# PHOTOMETRY WITH THE WFPC2

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**Abstract.** We present a practical guide for doing photometry with the WFPC2, with emphasis on determining a zeropoint, making various corrections to the data, and avoiding common problems. A specific example for a star in Omega Cen is provided. Using WFPC2 to obtain photometric accuracy of 5 – 10 % is now relatively easy. An accuracy of 2 – 5 % is possible if a few corrections are made.

**Key words:** WFPC2 – Photometry – SYNPHOT – Zeropoints

## 1. Introduction

Photometry means different things to different people. For some it means getting the most out of the data, right down to the 0.01 magnitude accuracy CCDs are capable of. For others this level of detail is overkill, and accuracies of 0.05 – 0.1 mag are perfectly adequate for their particular problem (e.g., photometry of low signal-to-noise objects). This paper attempts to provide information for both types of observers, starting with the basics that everyone will need (i.e., determining a zeropoint), including a section on various corrections you might want to consider, and then warning the observers about common problems that may arise. The paper concludes with a specific example of doing photometry for a star in Omega Cen.

## 2. Zeropoints

The zeropoint is the connection between the units found in your WFPC2 image (i.e., "counts" or "Data Number = DN"), and the astrophysically important quantities of flux or magnitudes.

The definition of the zeropoint is:

$$m = -2.5 \times log10(DN/EXPTIME) + ZEROPOINT$$

### 2.1 THREE APPROACHES TO DETERMINING YOUR ZEROPOINT

#### Approach # 1 –*Do it yourself*

If reliable photometry exists for objects in your field-of-view you may want to use it to calibrate your images, or at least check that your calibration is reasonable. The advantage of this approach is that the calibration targets are observed under exactly the same conditions. An example might be to use ground-based aperture photometry of a galaxy in your field to determine the zeropoint (using, for example, the PHOT task in the DAOPHOT or APPHOT packages), and then using this zeropoint to determine the magnitudes of star clusters around the galaxy. The main disadvantage of this technique is that *reliable* photometry may not be available for objects in your field.

### **Approach # 2** –*Use Holtzman et al. (1995b)*

Holtzman (1995b; hereafter Holtzman-2) has published an excellent summary of WFPC2 photometry. This includes zeropoints based on observations of Omega Cen for the five main broad band colors (i.e., F336W, F439W, F555W, F675W, F814W), as well as synthetic photometry for most of the other filters. Transformations from the WFPC2 filter set to UBVRI are included. The paper also includes a nice "cookbook" section describing in detail how to do photometry with WFPC2.

### **Approach # 3** – *Use Numbers in the Header (from SYNPHOT)*

The easiest way to determine your zeropoints is to simply pull the information out of the header that comes along with the image. The relevant keyword is PHOTFLAM, which is generated by SYNPHOT, a powerful synthetic photometry package that you may find useful for a wide range of photometric and spectroscopic analysis. The procedure for converting to a standard zeropoint is described below.

