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Preliminary Assessment of the FR533N Filter Anomaly

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ABSTRACT

Analysis of FR533N VISFLAT images has revealed an apparently randomly-occurring rotational offset of about 0.5 degrees in some images, a quantity that corresponds to one filter step. The pivot point for the rotation implicates the filter wheel as the source of this inconsistency. We expect no impact on observations; any photometric effect is less than 1%. A cursory check of several other filters (on other filter wheels) shows no similar problem. At this time, the source of this anomaly, whether it is mechanical or due to a software error, is not known.

Introduction

In the first three years of WFPC2 operation, VISFLAT observations using the FR533N filter were frequently taken to monitor gain ratios over time. The frequency of these observations was decreased when it was found that the VISFLAT lamp was degrading at a rate faster than expected.

A recent study of the gain ratios over time revealed anomalies that warranted further investigation. Gain ratio plots consist of ratios of gain 7 and 15 observation pairs that were closely related in time, plotted as ratio vs. time. Since gain ratios are not expected to change significantly, the plot (see Figure 1 for an example in the PC) should have indicated a steady ratio value over time. Instead, the plot showed unexpected quantized ratio values above and below the main expected result. The quantized nature of these points strongly suggested the effect could not be attributed to noise.

A further investigation revealed that some of the images were slightly offset with respect to others. This offset was clearly seen in the pinhole patterns visible in WF2 and

WF4 chips, as well as an overall shift in the filter patterns. Despite a detailed inspection of affected images, it was not possible to determine the “true” or “correct” position of FR533N, since the shift was relatively small.

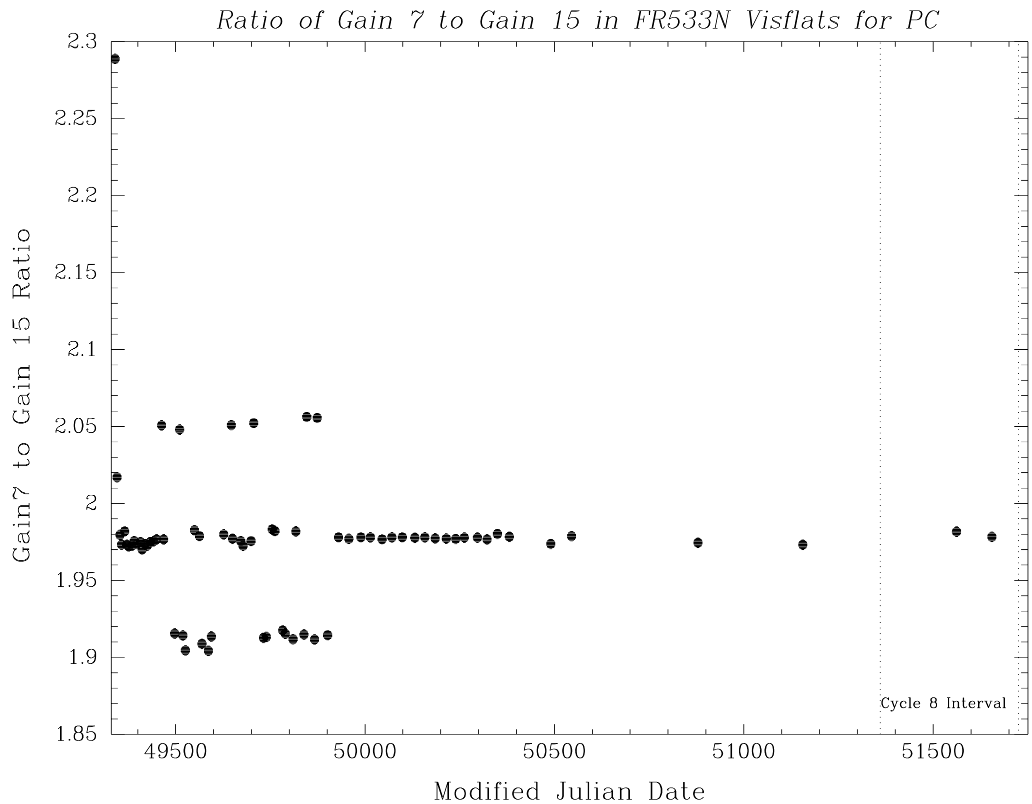


Figure 1. Plot of Gain 7 to Gain 15 Ratio vs. Modified Julian Date, in the PC.

Measurement of FR533N Filter Rotational Offset

Several steps were taken to better understand the problem.

First, how widespread was this problem? A visual survey of 44 random FR533N VISFLAT images revealed that 22 images seemed to be tilted with respect to the others, and that this offset appeared to be a constant value in all affected images.

To better understand the anomaly, we queried the archive database, extracting particular keyword values for all chips for all FR533N VISFLATS (146 images): MEANC300 (the mean value of a 300x300 region at the center of the chip for the uncalibrated images), DEZERO (the average bias level value for each chip), and EXPTIME (the exposure time). For each chip and each image, we subtracted the average bias level value (DEZERO) from the central 300x300 mean count (MEANC300). That result was then divided by the exposure time (EXPTIME) to obtain a countrate. The results, a plot of corrected countrate in the 300x300 chip center vs. time (in Modified Julian Date), for each chip, can be seen in Figures 4a and 4b, corresponding to gain 7 and gain 15 respectively.

Next, we searched for patterns of linear ramp filter usage to see if we could predict when a particular FR533N configuration would occur. No clear trends could be found.

