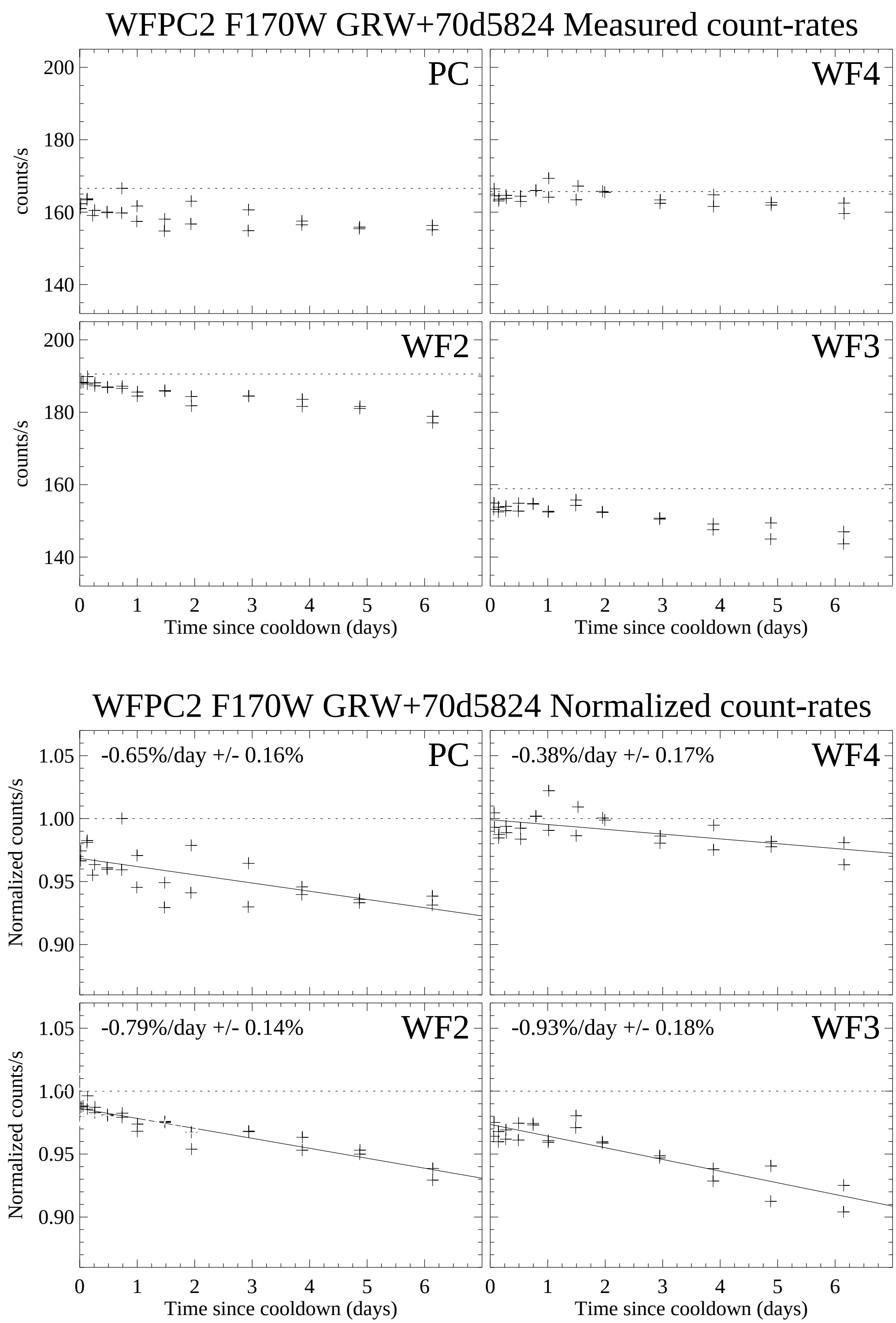

Figure 1: Measured decrease in throughput of GRW+70d5824 during the first week after cooldown, plotted for each of the cameras separately. The top panels show the measured count-rates, while the bottom panels show count-rates normalized to the pre-SMOV3B values. The bottom panels also show the rate of change of percentage throughput per day, fitted separately for each camera.