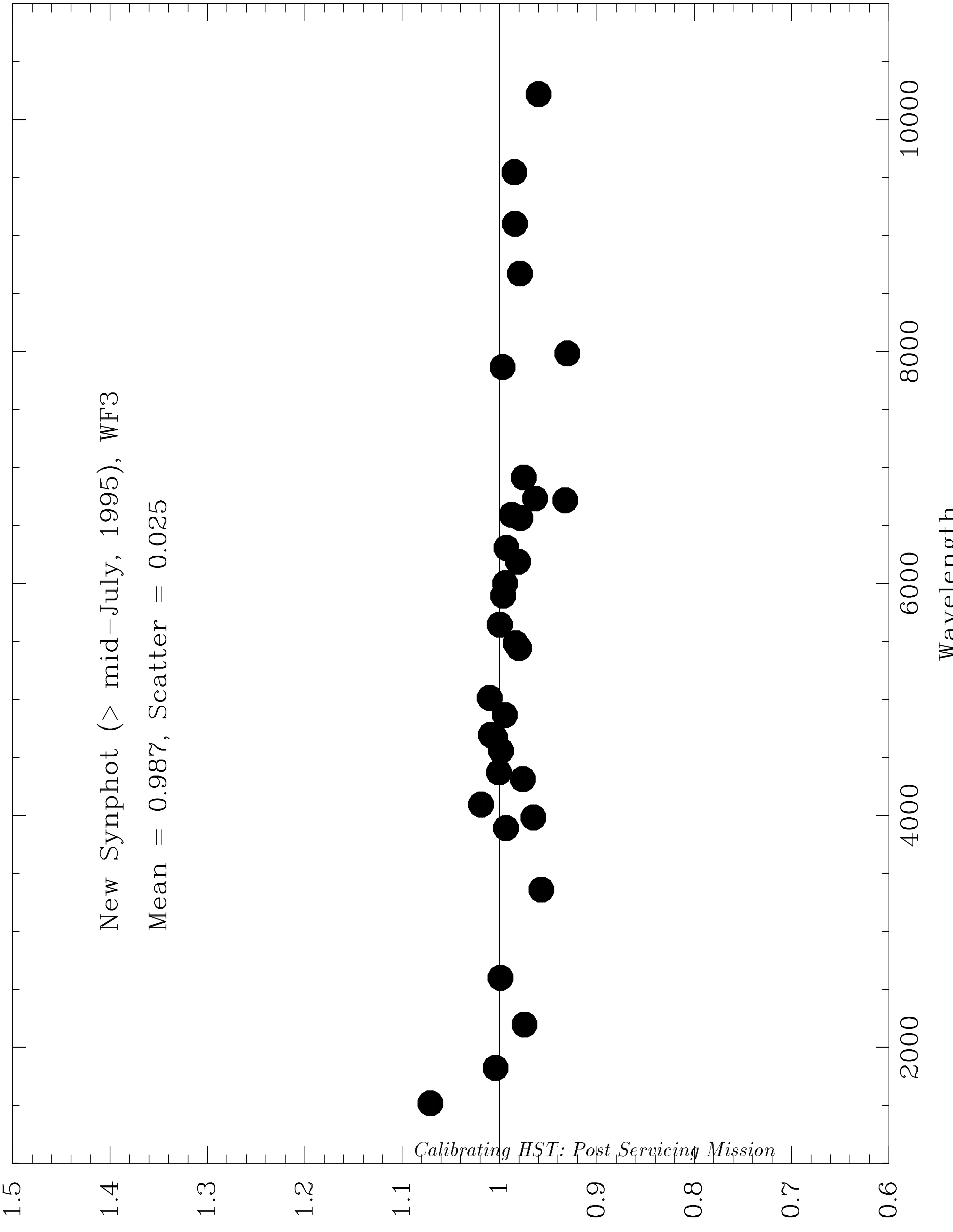
SYNPHOT was recently updated to match the numbers in Holtzman-2 and the WFPC2 Instrument Handbook (Version 3.0, June 1995: hereafter WFPC2-95). Figure 1 shows that SYNPHOT now provides accuracies of a few percent in nearly all cases, with a scatter of only 2 %. Previously, the scatter was about 8 % for most filters, with a few UV filters being considerably worse. Changes to values of PHOTFLAM range from +44 % (F160BW) to –18 % (F170W), with more typical values between +15 % to –5 % in the visible and infrared. Changes for the PC were similar, though generally somewhat less. If you have data taken before mid July 1995, and are using SYNPHOT to determine your zeropoint, you may want to use Table 1 to redetermine your zeropoint.

## 2.2 DETERMINING THE ZEROPOINT USING THE **PHOTFLAM** KEYWORD IN THE HEADER

The photometry information supplied in the header of the calibrated science data file (.c0h) can be used to determine your zeropoint. The equation for calculating a WFPC2 zeropoint is:

$$ZP_{STMAG} = -2.5 \times log10(PHOTFLAM) - 21.1$$

where PHOTFLAM is a keyword in the header of your image (i.e., the .c0h file; use the IMHEADER task to list the header).


New Synphot (> mid–July, 1995), WF3
Mean = 0.987, Scatter = 0.025
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
2000
4000
6000
8000
10000
Wavelength

**PREVIOUS PAGE: Figure 1.** Observed/Predicted counts for the September 1994 calibration observations of GRW+70d5829 using SYNPHOT.

A potential problem with this approach is that the resulting magnitude is in the STMAG system, which is based on a spectrum with constant flux per unit wavelength rather than the conventional system based on Vega's spectrum. Table 1 includes both the STMAG zeropoint, and the zeropoint for a more conventional magnitude system. Note that our values are roughly 0.85 mag larger than those in Holtzman-2. This is because his zeropoints are for the gain=14 setup (i.e., roughly $-2.5 \times \log10(2) = -0.75$ ), and assume a $0.5''$ radius aperture was used for the measurement (i.e., roughly $-0.10$ mag; Holtzman-1).