Thirdly, we set out to determine the amount of rotation. This was done by first choosing two pairs of VISFLAT images at gain 15, where one image in a pair was tilted with respect to the other. Images within each pair were also closely spaced in time to ensure that the intensity of the declining VISFLAT lamp would be almost identical.

The following images were used:

Pair 1: u2fd0e04t.d0h (10/06/94) & u2fd0o04t.d0h (16/06/94)

Pair 2: u2fd7w04t.d0h (1/06/95) & u2fd8604t.d0h (7/06/95)

Each image was mosaic'd using the STSDAS task *wmosaic*. From visual inspections of the images, the rotation appeared to be more pronounced at the edges of WF3 and WF4 areas farthest from the pivot point of the filter wheel. Most of the motion appeared to be in a vertical direction (with reference to the mosaic'd image).

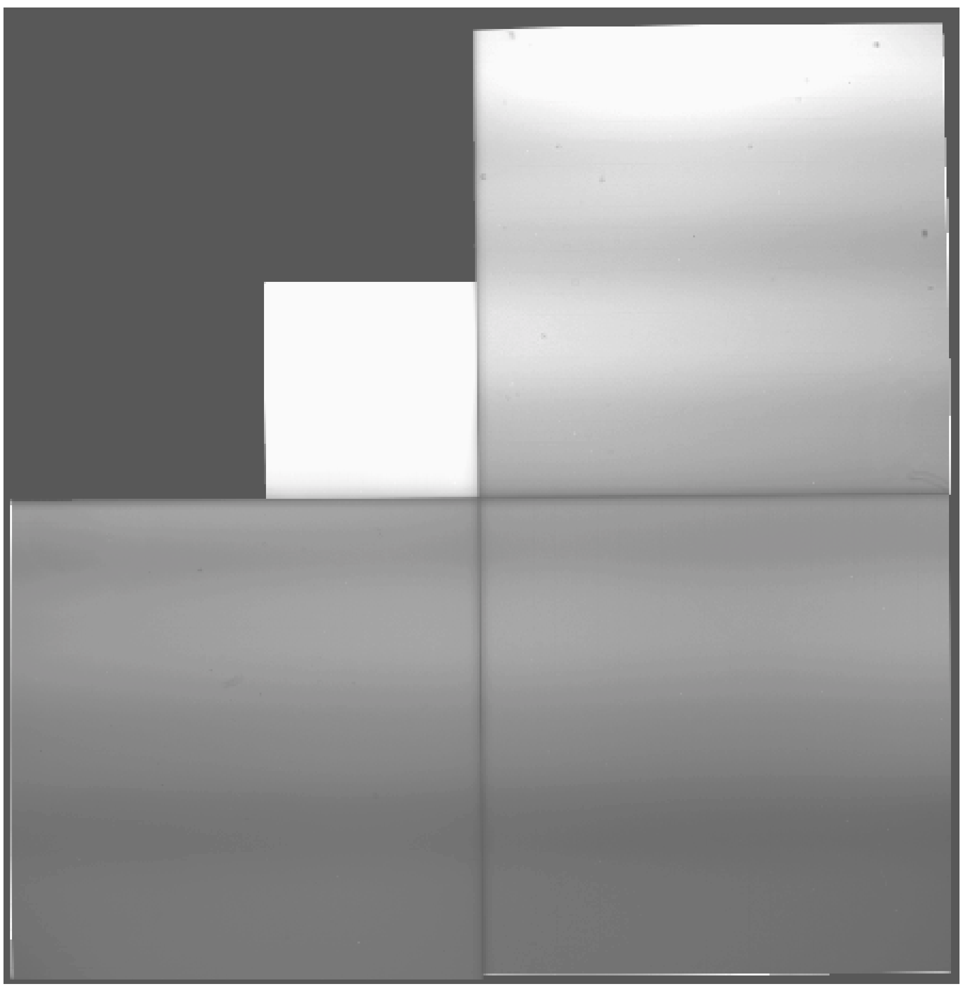


Figure 2. Mosaic of u2fd0e04t.d0h. Starting from the PC (the smallest chip) and moving clockwise are chips WF4, WF3, and WF2.

