

# Predicting Photometry Errors due to Linear Ramp Filter Offsets

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## ABSTRACT

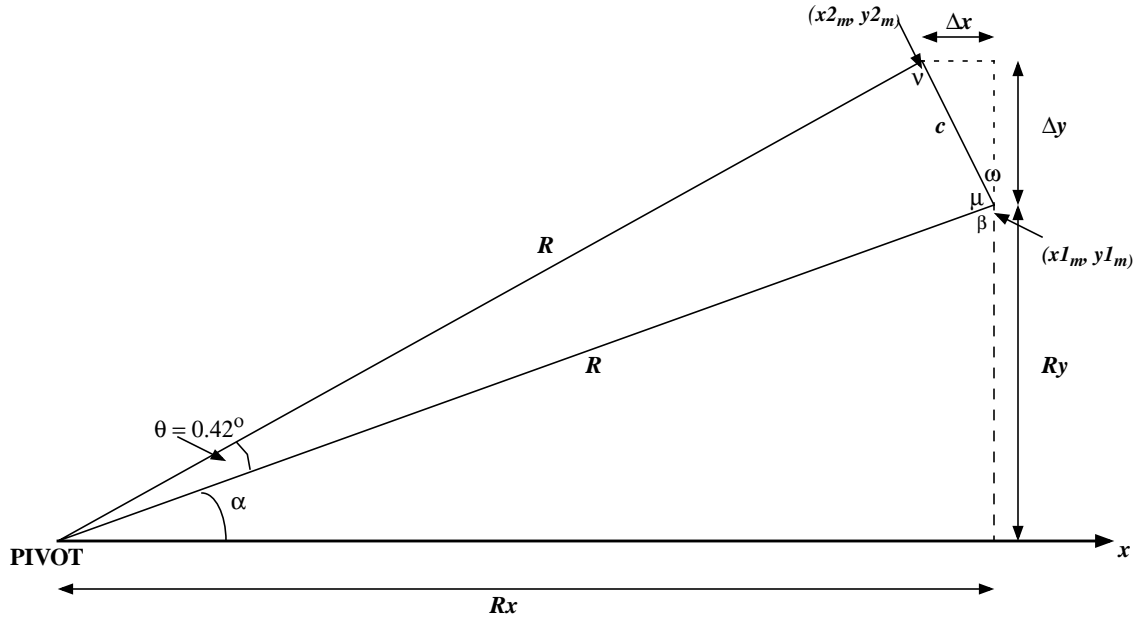
*This document complements Instrument Science Report 02-04, An Analysis of WFPC2 Filter Positional Anomalies, which documents a filter rotation anomaly seen in several WFPC2 filters. Only filters that projected unique filter features on flat-fields were studied because it was those filter features that showed the rotation error as a filter wheel moved from one position to another. In that ISR, the measured error offset was found to be  $0.42^\circ$ . The filter wheel rotation offset causes a wavelength shift in linear ramp filters; this document describes a method for calculating the photometry error due to this effect.*

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## Introduction

Linear ramp filters (LRFs) are used for narrow-band imaging. They are made up of filter strips that vary in wavelength along the length of each strip. Each wavelength region, ranging from  $3710 \text{ \AA}$  to  $9762 \text{ \AA}$  over the four LRFs, is mapped to a particular position in the WFPC2 field-of-view. The filter wheel rotation anomaly results in wavelength shifts in the linear ramp filters. For a rotation error of  $0.42^\circ$ , photometric errors were found to range from 0.2% for a location in the WF2 near the filter wheel rotation axis, to 3% in the WF4, farthest away from the rotation axis where the offsets are largest. More typical errors due to wavelength shift are expected to be less than 1%. Although the effect is small, it is still useful to determine the photometry errors that would be contributed by this filter anomaly.

## Method



**Figure 1:** Diagram illustrating the various parameters needed to calculate the  $\Delta x$  and  $\Delta y$  offsets due to the filter rotation anomaly (in the WFPC2 mosaic coordinate system).

The filter wheel rotation anomaly displaces the filter wheel by  $0.42^\circ$ . In an observation affected by the filter wheel rotation anomaly, a target placed in the chip position corresponding to  $\lambda_1$  will actually lie in a chip region occupied by a wavelength  $\lambda_2$  which corresponds  $-\Delta x$  and  $-\Delta y$  in an “unrotated” image. But it is impossible to determine the nominal position of the LRF, and so, impossible to tell if an observation is affected by the filter wheel rotation anomaly or not. Here, we determine the worst-case scenario.

To determine the possible error in LRF observations, it is necessary to determine the offsets  $\Delta x$  and  $\Delta y$ . This amount depends not only on the offset angle of  $0.42^\circ$ ; it also depends on the location in the chip that corresponds to a particular LRF wavelength (i.e. the angle ( $\alpha$ ) of that position to the x-axis), as well as its distance from the filter wheel rotation axis ( $R$ ).