A further, generally small correction is needed if you wish to convert to a different filter system, such as the Johnson UBV or Cousins RI system. This correction depends on the spectrum of the object. Here is an example of how to use the SYNPHOT task CALCPHOT to transform from the F814W filter to the Cousins I band for a K0III star (from the Bruzual atlas; file = crgridbz77$bz_54) on WF3 using the gain=7 setting:

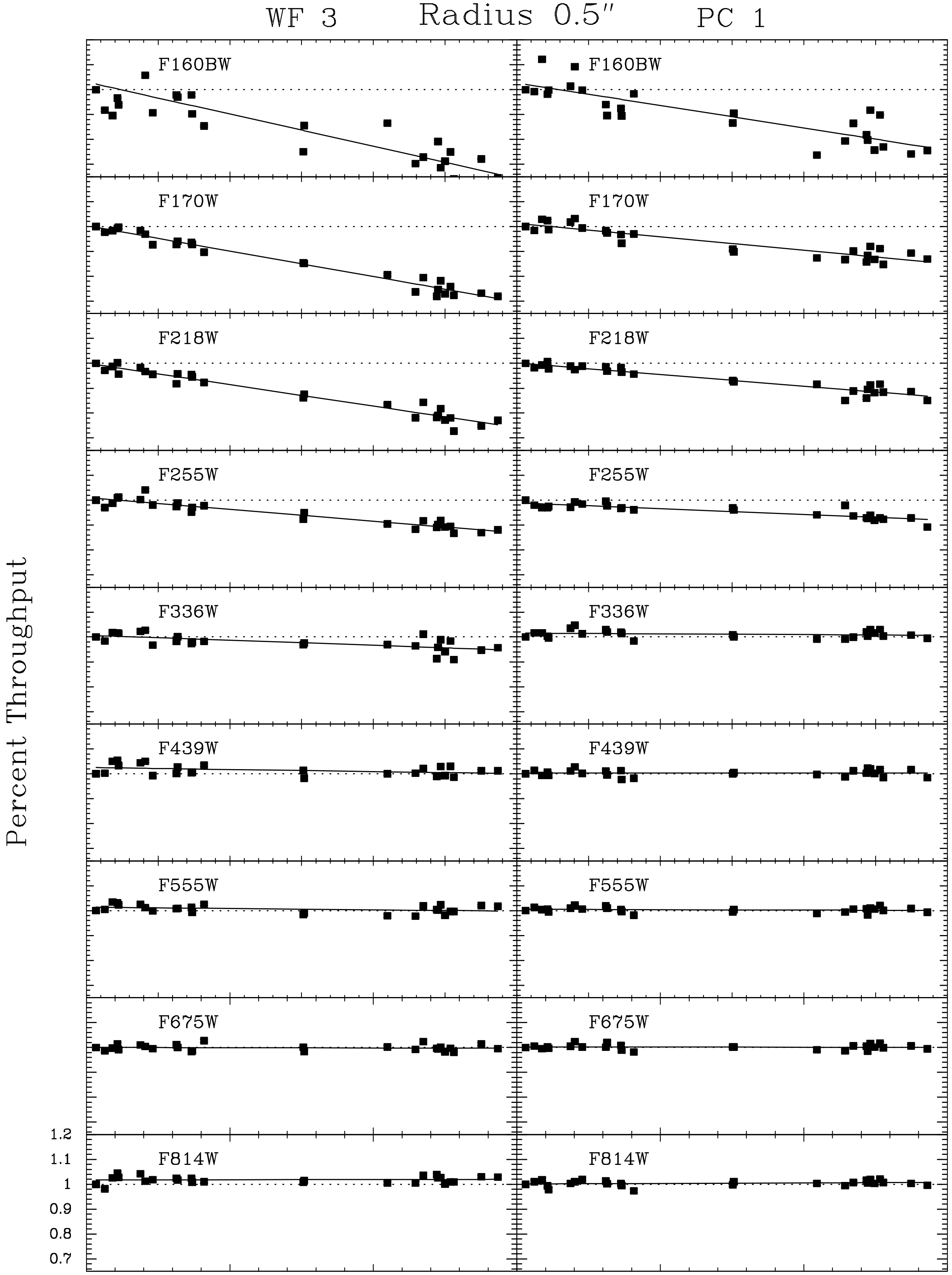
```
   calcphot "band(wfpc2,3,a2d7,f814W)" crgridbz77$bz_54 vegamag
calcphot "band(cousins,I)" crgridbz77$bz_54 vegamag
```