The rate of change of throughput was also measured separately for each camera, and are tabulated in Table 2 where we compare them to the normal (pre-SMOV) rates of change, as well as those from the last servicing mission.

Table 2. Measured rate of throughput decrease in F170W (expressed in %/day).

	Normal (2001-2002)	**SMOV3A**	**SMOV3B**
PC	0.330	1.4	0.65
WF2	0.486	2.0	0.79
WF3	0.516	2.0	0.93
WF4	0.373	1.5	0.38

It can be seen that the SMOV3B rates are somewhat higher than normal, up to a factor of 2. This is likely due to an increased presence of contaminants related to servicing mission activities and new instruments aboard the telescope. However, the rates are still significantly below those that were seen in SMOV3A, and at all times the cameras remained well within their safe limits for contamination rates. This is likely due to the fact that the WFPC2 cameras were not cooled down until 12 days after HST release, thereby allowing substantially more time for contaminants to escape than had been the case during SM3A. Moreover, the new instruments installed this time had been extensively treated before flight to ensure a minimum of outgassing material, and this has likely contributed to the reduced contamination rates that we observe.

In addition to measuring the decrease in throughput relative to the nominal count-rate, we also measure the rate of change of throughput relative to the first measurements taken after cooldown. Although this is subject to some slight uncertainties in the measurements as a result of the somewhat degraded PSF after the end of the BEA, we nevertheless obtain results that are consistent with those measured for the cameras independently. In Figure 2 we show the average contamination rate measured for all four cameras, normalized to the flux of the first observation after cooldown. In this figure we differentiate between the first and second observation of each split pair, and we explain here the reasons why.

We found that the second observation of each pair of observations typically gave a somewhat higher flux measurement than the first, particularly for measurements taken after the first day. One possible cause of this is that the first observation results in a mild “pre-flashing” of the pixels; although the second observation was offset from the first, it was by a dither of only a few pixels in each direction, thus many of the pixels sampling the star in the second observation would also have sampled it during the first observation. This mild pre-flashing would result in less CTE loss in the second observation, thereby increasing it by up to a few percent relative to the first. The reason why this effect is so strong is likely related to the fact that in the F170W the background is negligible, combined with the fact that the exposures are only 40s each and thus relatively short..