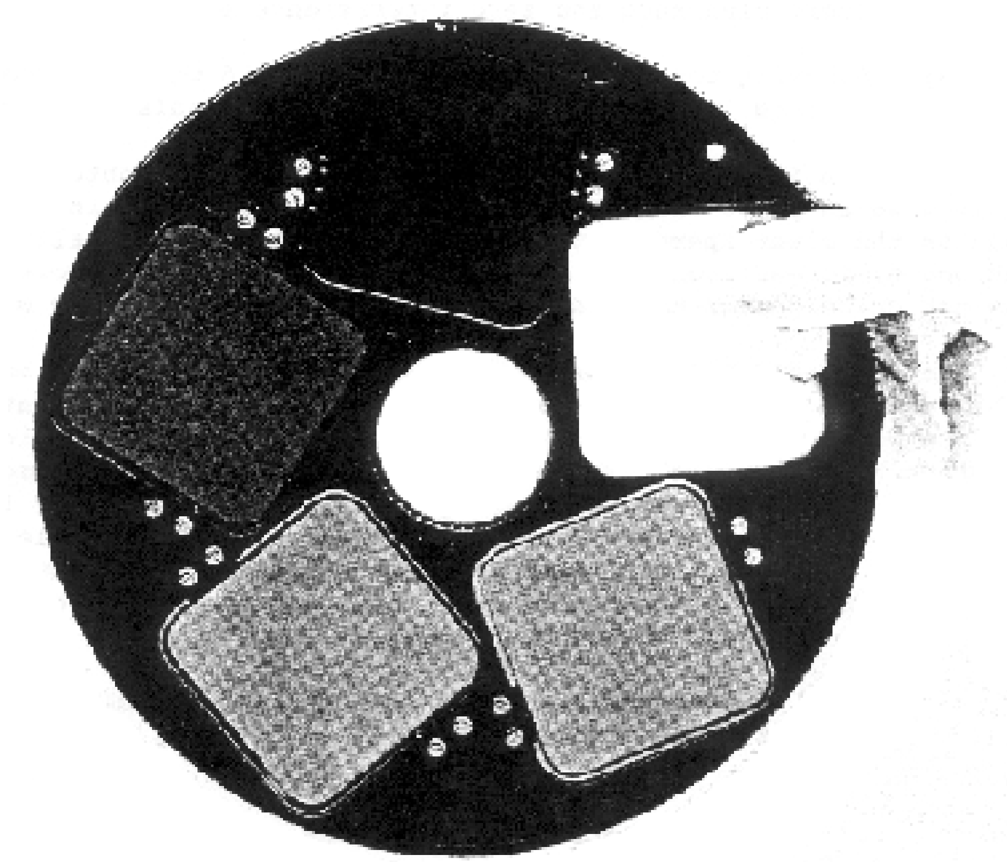


Figure 3: View of a Filter Wheel, showing Filters in Place. (From Document SE-01)

Therefore, we measured the size of this motion at two vertical strips of the mosaic'd image, one strip taken near the pivot point and another far from the pivot point. In a portion of a mosaic'd image that contained only WF2 and WF3, [50:1550,50:750], two sets of vertical strips were chosen: strip 1 from columns 200 to 250 (on WF2), and strip 2 from columns 1400 to 1450 (on WF3).

As shown in Figures 5 and 6, the row profile was plotted for both image pairs, with each strip having its own plot. The offset due to the tilt was measured (in pixels) by measuring the gap between the two image profiles at the steepest parts of the plot slopes. Ten measurements were taken along the steep slopes, and an average value was computed.

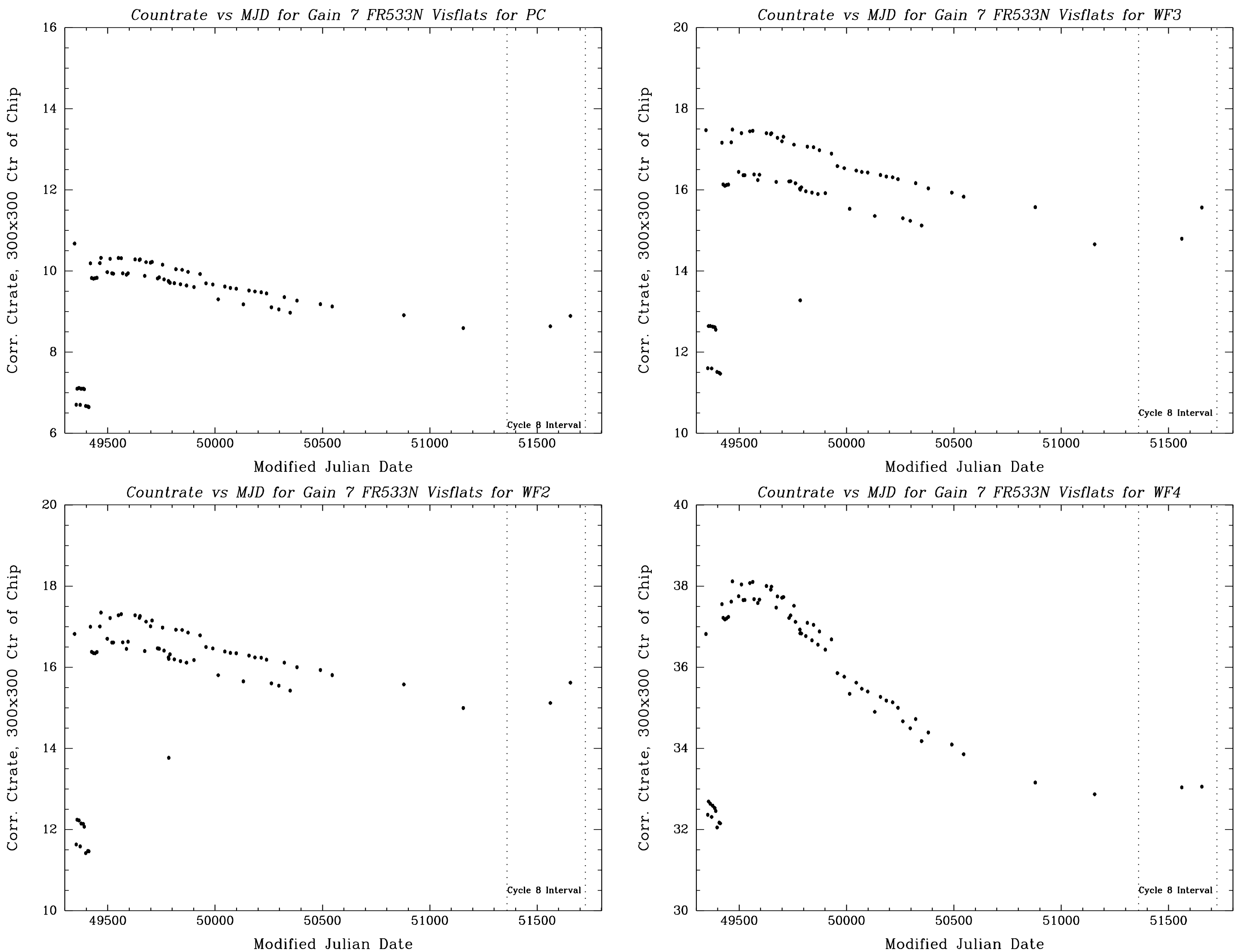


Figure 4a. Plot of Bias-corrected Mean Countrates (Central 300x300 Region) vs. MJD for Gain 7.