**NEXT PAGE: Table 1.** New values of PHOTFLAM and Zeropoints

| Filter | PHOTFLAM (Old) | PHOTFLAM (New) | ZP (STMAG) | ZP (Vega) |
|---|---|---|---|---|
| F160BW | 3.990 E-15 | 5.747 E-15 | 14.501 mag | 14.737 mag |
| F170W | 1.789 E-15 | 1.471 E-15 | 15.981 | 16.287 |
| F218W | 9.060 E-16 | 9.997 E-16 | 16.400 | 16.506 |
| F255W | 5.210 E-16 | 5.308 E-16 | 17.088 | 16.985 |
| F336W | 5.737 E-17 | 5.675 E-17 | 19.515 | 19.399 |
| F380W | 2.387 E-17 | 2.517 E-17 | 20.400 | 20.962 |
| F390N | 6.419 E-16 | 6.480 E-16 | 16.871 | 17.552 |
| F410M | 9.122 E-17 | 1.022 E-16 | 18.876 | 19.650 |
| F437N | 6.945 E-16 | 7.313 E-16 | 16.740 | 17.308 |
| F439W | 2.558 E-17 | 2.964 E-17 | 20.220 | 20.887 |
| F450W | 8.136 E-18 | 8.863 E-18 | 21.531 | 22.018 |
| F467M | 4.780 E-17 | 5.729 E-17 | 19.505 | 20.002 |
| F469N | 4.298 E-16 | 5.277 E-16 | 17.094 | 17.571 |
| F487N | 3.401 E-16 | 3.936 E-16 | 17.412 | 17.392 |
| F502N | 3.053 E-16 | 3.001 E-16 | 17.707 | 17.990 |
| F547M | 7.410 E-18 | 7.649 E-18 | 21.691 | 21.689 |
| F555W | 3.128 E-18 | 3.459 E-18 | 22.553 | 22.573 |
| F569W | 3.844 E-18 | 4.131 E-18 | 22.360 | 22.268 |
| F588N | 5.396 E-17 | 6.090 E-17 | 19.438 | 19.203 |
| F606W | 1.692 E-18 | 1.862 E-18 | 23.225 | 22.933 |
| F622W | 2.511 E-18 | 2.778 E-18 | 22.791 | 22.392 |
| F631N | 8.886 E-17 | 9.210 E-17 | 18.989 | 18.531 |
| F656N | 1.035 E-16 | 1.392 E-16 | 18.541 | 17.765 |
| F658N | 8.481 E-17 | 1.032 E-16 | 18.865 | 18.103 |
| F673N | 5.994 E-17 | 5.995 E-17 | 19.456 | 18.781 |
| F675W | 2.597 E-18 | 2.878 E-18 | 22.752 | 22.077 |
| F702W | 1.690 E-18 | 1.852 E-18 | 23.231 | 22.469 |
| F785LP | 4.792 E-18 | 4.740 E-18 | 22.211 | 20.739 |
| F791W | 2.814 E-18 | 2.905 E-18 | 22.742 | 21.554 |
| F814W | 2.399 E-18 | 2.480 E-18 | 22.914 | 21.688 |
| F850LP | 8.786 E-18 | 8.325 E-18 | 21.599 | 20.002 |
| F953N | 2.991 E-16 | 2.551 E-16 | 17.883 | 16.076 |
| F1042M | 1.973 E-16 | 1.936 E-16 | 18.183 | 16.309 |

NOTES:

1. Values are for WF3 using the gain=7 setup. For the other chips multiply PHOTFLAM by 0.9905 (PC1), 0.9985 (WF2), and 0.9746 (WF4), or add –0.010 (PC1), –0.002 (WF2), –0.028 (WF4) to the zeropoints, as derived from Table 5 below. You can also use the IMHEADER command to retrieve PHOTFLAM for each chip, or to determine PHOTFLAM for the gain=14 setup.



Used aperture radius of 0.5″

**PREVIOUS PAGE: Figure 2.** Degradation of throughput following each decontamination for the period from April 1994 to May 1995. An aperture with a $0.5''$ radius was used.

The calculation shows that a correction value of only –0.003 mag is needed to transform from F814W to Cousins I for K0III stars. Consult the Synphot User's Guide (Version 1.3.3; Bushouse 1995) for more details, and a wide variety of spectral catalogs.