From the diagram in figure 1:

$$\alpha = \text{atan}(R_y/R_x)$$

$$\beta = 90^\circ - \text{atan}(R_y/R_x)$$

$$\mu = \nu = (180^\circ - 0.42^\circ)/2 = 89.79^\circ$$

Find  $\omega$  to get  $\Delta x$  and  $\Delta y$ :

$$\beta + \mu + \omega = 180^\circ$$

$$\omega = 180 - 89.79 - 90 - \text{atan}(Ry/Rx)$$

$$\omega = 0.21 - \text{atan}(Ry/Rx)$$

Therefore,

$$\Delta x = c \cdot \sin \omega = c \cdot \sin(0.21 - \text{atan}(Ry/Rx)) \quad \text{----- (1)}$$

$$\Delta y = c \cdot \cos \omega = c \cdot \cos(0.21 - \text{atan}(Ry/Rx)) \quad \text{----- (2)}$$

All rotation offsets in this document have been calculated in the WFPC2 mosaic coordinate system (a 1600x1600 image). To determine the photometry error in linear ramp filters, these positions need to be transformed to the chip coordinate system.

A quick way to convert between the mosaic and individual chip coordinate systems is to use a 4-group WFPC2 image as a reference image -- the image must be an external (not an internal calibration target) so that the target RA and Dec values are properly populated in the header keywords CRVAL1 and CRVAL2.

### Procedure to Estimate Upper Limit of LRF Photometric Errors

1. Create a mosaic of that reference image using the task *wmosaic*. Use the tasks *metric*, *xy2rd*, and *rd2xy* to convert back-and-forth between (x,y,chip#) and (RA,DEC) for these two images.
2. For LRFs, wavelength regions are associated with specific positions in each chip. Convert the position for the wavelength at (x1,y1,chip#) to RA and DEC using the task *metric*.
3. Determine where that position would lie in a mosaic'd image by converting RA and DEC to the (x1<sub>m</sub>,y1<sub>m</sub>) position in the mosaic coordinate system, using the task *rd2xy*.
4. Use (x1<sub>m</sub>,y1<sub>m</sub>) to get the value of Rx and Ry where Rx=x<sub>m</sub>+1218 and Ry=y<sub>m</sub>-142. Then calculate the offsets using these equations:

$$\Delta x = c \cdot \sin \omega = c \cdot \sin(0.21 - \text{atan}(Ry/Rx))$$

$$\Delta y = c \cdot \cos \omega = c \cdot \cos(0.21 - \text{atan}(Ry/Rx))$$

Therefore, the position for the new LRF wavelength in the offset image, in the mosaic coordinate system is now:

$$x2_m = x1_m - \Delta x$$

$$y2_m = y1_m - \Delta y$$

5. Convert (x2<sub>m</sub>,y2<sub>m</sub>) in the mosaic coordinate system to the chip coordinate system (x2,y2,chip#): first use the task *xy2rd* on the mosaic'd image to get an RA and Dec, then find the chip position for that RA and Dec using *rd2xy*.

6. Using the LRF wavelength calculator at [http://www.stsci.edu/instruments/wfpc2/Wfpc2\\_lrf/wfpc2\\_lrfcalc.html](http://www.stsci.edu/instruments/wfpc2/Wfpc2_lrf/wfpc2_lrfcalc.html), get the wavelength values for (x1,y1) and (x2,y2).
7. Use the WFPC2 exposure calculator at [http://www.stsci.edu/instruments/wfpc2/Wfpc2\\_etc/wfpc2-etc.html](http://www.stsci.edu/instruments/wfpc2/Wfpc2_etc/wfpc2-etc.html), or *synphot*, to compute the object counts for your target at the two different wavelength regions obtained in (6). (Spectral tables for use with *synphot* can be retrieved from [http://www.stsci.edu/instruments/observatory/cdbs/astronomical\\_catalogs\\_alt.html](http://www.stsci.edu/instruments/observatory/cdbs/astronomical_catalogs_alt.html).)
8. The ratio of the counts in a particular LRF at (x1,y1), corresponding to a wavelength  $\lambda_1$ , and counts in (x2,y2), corresponding to  $\lambda_2$ , provide the percentage difference in counts to expect.

Two examples are presented below, one for a position in the WF2 (near the filter wheel rotation axis), and another one in WF4 (far from the filter wheel rotation axis), to illustrate two extremes in the errors as a result of distance from the filter wheel rotation axis.

### Example 1

Determine the possible photometric errors for an object placed at the position (x1,y1,WF2) = (684,645) that corresponds to 5015.14Å at the nominal FR533N18 filter position. The object is GRW+70D5824, an HST photometric standard white dwarf star of type DA3 and V = 12.77.