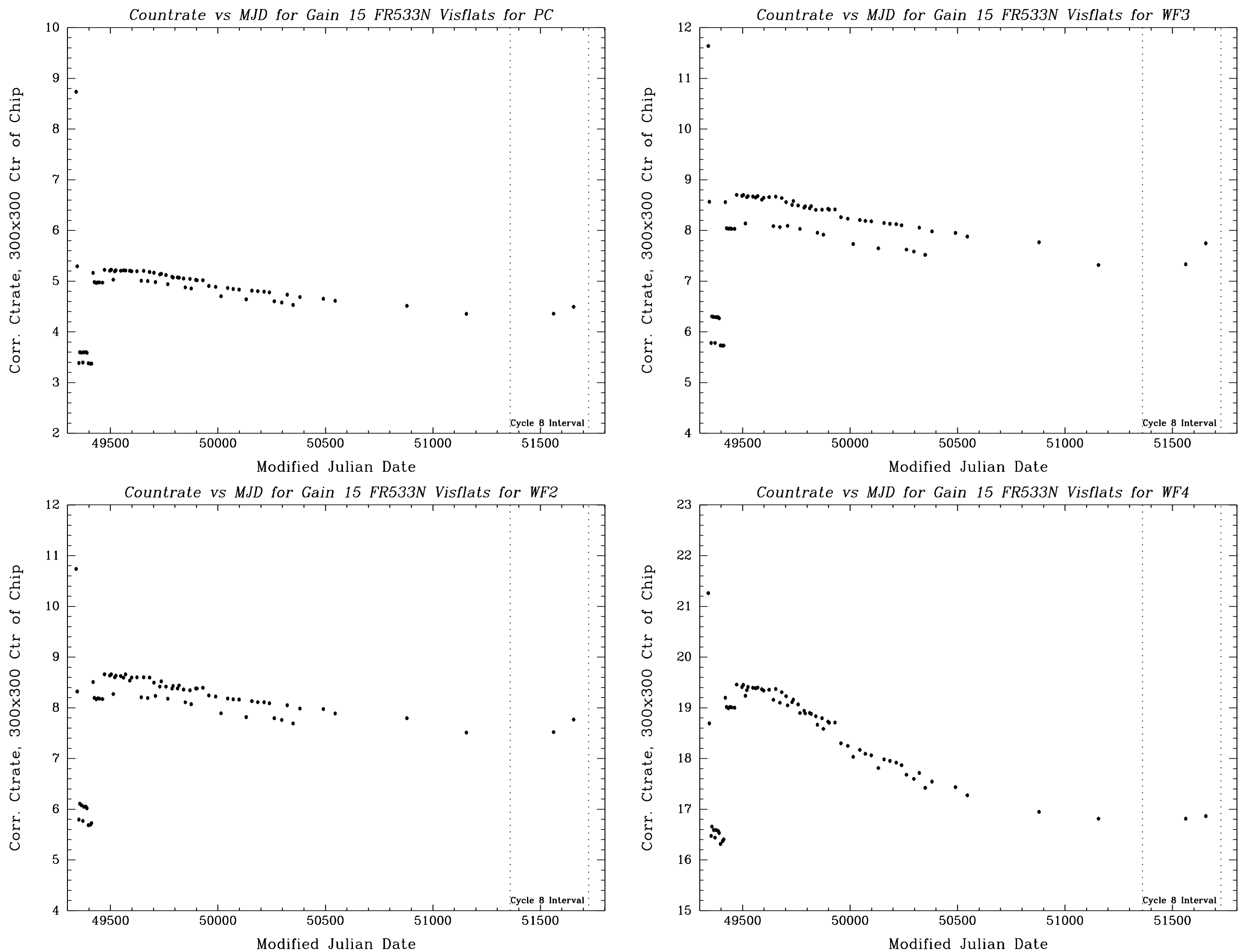
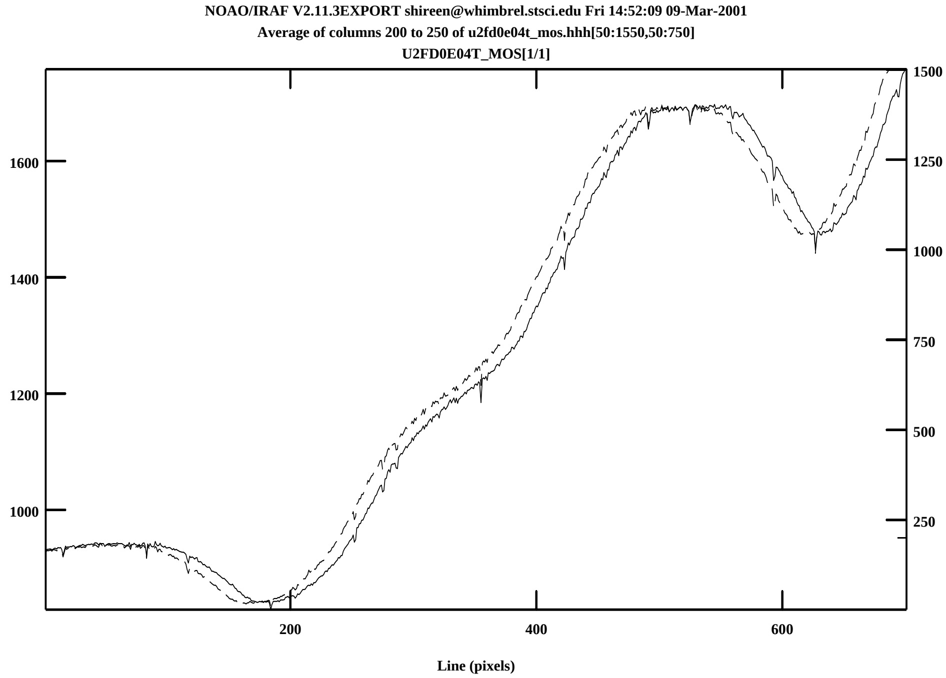