For those wanting to convert to flux units rather than magnitudes, the conversion is simply:

$$FluxDensity = DN \times PHOTFLAM/EXPTIME$$

## 3. Photometric Corrections

An examination of the same star observed once a month in the F814W filter at the same position on the chip shows that the limiting stability of the WFPC2 is better than 1 %. Unfortunately, the following time- and position-dependent effects compromise this stability.

### 3.1 TIME VARIABILITY

#### *3.1.1 Contamination*

Figure 2 shows the effect of the buildup of contaminants following the monthly decontamination on the photometric throughput. While the effect is nearly negligible in the visible and near infrared, the effect in the UV is quite dramatic, reaching values of about 30 % after 30 days for the F160BW filter. Fortunately, the effect is both linear and stable, as shown in Figure 2, and it can therefore be removed using a simple linear interpolation based on the numbers in Table 2.

Note that only the PC1 and WF3 have been carefully monitored. All four chips will be monitored in Cycle 5. For the present, we recommend using the values for WF3 for the other WF chips. In addition, the contamination rate has only been monitored using a single star (a white dwarf) at a single position on the chip. We are currently examining observations of Omega Cen to determine how position on the chip, spectral type, and aperture size affects the results. The contamination rates reported in Table 2 use the standard $0.5''$ aperture, hence they are slightly different than the rates listed in WFPC2-95.

SYNPHOT can be used to determine the effect of contamination on your observations. For example, to compute the expected countrate for a WF3, F218W observation of GRW+70d5824 taken 20 days (MJD=49835.0) after the April 8,1995 decontamination, with the gain=7 setup, use:

```
calcphot "wfpc2,3,f218w,a2d15,cont#49835.0" spec=grw_70d5824_003.tab form=counts
```

Removing the `cont#49835.0` from the command will determine the countrate if no contamination was present.

See Holtzman-2 for values of the contamination rate before the April 24, 1994 cooldown.

TABLE 2
Contamination Rates per Day

| Filter | PC1 | WF3 |
|---|---|---|
| F160BW | 0.00902 ± 0.00112 | 0.01293 ± 0.00192 |
| F170W | 0.00540 ± 0.00047 | 0.01021 ± 0.00036 |
| F218W | 0.00468 ± 0.00032 | 0.00866 ± 0.00040 |
| F255W | 0.00233 ± 0.00028 | 0.00472 ± 0.00034 |
| F336W | 0.00031 ± 0.00030 | 0.00202 ± 0.00045 |
| F439W | 0.00000 | 0.00084 ± 0.00039 |
| F555W | 0.00000 | 0.00054 ± 0.00030 |
| F675W | 0.00000 | 0.0000 |
| F814W | 0.00000 | 0.0000 |

NOTES:

1. The correction for contamination has *not* been made to the image or to the value of PHOTFLAM in the header. This must be done manually.

2. Values of 0.00000 are assumed for cases where no statistically significant correlation is present.

TABLE 3
Decontamination Dates

| Year.Day:Hour:Sec | Month-Day-Year | MJD |
|---|---|---|
| 1994.114:01:22 | Apr-24-1994 | 49466.06 |
| 1994.144:00:08 | May-24-1994 | 49496.01 |
| 1994.164:17:35 | Jun-13-1994 | 49516.73 |
| 1994.191:18:13 | Jul-10-1994 | 49543.76 |
| 1994.209:13:45 | Jul-28-1994 | 49561.57 |
| 1994.239:16:19 | Aug-27-1994 | 49591.68 |
| 1994.268:07:19 | Sep-25-1994 | 49620.30 |
| 1994.294:07:14 | Oct-21-1994 | 49646.30 |
| 1994.323:18:02 | Nov-19-1994 | 49675.75 |
| 1994.352:06:33 | Dec-18-1994 | 49704.27 |
| 1995.013:16:47 | Jan-13-1995 | 49730.70 |
| 1995.043:02:27 | Feb-12-1995 | 49760.10 |
| 1995.070:15:03 | Mar-11-1995 | 49787.63 |
| 1995.098:11:02 | Apr-08-1995 | 49815.46 |
| 1995.127:01:46 | May-07-1995 | 49844.07 |
| 1995.153:19:03 | Jun-02-1995 | 49870.79 |
| 1995.178:20:33 | Jun-27-1995 | 49895.86 |

### *3.1.2 April 24, 1994 Cooldown*

The temperature of the WFPC2 was lowered from –76 C to –88 C on April 24, 1994, in order to reduce the level of hot pixel production and minimize the CTE problem. Besides increasing the contamination rates (see above) this also improved the photometric throughput, especially in the UV. Note that PHOTFLAM and the zeropoints in Table 1 are for post-cooldown observations.