1. Using an arbitrarily-selected reference image with an external target, u5kl0101r.c0h, run *wmosaic* to create a mosaic'd version of that image.

```
wmosaic u5kl0101r.c0h u5kl0101r_mos.hhh
```

2. The wavelength area of interest is 5012.90 Å which corresponds to (694,643) in WF2 for the “unrotated” FR533N18 filter. Get the RA and Dec at that chip position.

```
metric u5kl0101r.c0h[2] 684 645
# METRIC version: 2.1 (Jun 1995)
# input file: u5kl0101r.c0h[2]
# centroid box size = 7 pixels
#x(raw) y(raw) x(cent) y(cent) x(geom) y(geom) x(meta) y(meta) RA Dec
684.00 645.00 684.00 645.00 682.48 643.78 682.48 643.78 13:11:31.7900 -1:18:54.367
```

3. Convert the RA and Dec values to (x1<sub>m</sub>,y1<sub>m</sub>) in the mosaic coordinate system.

```
rd2xy u5kl0101r_mos.hhh 13:11:31.7900 -1:18:54.367 hour+
X = 127.52, Y = 166.22
```

4. Compute the offsets that a  $0.42^\circ$  rotation could cause at that position:

$$\begin{aligned} R_x &= 127 + 1218 = 1345 \text{ pixels} \\ R_y &= 166 - 142 = 24 \text{ pixels} \\ R &= 1345.21 \text{ pixels} \\ c &= \sin(0.21) * 2R = 0.0037 * 2R = 9.86 \text{ pixels} \\ \omega &= 0.21 - \text{atan}(R_y/R_x) = 0.21 - 1.022 = -0.81^\circ \\ \Delta x &= c * \text{Sin}(\omega) = -0.14 \text{ pixels} \\ \Delta y &= c * \text{Cos}(\omega) = 9.86 \text{ pixels} \\ \text{Therefore,} \\ x_{2m} &= x_{1m} - \Delta x = 127.52 - (-0.14) = 127.66 \\ y_{2m} &= y_{1m} - \Delta y = 166.22 - 9.86 = 156.36 \end{aligned}$$

5. Convert the positions in the mosaic coordinate system to the WF2 coordinate system.

**xy2rd u5kl0101r\_mos.hhh 127.66 156.36 hms+**  
 RA = 13:11:31.8373, Dec = -1:18:53.687

**rd2xy u5kl0101r.c0h[2] 13:11:31.8373 -1:18:53.687 hour+**  
 X = 682.34, Y = 653.64

Therefore,  $(x_2, y_2) = (682, 654)$  in WF2.

6. Using the LRF wavelength calculator:

At  $(x_1, y_1) = (684, 645)$  in WF2, using FR533N18,  $\lambda_1 = 5015.14 \text{ \AA} \pm 5 \text{ \AA}$ .

At  $(x_2, y_2) = (682, 654)$  in WF2 using FR533N18,  $\lambda_2 = 5016.14 \text{ \AA} \pm 5 \text{ \AA}$ .

(Note: the LRF wavelength calculator states that the wavelength mapping of the filters is accurate to about  $5 \text{ \AA}$ )

7. Calculate the countrate for GRW+70D5824 at these two positions/wavelengths, where the table grw\_70d5824\_012.fits contains the spectrum of the star, and can be downloaded from <http://www.stsci.edu/instruments/observatory/cdbs/calobs.html>.

```
calcpht "wfpc2,2,lrf#5015.1,a2d7" grw_70d5824_012.fits counts
Mode = band(wfpc2,2,lrf#5015.1,a2d7)
Pivot   Equiv Gaussian
Wavelength   FWHM
5015.521    57.7925 band(wfpc2,2,lrf#5015.1,a2d7)
Spectrum: /data/cdbs2/calobs/grw_70d5824_012.fits
VZERO      (COUNTS s^-1 hstarea^-1)
0.         196.397
```

```

calcpht "wfpc2,2,lrf#5016.1,a2d7" grw_70d5824_012.fits counts
Mode = band(wfpc2,2,lrf#5016.1,a2d7)
Pivot   Equiv Gaussian
Wavelength   FWHM
5016.523    57.80952  band(wfpc2,2,lrf#5016.1,a2d7)
Spectrum: /data/cdbs2/calobs/grw_70d5824_012.fits
VZERO      (COUNTS s^-1 hstarea^-1)
0.         196.7272
    
```

The percentage difference between counts at these two wavelengths is 0.17%, well below WFPC2 photometric uncertainties.

**Example 2:**

Determine the possible photometric errors for an object placed at the position  $(x_1, y_1, WF4) = (720, 737)$  that corresponds to  $3714.59 \text{ \AA}$  at the nominal FR418N filter position. The object is GRW+70D5824, an HST photometric white dwarf standard star of type DA3 and  $V = 12.77$ .