Figure 4b. Plot of Bias-corrected Mean Countrates (Central 300x300 Region) vs. MJD for Gain 15.



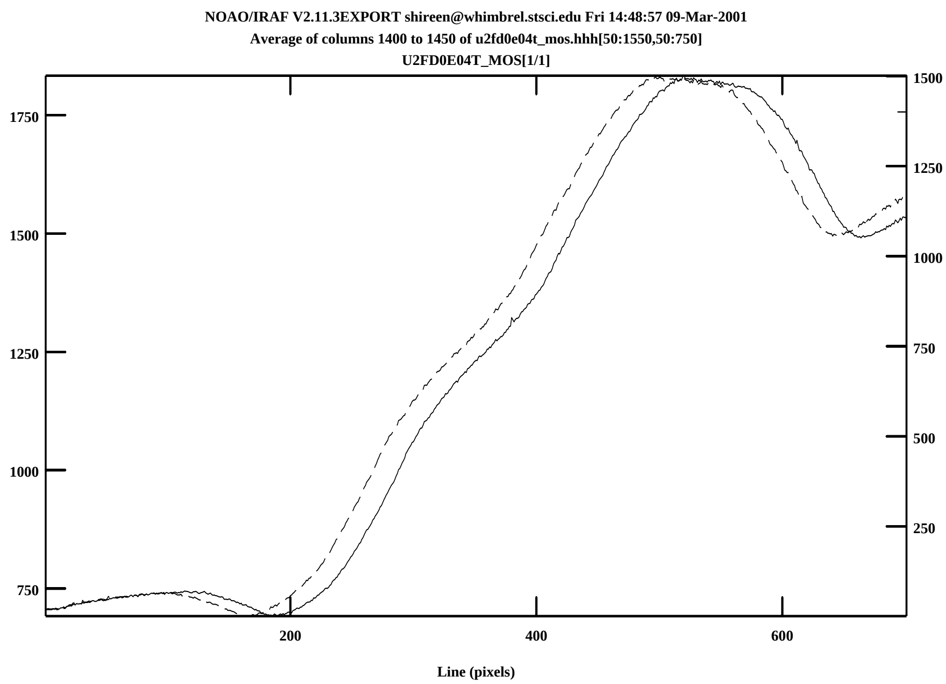


Figure 5. Row profile plots along strip 1 and strip 2 for mosaics of u2fd0e04t.d0h & u2fd0o04t.d0h