TABLE 4
Pre-cooldown Throughput Relative to Post-cooldown

| Filter | PC | (mag) | WF | (mag) |
|---|---|---|---|---|
| F160BW | 0.865 | –0.157 mag | 0.895 | –0.120 mag |
| F170W | 0.910 | –0.102 | 0.899 | –0.116 |
| F218W | 0.931 | –0.078 | 0.895 | –0.120 |
| F255W | 0.920 | –0.091 | 0.915 | –0.096 |
| F336W | 0.969 | –0.034 | 0.952 | –0.053 |
| F439W | 0.923 | –0.087 | 0.948 | –0.058 |
| F555W | 0.943 | –0.064 | 0.959 | –0.045 |
| F675W | 0.976 | –0.026 | 0.962 | –0.042 |
| F814W | 0.996 | –0.004 | 0.994 | –0.007 |

NOTES

1. The value in magnitudes should be added to the zeropoint for observations taken before April 24, 1994. A typical uncertainty in these values is 0.006 mag.

### *3.1.3 "Breathing"*

As the thermal load on the spacecraft varies during an orbit the focus also changes slightly, at a level corresponding to about a 5 micron movement of the secondary. This effect has been termed "breathing". This may result in small changes to the aperture correction. The effect has not been quantified yet, but is generally negligible unless an extremely small aperture (e.g., 1 pixel) is used.

### *3.1.4 Focus Change Due to Desorption*

The focus changes by about 0.85 microns per month as a result of desorption of water from the OTA. The secondary is moved roughly twice a year to keep the focus within 2.5 microns of the optimal value. This effect is negligible in nearly all cases, and is generally smaller than the "breathing".

### *3.1.5 Jitter*

The jitter caused by movement in the solar arrays following a transition from night-to-day or day-to-night has been greatly reduced by the installation of new solar arrays during the refurbishment mission. However, it is still possible that jitter may occasionally cause some degradation of the PSF, and hence affect the aperture corrections if very small apertures are used. Observatory Monitoring System files (OMS), including information about the jitter have been included with data sent to observers since Spring 1995. OMS files for observations before this time are available by contacting `help@stsci.edu`.

## 3.2 POSITIONAL DEPENDENCIES

### *3.2.1 Charge Transfer Efficiency (CTE) Problem*

Shortly after launch it was discovered that WFPC2 had a severe charge transfer efficiency problem, in the sense that objects appeared to be 10 – 15 % fainter when observed at the top of the chip compared to when they were observed at the bottom of the chip (Holtzman-1). The April 24, 1994, cooldown reduced the CTE problem to about a 4 % effect peak-to-peak (Holtzman-2). The effect appears to be smaller, or nonexistent, in the presence of a moderate background. A simple linear ramp provides an approximate correction, reducing the peak-to-peak deviations to 1 – 2 %. For observations after the cooldown, ignoring CTE when doing photometry of a random set of bright stars affects the scatter at the 0 to 1.5 % level. New calibration observations are being made in Cycle 5 to characterize the effect more precisely, and determine whether a preflash can minimize or remove it.

### *3.2.2 Edge Effects*

The beam is still aberrated when it hits the pyramid, hence light from a star along the edge will go into both cameras. This is about a 10 % effect at $1''$ from the edge and 1 % at $2''$. The flat field attempts to correct for this, but may be in error by a few percent at the edge.

### *3.2.3 Geometrical Distortion*

Geometrical distortion near the edges of the chips results in a change of the surface area covered by each pixel. The flatfielding corrects for this so that surface photometry is unaffected. However, this means that integrated point-source photometry using a fixed aperture *will* be affected. This introduces a 1 – 2 % effect near the edges with a maximum of about 4 – 5 % in the corners. A correction image has been produced by Holtzman-2 and is available from the archives (f1k1552bu.r9h), or from the WWW at:
`http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_phot`.

### *3.2.4 Aperture Corrections*

Aperture corrections may vary with position due to changes in the PSF. This has not yet been quantified, but is generally only an issue for very small apertures (e.g., < 2 pixels).

### *3.2.5 Different Sensitivities for the Four Chips*

The flat fields have been determined using the gain=14 setup, with the centers of the chips [200:600,200:600] all normalized to 1.000. However, most science observations are taken using the gain=7 setup, where the flats have not been normalized and each chip therefore has a slightly different sensitivity. The count ratios for the different chips from Holtzman-2 are listed in Table 5. These should be included in your zeropoint calculation if using values from Holtzman-2.

