

## The WFPC Calibration Pipeline

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### Abstract

We review the basic functions of, and major changes to, the WFPC calibration pipeline. Known bugs and errors are described. Finally, we summarize situations where later re-calibration might give some improvement over the pipeline calibration.

### I. Introduction

The purpose of the WFPC calibration pipeline is to provide an initial calibration of data immediately after each observation is made. The level of calibration is that which is *routinely available at the time of the observation*. The necessity of calibrating every frame in near real time means that little consideration can be given to the science goals of each individual proposal. Observers with unusual programs, or with programs requiring an extremely accurate calibration, may find they need to tailor the calibration to their individual science goals. Furthermore, the calibration algorithms and reference files are routinely updated, so there will be many situations where later re-calibration gives a better result than could be obtained immediately after the observation.

### II. Post-Observation Processing and the Calibration Pipeline

There are many important data processing steps which lead up to the actual pipeline calibration. We briefly summarize the more prominent ones here. After readout of the WFPC CCDs, the data initially reside on one of two tape recorders on-board the *HST*. At pre-scheduled times a high baud rate forward link is established between *HST* and a TDRSS satellite, and the tape recorder is then dumped via TDRSS to a ground station at White Sands, NM. The data are recorded there, and then transmitted to STScI via NASCOM satellite. The data arrive at STScI in the form of packets of spacecraft data, wherein the WFPC images are interspersed with other *HST* telemetry, data from other science instruments, and the like.

The Post-Observation Data Processing System (PODPS) assembles raw WFPC images from the spacecraft packets. An assembled raw WFPC data set consists of several headers and data files whose type are indicated by the file name suffix, as shown in Table 1.

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**Table 1: File Name Convention for WFPC Data**

Suffix	File Contents	Size (Data Type)
.D0H	Raw image header	(ASCII)
.D0D	Raw image	800x800x4 pixels (I*2)
.Q0H	Data quality file for raw image header	(ASCII)
.Q0D	Data quality file (DQF) for raw image	800x800x4 pixels (I*2)
.X0H	Raw engineering data header	(ASCII)
.X0D	Raw engineering data (includes CCD overscan columns)	14x800x4 pixels (I*2)
.Q1H	DQF for raw engineering data (header)	(ASCII)
.Q1D	DQF for raw engineering data	14x800x4 pixels (I*2)
.SHH	Standard header packet	(ASCII)
.SHD	Standard header packet binary data	965 (I*2)

Each data set is named with a unique prefix which contains an encoded proposal number, spacecraft alignment number, and exposure number. For example, a file name W13L0103t.D0D indicates: W = WFPC data; 13L = sequential executed proposal number encoded in base 36; spacecraft alignment number 01 for this proposal; frame number 03 of this alignment; 't' indicates data path (i.e. tape recorder); and finally .D0D indicates the file contains a raw image.

Once the raw files are assembled, PODPS sets a number of keyword parameters in the header files (.D0H files) which control the pipeline calibration. These parameters include YES / NO switches, as well as the names of the calibration files to be used. Table 2 shows an excerpt of a .D0H header file prepared for calibration.

**Table 2:** Example of calibration control header keywords in a .D0H file. Note the suffixes on the reference file names (e.g. .r0h) which are specific to each file type.

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Keyword = Value / Explanation
MASKCORR= 'YES ' / Do mask correction: YES, NO, DONE
ATODCORR= 'YES ' / Do A-to-D correction: YES, NO, DONE
BLEVCORR= 'YES ' / Do bias level correction: YES, NO, DONE
BIASCORR= 'NO ' / Do bias correction: YES, NO, DONE
PREFCORR= 'NO ' / Do preflash correction: YES, NO, DONE
PURGCORR= 'NO ' / Do purge correction: YES, NO, DONE
DARKCORR= 'NO ' / Do dark correction: YES, NO, DONE
FLATCORR= 'NO ' / Do flat field correction: YES, NO, DONE
DOSATMAP= 'NO ' / Output Saturated Pixel Map: YES, NO, DONE
DOPHOTOM= 'NO ' / Fill photometry keywords: YES, NO, DONE
DOHISTOS= 'NO ' / Make histograms: YES, NO, DONE
OUTDTYPE= 'REAL ' / Output image datatype: REAL, LONG, SHORT
MASKFILE= 'bb615191w.r0h' / name of the input DQF of known bad pixels
ATODFILE= 'c2614032w.r1h' / name of the A-to-D conversion file
BLEVFILE= 'wcal$w13l0103t.x0h' / Engineering file with extended register data
    