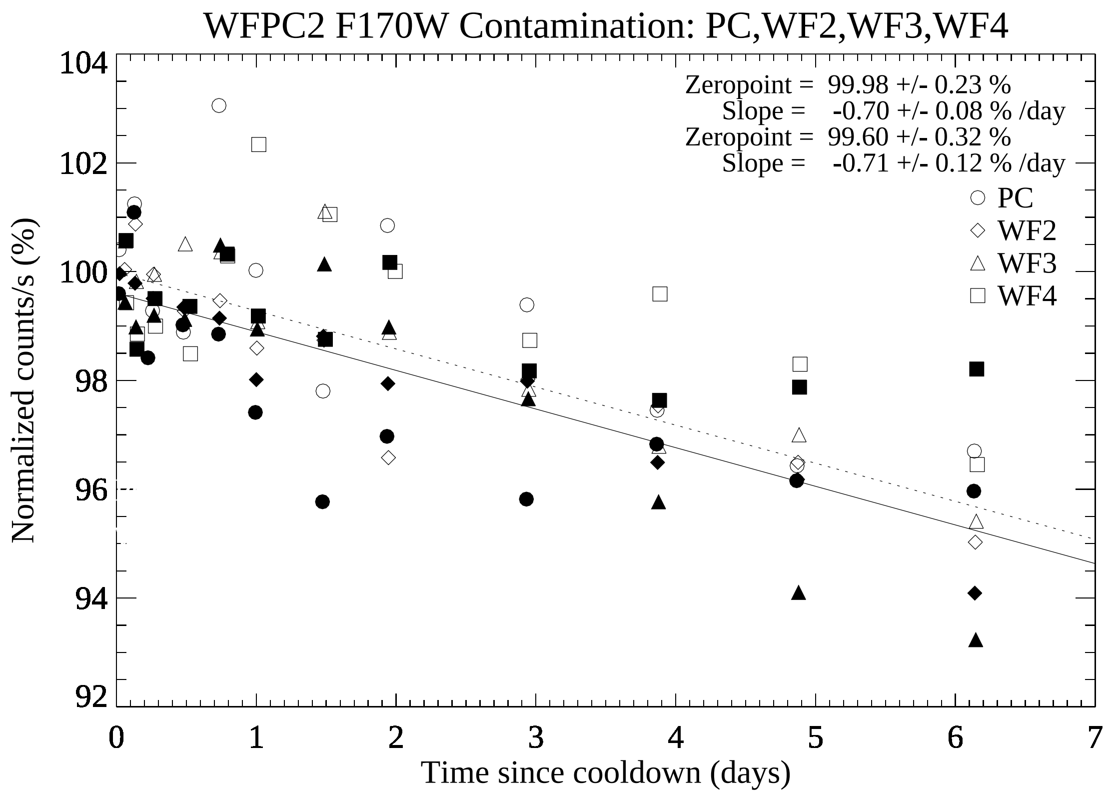

Figure 2: Measured decrease in throughput of GRW+70d5824 during the first week after cooldown, for each of the chips, plotted on the same set of axes and normalized to the count-rate of the first data-points after cooldown. At each epoch there are two split observations per chip; we use solid symbols to denote the first exposure in each pair and open symbols to denote the second exposure. The second exposure is often systematically brighter than the first by about a percent, which is likely attributable to mild “pre-flashing” of the pixels by the first exposure. The reason that the effect is so noticeable is probably a result of the negligible background at F170W, combined with the short exposure times. The two lines correspond to fits with and without the second exposure in each pair, showing consistent slopes but a constant offset.

Therefore, in Figure 2 we differentiate between the two points of each pair by plotting the first point with a solid symbol and the second with an open symbol. We also carried out two sets of fits to the data, one involving all the points and the second fit involving only the first point of each pair. It can be seen that the average rate of decline for both fits is almost identical, at around 0.7% / day, but that the two lines are offset from one another by around 0.4%, corresponding to the contribution from the increased flux in the second measurement of each split pair.

Finally, we show in Figure 3 the results of the subsequent UV monitoring observations, carried out during the rest of SMOV3B after the first week. Unfortunately a guide star acquisition failure prevented us from obtaining a measurement just before the 26-day decon, but we were nonetheless successful in obtaining measurements before and after each of the other decons. It can be seen that the measurements just before the 14-day decon generally have a much smaller decrease in throughput compared to those immediately before the 7-day decon, and this is attributable to the successful removal of contaminants by the decontamination procedure, as well as the fact that more time has elapsed for material to escape form the system. Moreover, the points immediately after the 14-day and 26-day decontamination procedures show that the F170W throughput is essentially recovered each time, to within the 1-2% errors related to the actual measurement as well as systematic uncertainties, and the contamination rate is also back to nominal.