If you use the value of PHOTFLAM from the header to determine your zeropoint, the different gains for the different chips will already be included. Remember to use the new PHOTFLAM values provided in Table 1; those included in the header for data taken before mid July 1995 will have less accurate values.

TABLE 5
Count Ratios Between the Gain=7 and Gain=14 Setups

| PC1 | WF2 | WF3 | WF4 |
|---|---|---|---|
| 1.987 | 2.003 | 2.006 | 1.955 |

NOTES
1. These are for gain=7 / gain=14. The uncertainty in these values is about 1 %.

#### *3.2.6 Pixel Centering*

The position of an object on a pixel (i.e., centered on the middle of a pixel or near the corner), can introduce a scatter of about 1 % level for a $0.5''$ radius aperture (Holtzman-2).

## 4. Miscellaneous Problems

### 4.1 Aperture Corrections

It is difficult to directly measure total magnitude with the WFPC2 due to the extended wings of the PSF, scattered light, and the small pixel size. A more accurate method is to measure the light within a smaller aperture and then apply an offset to determine the total magnitude if that is necessary. A standard aperture radius of $0.5''$ has been adopted by Holtzman-2 (note that Holtzman-1 used a value of $1.0''$), and by the WFPC2 group at STScI. Even smaller apertures are better for faint point sources. An aperture radius of 2 – 3 pixels for stars, with a background annulus around 10 – 15 pixels, has been found to be near optimal for simple aperture photometry of faint point sources by several groups.

Aperture corrections can be determined using Table 2 from Holtzman-1, or by measuring them from your own image if there are well exposed stars in your field of view.

Another method of doing photometry is PSF fitting, as employed by programs such as DAOPHOT (Stetson 1987). This can be especially useful in crowded fields with overlapping PSF's.

## 4.2 Transformations to UBVRI (Color Terms)

In some cases it may be necessary to transform from the WFPC2 filter set to more conventional filters (e.g., Johnson UBV or Cousins RI) in order to make comparisons with other data sets.

The accuracy of these transformations is determined by how closely the WFPC2 filter matches the conventional filter and by how closely the spectral type (e.g., color, metallicity, surface gravity) of the object matches the spectral type of the calibration observations. Accuracies of 1 – 2 % are typical for many cases, but much larger uncertainties are possible for certain filters (e.g., F336W with a redleak), and for certain spectral types (e.g., very blue stars). Transformations can be determined by using SYNPHOT, or by using the transformation coefficients in Holtzman-2.

## 4.3 Digitization Noise

The quantized nature of the pixel values adds noise to the signal, and can also result in subtle systematic errors. The most straightforward effect is that it adds a 0.5 DN peak-to-peak uncertainty to each pixel value.

A more subtle effect is that the mean and median may be systematically offset from each other. For example, if half the background counts are near 1 (there is actually a small spread due to the flatfielding) and the other half are near 2, the mean would be 1.5 but the median would be either 1 or 2, since there are no values at 1.5 for the median to register. Hence, while using a median might be a good way to help filter out objects that fall within the background annulus in crowded fields, it can cause a systematic error. This can easily be several percent or even larger if an especially large object aperture is used. It is generally safer to use the mean, though care must then be taken to remove objects in the background annulus.

An even more subtle effect is that some statistics programs assume Gaussian noise characteristics when computing properties such as the “median” and “mode”. Quantized noise can throw these estimates all over the map.

## 4.4 Red Leaks

Several of the UV filters have substantial red leaks that may affect the photometry. For example, the “U” filter (F336W) has a transmission at 7500 Å that is only about a factor of 100 less than at the peak transmission at about 3500 Å (see Figure 6.2 in WFPC2-95). The increased sensitivity of the CCDs in the red, coupled with the fact that most sources are brighter in the red, makes this an important problem in many cases. SYNPHOT, or Table 6.5 in WFPC2-95, can be used to estimate the effect of the red leak.

## 4.5 Charge Transfer Traps or Pixel Defects

There are about 30 pixels with macroscopic charge transfer traps, where as little as 20 % of the electrons are transferred during each time step during the readout. These defects result in “bad pixels”, or in the worst cases, “bad columns”, and are not to be confused with microscopic charge traps which are believed to be the cause of the CTE problem. The traps result in dark tails just above the bad pixel, and bright tails for objects farther above the bad pixel that get clocked out through the defect during the readout.