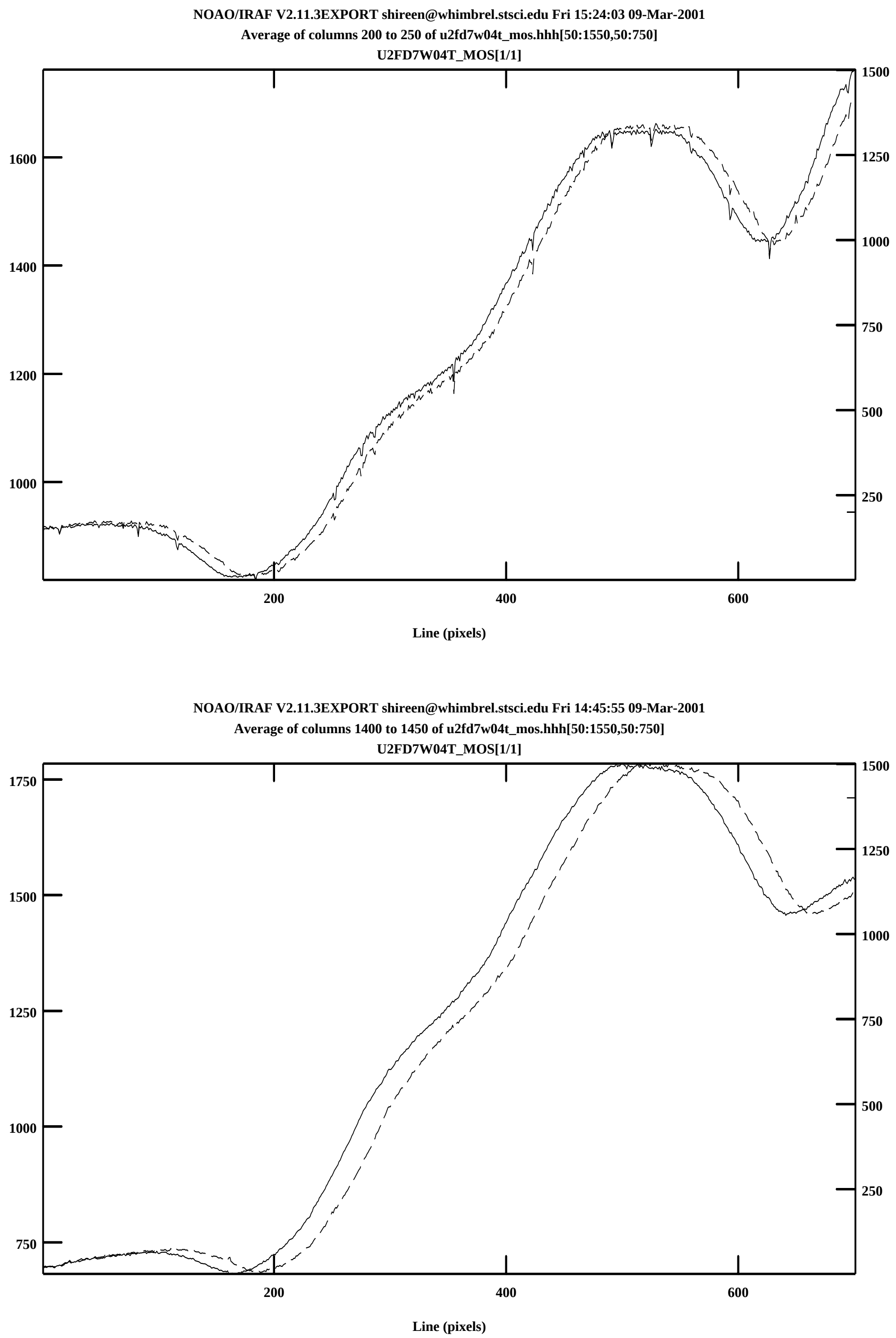


Figure 6. Row profile plots along strip 1 and strip 2 for mosaics of u2fd7w04t.d0h & u2fd8604t.d0h

Determining the offset at a point close to the pivot, and another offset further away from the pivot allowed us to estimate a value for the offset angle.The diagram below (figure 7) illustrates the procedure.

$r1$ is the distance from the pivot to strip1 (columns 200-250 in WF2).

$r2$ is the distance from the pivot to strip2 (columns 1400-1450 in WF3).

$c1$ is the offset between two images tilted with respect to each other at strip1.

$c2$ is the offset between two images tilted with respect to each other at strip2.

We were unable to determine the distance from the pivot to the edge of a WFPC2 chip from the available WFPC2 documentation. Therefore, we assumed that

$r2 - r1 = 1200$ pixel lengths. (the distance between strip 1 and strip 2)

While this is not strictly correct, it was a reasonable assumption to make for a small angle, and we felt that the error introduced would be fairly small.

Next we used

$$\theta = 2\operatorname{asin}\left(\frac{c1}{2r1}\right) = 2\operatorname{asin}\left(\frac{c2}{2r2}\right)\ldots\ldots\ldots(1)$$

which gives

$$\sin\left(\frac{\theta}{2}\right) = \frac{c1}{2r1} = \frac{c2}{2r2}\ldots\ldots\ldots(2)$$

Where, $r2 = r1 + 1200\ldots\ldots\ldots(3)$

Therefore, $r1 = \dfrac{1200}{(c2)/(c1) - 1}\ldots\ldots\ldots(4)$

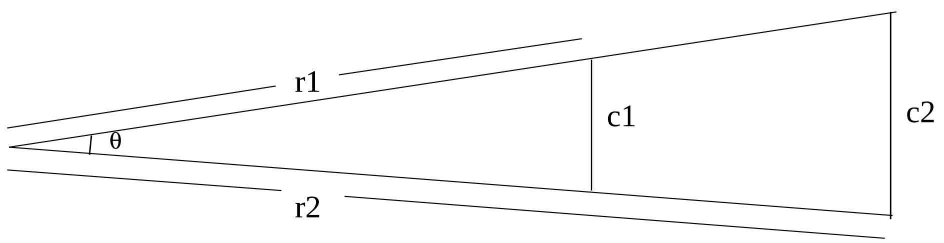


Figure 7. Illustration of the method used to calculate the image offset.

Measurements from image pair 1 gave the following values:

$c1$ = 12.6 +/- 1.6 pixel lengths (average of 10 measurements)

$c2$ = 20.7 +/- 1.2 pixel lengths (average of 10 measurements)

Therefore,

$r1$ = 1866.67 pixel lengths

θ = 0.3867 +/- 0.157 degrees

Measurements from image pair 2 gave the following values:
$c1$ = 11.8 +/- 1.9 pixel lengths (average of 10 measurements)
$c2$ = 20.2 +/- 1.9 pixel lengths (average of 10 measurements)
Therefore,
$r1$ = 1685.71 pixel lengths
θ = 0.4000 +/- 0.191degrees

To verify that these results were reasonable, we also measured the positions of the pinholes (in WF2 and WF4) in pair 1. This was difficult to do because the pinhole features were not well-defined, so there is a fair amount of error in the measurement. Measurements at different locations on the pinhole features were taken on WF2 (4 measurements) and WF4 (3 measurements). The distance between the pinholes ($r2 - r1$) was done by estimating the distance between the centers of these circular features. The distance was,
$r2 - r1$ = 1420.4 pixel lengths.
From this image pair, we obtained the following values
$c1$ = 12.0 +/- 1.5 (average of 4 measurements, pinhole on WF2)
$c2$ = 22.3 +/- 1.5 (average of 3 measurements, pinhole on WF4)
Therefore,
$r1$ = 1654.86 pixel lengths
θ = 0.415 +/- 0.159 degrees

The values from these two methods indicate a rotational offset of ~0.4 degrees with formal errors of order ~0.15 degrees. Given the measurement errors, and that we have neglected to consider the very small horizontal offsets (as seen in the mosaic'd images), the measured offsets and errors are consistent with the magnitude of one filter step, which is a 0.5 degree rotation of the filter wheel.