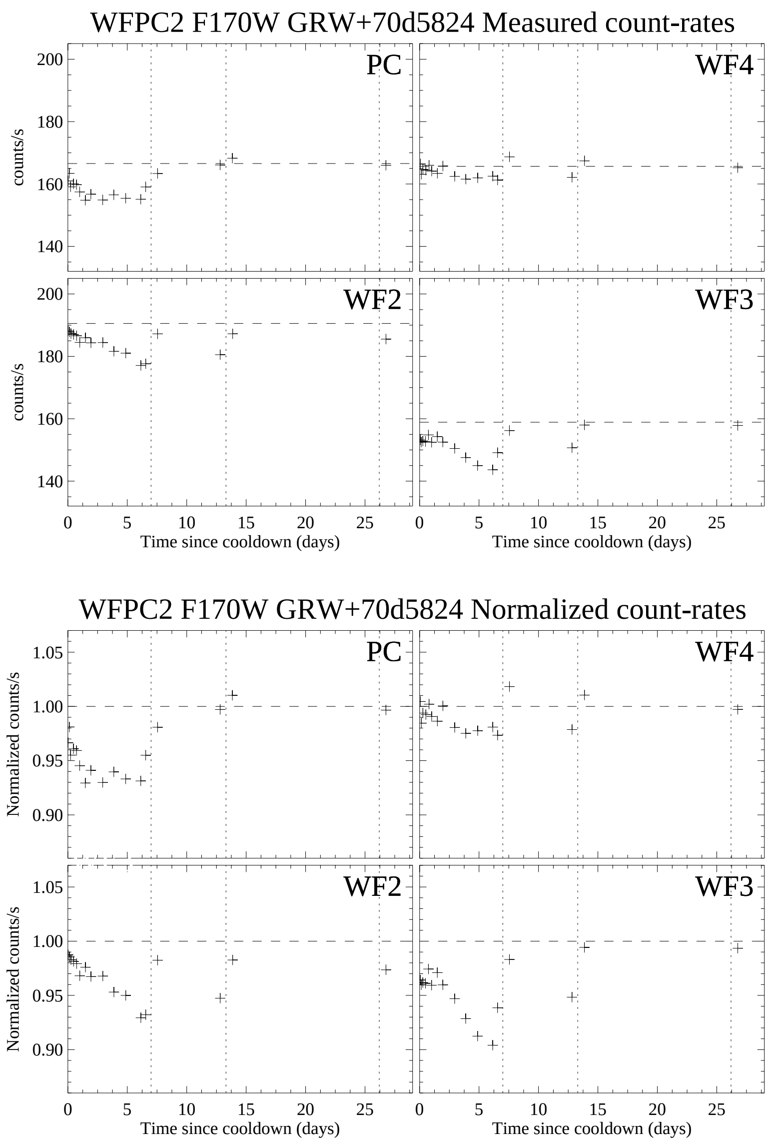

Figure 3: Measured decrease in throughput of GRW+70d5824 during the first month after cooldown, for each of the chips, plotted on the same set of axes and normalized to the pre-SMOV3B count-rates.

5. Conclusions

We have presented the results from our program of intensive monitoring of the UV throughput at F170W due to growth of contaminants on the cold (-88^{o} C) CCD windows. We have verified the following:

- At no point did the contamination on any of the CCD windows exceed a 15% drop in throughput, which is well above the safety limit of a 30% drop in throughput.
- While the contamination rate was measured to be slightly higher in each of the cameras (up to a factor of 2 above normal), the rates were still well below those observed during the previous servicing mission. This is likely due to a combination of factors, including not cooling down the camera until 12 days after release (allowing extra time for contaminants to escape), as well as possibly a reduced level of contaminants from the new instruments compared to previous servicing missions.
- The decontamination procedures carried out during SMOV3B demonstrated that the UV throughput in the F170W filter was successfully recovered to its nominal value (within our measurement errors and systematic uncertainties of 1-2%). Moreover, the contamination rates for each camera now appear to have returned to their nominal values.

Thus we conclude that our program of delayed cooldown, pro-active UV monitoring, and frequent decontaminations during SMOV3B were successful in fully retaining the UV throughput capabilities of WFPC2 as measured in the F170W filter.

6. References

Casertano, S. et al., “Results of the WFPC2 Observatory Verification after Servicing Mission 3A”, Instrument Science Report WFPC2-00-02

Koekemoer, A. M., et al., “Summary of WFPC2 SM3B Plans”, Instrument Science Report WFPC2-2001-11