The tails can cause large errors in photometric and astrometric measurements. In a random field, about 1 out of 100 stars are likely to be affected. Using a program which interpolates over bad pixels or columns (e.g., WFIXUP or FIXPIX) to make a cosmetically better image can result in very large (e.g., tenths of magnitude) errors in the photometry in these rare cases.

The data quality file (.c1h) sent to observers along with their data was updated in July 1995 to include 3 previously unidentified traps. In addition, two regions of the affected columns were flagged. The region just above the defect, where the image is always affected, is flagged with a value of 2 for "defect". The region farther above the trap, where point sources are affected but diffuse sources are not, is flagged with a value of 256 for "questionable pixel". In addition, the WFIXUP task was modified to allow the user to set a switch to define which flag values to mask in the image. See Instrument Science Report WFPC2 95-03 for more details.

### 4.6 SERIAL CLOCKS

The serial clocks option (i.e., the optional parameter CLOCKS = YES in the proposal instructions) is occasionally useful when an extremely bright star is in the field of view, in order to minimize the effects of bleeding. However, when using this option the shutter open time can have errors of up to 0.25 seconds. In addition, if a non-integral exposure time is specified in the proposal it will be rounded to the nearest second, and the exposure time listed in the header information will be incorrect. See §2.6 in WFPC2-95 for more details.

## 5. An Example: Measuring the Magnitude of a Star in Omega Cen

This example shows the steps involved in measuring the magnitude of the star # 1461 (Harris, 1993) in the Cousins I passband. The image used for this example can be obtained from the HST archives, or from the WWW at:

`http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_phot`

This WWW directory contains the materials for Instrument Science Report WFPC2-04 – *A Demonstration Analysis Script for Performing Aperture Photometry.* Table 6 show the results from an analysis script similar to ISR WFPC2-04, but including some of the corrections discussed above.

## TABLE 6
Measuring the Magnitude of Star # 1461 in Omega Cen

Images: u2g40o09t.c0h[1] and u2g40o0at.c0h[1]
Position: (315.37,191.16)
Filter: F814W
Exposure Time: 14 seconds
Date of observation: MJD = 49763.4

| Value | Description |
|---|---|
| 2113.49 counts | Raw counts in 0.5″ radius aperture (11 pixels for the PC). |
| –13.49 = 2100.00 counts | Background subtraction (0.03544 counts × 380.522 pix$^2$). |
| × 0.9915 = 2082.15 counts | Correction for geometrical distortion. Not needed if doing surface photometry. |
| ⇒ 15.512 mag | Raw magnitude (= –2.5 × log10(2082.15 / 14 sec) + 20.943) NOTE: –2.5 × log10(1.987) has been added to the zeropoint from Table 1, since these calibration observations were taken using the gain=14 setup (see Table 5). This also corrects for the position on PC1. Hence the zeropoint is 21.688 - 0.745 = 20.943 mag). Most science observations are taken with gain=7, so the zeropoint would be 21.688 - 0.010 = 21.678 mag, where -0.010 corrects for the position on the PC (see Notes to Table 1). |
| – 0.10 = 15.412 mag | Aperture correction estimated from Holtzman-1 (Table 2a). |
| – 0.016 = 15.396 | CTE correction (–0.04 × 315 / 800; assuming a 0.04 mag linear ramp and Y position of 315). |
| – 0.000 ⇒ $m_{F814W}$ = 15.396 | Contamination correction (0.000 × [49763.4 - 49760.1]; from Tables 2 and 3). |
| – 0.003 ⇒ $m_I$ = 15.393 mag | Transformation to Cousins I passband (see §2.2). |

Our measurement of $m_{F814W}$ = 15.396 mag for star # 1461 is in fair agreement with Harris (1993), who measures $m_{F814W}$ = 15.348 mag. The agreement in $m_{F555W}$ is even better, with our measurement being 16.348 mag and Harris at 16.359 mag.

## 6. SUMMARY

It is now relatively easy to obtain WFPC2 photometric accuracies of 5 – 10 %, and possible to reach accuracies of 2 – 3 % if a few corrections are made. Our ultimate goal is to achieve accuracies of about 1 % for the major filters. The primary limiting factors at present are contamination effects (mainly in the UV), the CTE problem, flat field accuracy, and transformations to other passbands. Our Cycle 5 calibration plan is designed to address these problems.

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