1. Using an arbitrarily-selected reference image with an external target, `u5kl0101r.c0h`, run `wmosaic` to create a mosaic'd version of that image.

```
wmosaic u5kl0101r.c0h u5kl0101r_mos.hhh
```

2. The wavelength area of interest is  $3714.59 \text{ \AA}$  that corresponds to  $(720, 737)$  in WF4 for the "unrotated" FR418N filter. Get the RA and Dec at that chip position.

```

metric u5kl0101r.c0h[4] 720 737
# METRIC version: 2.1 (Jun 1995)
# input file: u5kl0101r.c0h[4]
# centroid box size = 7 pixels
#x(raw) y(raw) x(cent) y(cent) x(geom) y(geom) x(meta) y(meta) RA      Dec
720.00 737.00 720.00 737.00 717.61 734.32 -610.57 -670.01 13:11:31.6039 -1:21:57.850
    
```

3. Convert the RA and Dec values to  $(x_{1_m}, y_{1_m})$  in the mosaic coordinate system.

```

rd2xy u5kl0101r_mos.hhh 13:11:31.6039 -1:21:57.850 hour+
X = 1420.56, Y = 1480.01
    
```

4. Compute the offsets that a  $0.42^\circ$  rotation could cause at that position:

```

Rx = 1420.56+1218 = 2638.56 pixels
Ry = 1480.01 -142 = 1338.01 pixels
R = 2958.42 pixels
c = sin(0.21) * 2R = 0.0037 * 2R = 21.89pixels
 $\omega = 0.21 - \text{atan}(Ry/Rx) = 0.21 - 26.88 = -26.68^\circ$ 
    
```

$$\Delta x = c * \sin(w) = -9.83 \text{ pixels}$$

$$\Delta y = c * \cos(w) = 19.56 \text{ pixels}$$

Therefore,

$$x_{2m} = 1420.6 - (-9.83) = 1430.43$$

$$x_{2m} = 1480 - 19.56 = 1460.44$$

- Convert the positions in the mosaic coordinate system to the WF2 coordinate system.

**xy2rd u5kl0101r\_mos.hhh 1430 1460 hms+**

RA = 13:11:31.7425, Dec = -1:21:57.119

**rd2xy u5kl0101r.c0h[4] 13:11:31.7425 -1:21:57.119 hour+**

X = 727.01, Y = 714.35

Therefore, (x<sub>2</sub>,y<sub>2</sub>) = (727,714) in WF4.

- Using the LRF wavelength calculator:

At (x<sub>1</sub>,y<sub>1</sub>) = (720,737) in WF4, using FR418N,  $\lambda_1 = 3714.59 \text{ \AA} \pm 5 \text{ \AA}$ .

At (x<sub>2</sub>,y<sub>2</sub>) = (727,714) in WF4 using FR418N,  $\lambda_2 = 3713.51 \text{ \AA} \pm 5 \text{ \AA}$ .

- Calculate the countrate for GRW+70D5824 at these two positions/wavelengths, where the table grw\_70d5824\_012.fits contains the spectrum of the star, and can be downloaded from <http://www.stsci.edu/instruments/observatory/cdbs/calobs.html>.

**calcpHOT "wfpc2,4,lrf#3714.6,a2d7" grw\_70d5824\_012.fits counts**

Mode = band(wfpc2,4,lrf#3714.6,a2d7)

Pivot Equiv Gaussian

Wavelength FWHM

3714.767 42.04356 band(wfpc2,4,lrf#3714.6,a2d7)

Spectrum: /data/cdbs2/calobs/grw\_70d5824\_012.fits

VZERO (COUNTS s<sup>-1</sup> hstarea<sup>-1</sup>)

0. 14.59653

**calcpHOT "wfpc2,4,lrf#3713.5,a2d7" grw\_70d5824\_012.fits counts**

Mode = band(wfpc2,4,lrf#3713.5,a2d7)

Pivot Equiv Gaussian

Wavelength FWHM

3713.686 42.03662 band(wfpc2,4,lrf#3713.5,a2d7)

Spectrum: grw\_70d5824\_012.fits

VZERO (COUNTS s<sup>-1</sup> hstarea<sup>-1</sup>)

0. 14.24223

The percentage difference between counts at these two wavelengths is 2.43%.

## **Acknowledgements**

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## **References:**

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Linear Ramp Filter Calculator on the WFPC2 Webpage at STScI

[http://www.stsci.edu/instruments/wfpc2/Wfpc2\\_lrf/wfpc2\\_lrfcalc.html](http://www.stsci.edu/instruments/wfpc2/Wfpc2_lrf/wfpc2_lrfcalc.html)

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