Impact on Observations

The next task was to determine how this offset affected the magnitudes of stars observed with the FR533N filter. Time constraints only allowed for a spot-check of eight positions, four each on WF3 and WF4, where the effect of the rotation was at its maximum.

We examined a subset of positions (8 out of 32) where the standard star GRW+70D5824 had been measured in FR533N for calibration purposes (proposals 6939, 8054 and 8454). These positions, listed in table 1, were overplotted on FR533N VISFLAT image profiles of pair 1 (u2fd0e04t.d0h & u2fd0o04t.d0h), as shown in figure 8.

A plot of image pair 1 (u2fd0e04t.d0h & u2fd0o04t.d0h) in WF3 was generated, plotting the average intensity of columns in a strip spanning rows 650 to 730. The positions of the standard star were then overplotted. Similarly, in WF4, the average intensity of rows in a strip spanning columns 700 to 750, was plotted, with star positions marked. The results are presented in figure 8. In all 8 cases, the impact on photometry appears to be negligible since the two positions give identical throughput at the star's locations. Any photometric effect is less than 1%.

Wavelength	Detector	Star Position
4750	3	695 725
4750	3	694 719
5305	3	232 659
5305	3	233 652
5340	4	742 291
5345	4	715 295
6000	4	700 750
6005	4	731 760

Table 1. Positions of GRW+70D5824 in the linear ramp filter for WF3 and WF4.

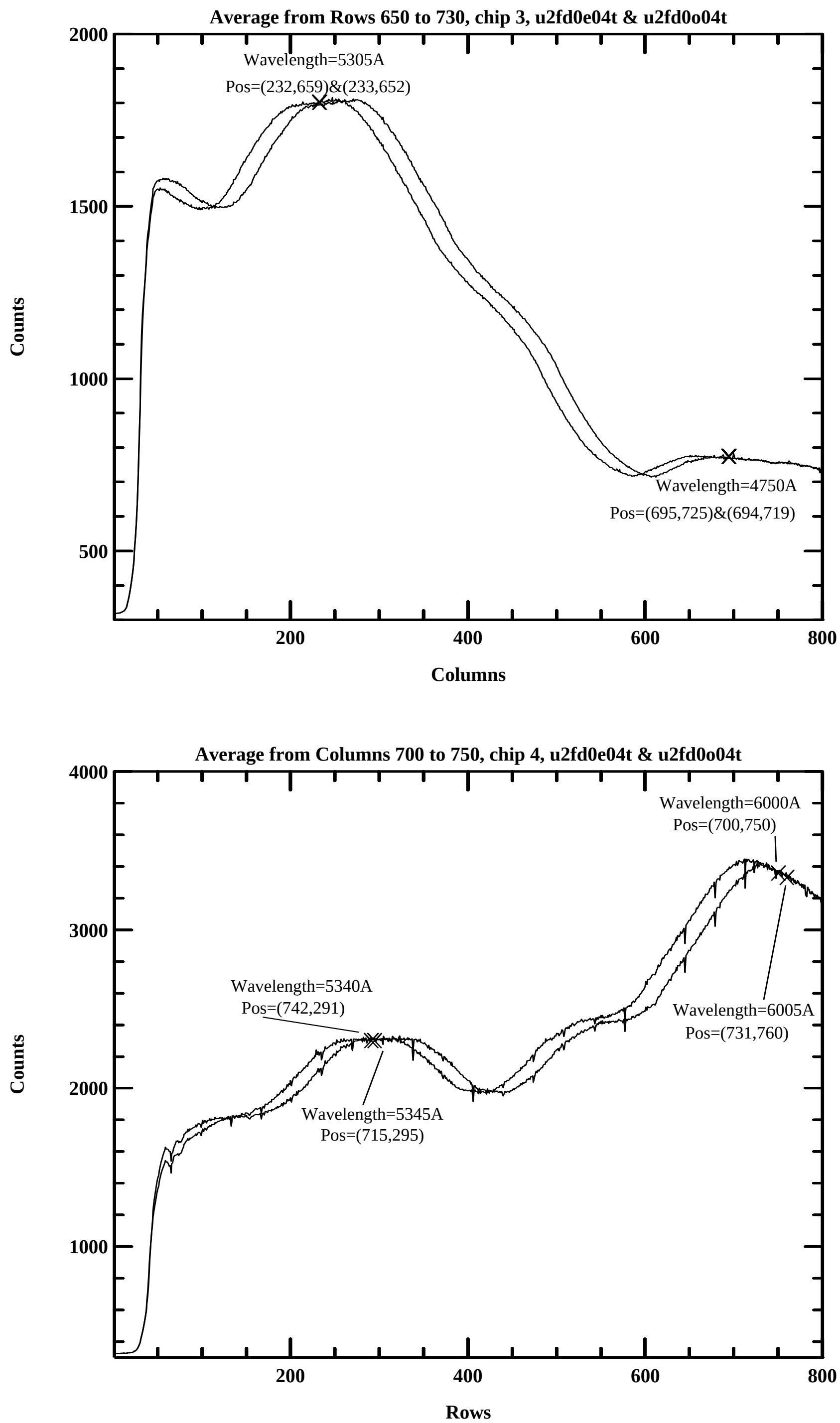


Figure 8: Plots of average intensity along the FR533N filter profile, overlaid with the positions of standard star GRW70D5824.

Tests of Other Filters

We also checked VISFLATS in a few other filters on other wheels for evidence of the same kind of movement anomaly seen in FR533N. Time constraints and lack of sufficient images prevented us from conducting a more comprehensive inspection of all filters. Based on a preliminary sample of some data:

- All linear ramp filters with 2 or more identical filter usages were checked but no conclusions could be drawn due to insufficient data. (linear ramp filters are on wheel 12.)
- This anomaly was not seen in a sample of eleven F555W/POLQ (wheels 9 and 11), and eleven F814W/POLQ (wheels 10 and 11) VISFLAT images.
- It was not seen in ten F160BW (wheel 1) VISFLATS
- It was not seen in thirty-four F300W (wheel 9) VISFLATS that had pinholes.

In general, since each filter wheel is mechanically independent, we can reasonably conclude that, at worst, the problem might impact only the four linear ramp filters, the filters on wheel 12.

Conclusions

Despite the errors due to measurement and the small horizontal motion (with respect to mosaic'd images) that was not included in the analysis, we believe that the size of the displacement in some FR533N filter images to be 0.5 degrees, which corresponds to one filter step. We do not expect this to have any significant impact on observations as the photometric effects are very small.

Recommendations

Currently, we cannot definitively determine whether the anomaly is due to a software error or a mechanical problem. The problem in FR533N was caught because of the relatively large amount of available data. But due to the VISFLAT lamp degradation, similar datasets do not exist for other filters. We plan to submit a cycle 10 calibration proposal to take more VISFLAT observations using several other linear ramp filters, and perhaps also with other filters with prominent patterns (like pinholes) that would allow rotational displacements to be identified. Such additional data should help us identify the cause of the anomaly and test whether other filters are impacted.

Acknowledgements

Thanks to Sito Balleza for details concerning the filter mechanisms, and Matt McMaster for the positions of GRW70D5824 in Table 1.

References

SE-01: WFPC2 Instrument Description and User Handbook, Dec. 1993. Publ. by Jet Propulsion Laboratory, CalTech.

Instrument Science Report 99-01: Internal Flat Field Monitoring II. Stability of the Lamps, Flats, and Gains, O'Dea, et al.

Appendix A

According to the WFPC2 Instrument Description and User Handbook, Dec. '93 (document SE-01), each filter is 72 degrees from the other -- this corresponds to 144 steps. There are 12 filter wheels in the WFPC2 SOFA, 4 filters per wheel.

Jesus (Sito) Balleza, the WFPC2 engineer in ESS kindly provided the following details concerning the WFPC2 filter wheel management:

> Here is how the filter is managed:
>
> Normal filter stepping
>
> 1. A prepare/readout command is latched on port2. The last 8 bits of this word is broken to filter wheel bits 6-3 (4 msb) and filter slot bits 2-0 (4 lsb). An expose/execute is sent to port1 and activates this command in the next major frame.
> 2. Upon receiving this instruction the microprocessor proceeds to the RAM address '412 B'X and '412C'X where the SOFA stepping subroutine is located.
> 3. The microprocessor then uses this subroutine to select the filter wheel and step the chosen filter into position.
> 4. In normal non ramp and non quad filters, the filters are rotated only in a positive direction in values of 72 degrees or 144 steps (1 degree = 2 steps). Depending on the filter the microprocessor will apply 144*N pulses to place the chosen filter in the optical path. N is the filter slot.
> 5. At the end of the exposure the filter remains in position until the next prepare/readout command is latched and executed. If bit 7 is set to 1 the filter is cleared, and the new filter is placed in position if selected.
>
> Partial Stepping
>
> 1. For linear ramp and quad filters the time taken to place these filters in position takes two major frames instead of one in the normal filter mode.
> 2. The prepare command sets the selected filter in a pre-use position. After the filter has been positioned, another prepare command is sent to move the filter a delta amount of steps from this pre-use position.

3. In the next major frame the filter SOFA subroutine address is patched to ’4A’X and ’00’X and this points the microprocessor to the partial stepping subroutine.

4. The filter is now moved using the partial stepping routine. For delta +15 degrees, the filter is placed in the nominal optical path and filter moved 30 steps forward. In the negative delta position, the filter behind the chosen filter (moving in a positive counter clockwise direction) is first set in the optical path in the pre-use position. The selected filter now in a -72 degrees position, is then stepped backwards in the negative direction. For -15 degrees, it is stepped 114 steps (144-114), likewise for -18 and -33 degrees (144-108, 144-78).

5. Once the filters have been placed in position, the filter stepping subroutine repatches the SOFA filter subroutine address back to the nominal address. The next observation will proceed with normal filter stepping unless commanded to partial stepping.

6. The filter itself is homed into position by the filter wheel electronics. The filter itself has reflective mirrors on the wheel which reflect IR from an IR LED. This signal is then reflected onto a mirror to a corresponding IR photo transistor which uses the signal to slowly step the filter to home position. These IR photo transistors are of the same type used on the shutters. Radiation degradation may be affecting the homing accuracy of the filters. The signal may be triggering past the one step in nominal position thus triggering the homing steps past the nominal position.