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BLEVDFIL= 'wcal$w13l0103t.q1h' / Engineering file DQF
BIASFILE= 'wref$c261403gw.r2h' / name of the bias frame reference file
BIASDFIL= 'wref$c261403gw.b2h' / name of the bias frame reference DQF
PREFFILE= 'wref$c8e0939jw.r3h' / name of the preflash reference file
PREDFIL= 'wref$c8e0939jw.b3h' / name of the preflash reference DQF
PURGFILE= 'wref$9ck1027hw.r4h' / name of the purge reference file
PURGDFIL= 'wref$9ck1027hw.b4h' / name of the purge reference DQF
DARKFILE= 'wref$c5t10337w.r5h' / name of the dark reference file
DARKDFIL= 'wref$c5t10337w.b5h' / name of the dark reference DQF
FLATFILE= 'wref$a1b0845dw.r6h' / name of the flat field reference file
FLATDFIL= 'wref$a1b0845dw.b6h' / name of the flat field reference DQF
PHOTTAB = 'wtab$c7e13087w.cw0' / name of the photometry calibration table
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Once the .DOH header is properly set, PODPS performs the actual calibration by running the program CALWFP. This is identical to the CALWFP program in the STSDAS package, so observers can perform the same calibration outside the STScI pipeline.

### III. Major CALWFP Pipeline Operations

We now describe the individual calibration steps which can be performed by the pipeline. The normal situation is to perform nearly all these steps. But observers can choose to perform only a subset by setting the appropriate switches to “NO” in the .DOH file and running CALWFP again. The steps are: mask correction, A-to-D correction, bias level subtraction, bias image subtraction, preflash subtraction, CTE correction, residual image correction, dark current subtraction, flat-field correction, and filling of the photometry keywords.

*Mask Correction.* This step merely marks known bad pixels in the data quality file (DQF) for the output image. It does not alter the data image itself.

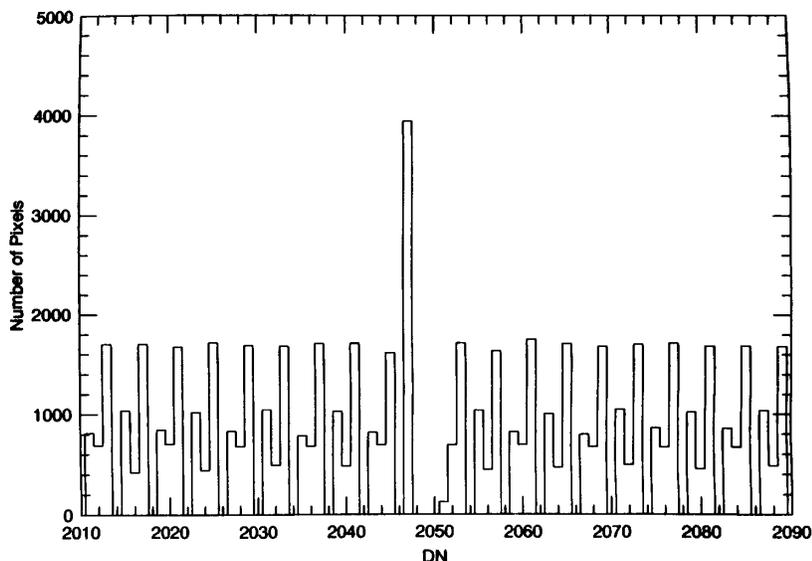


Figure 1. Histogram of digitized pixel values (DN). From Lauer 1992.

*A-to-D Correction.* A problem in the WFPC “sample and hold” circuitry causes stray signals to corrupt the analog-to-digital conversion process. The result is that some A-to-D converter bits fail to set, which causes a negative bias on the digital output values. The effects can be readily seen in a histogram of output digital values (Figure 1). Instead of a smooth, uniform distribution of digital values, some values are totally absent, while others occur much too often.

This problem impacts science data in two ways: First, many pixel values are systematically too low by an amount of order 1 DN. This can easily be corrected by reassigning pixel values to slightly higher values, and this is what is done during pipeline calibration. A simple look-up table is used to reassign the pixel values based on their raw values. Figure 2 illustrates this process. A second impact is that information regarding the true analog value has been lost, hence noise is effectively added to the data. This increased noise cannot be corrected.

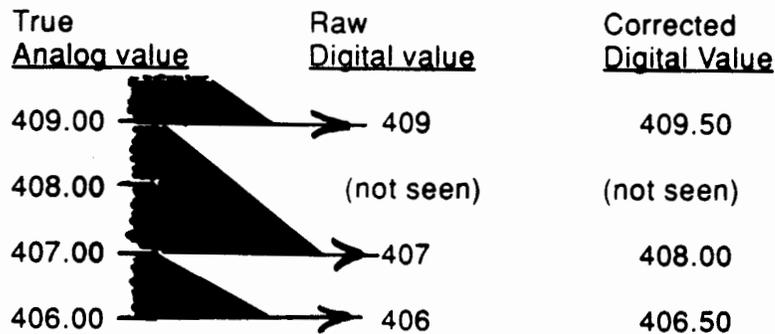


Figure 2: Example of A-to-D correction showing true analog values, raw digital values, and corrected digital values.

*Bias Level Subtraction.* The purpose of this step is to remove a uniform zero-level offset voltage, or bias level, from the images. The even and odd CCD columns have slightly different bias levels, the difference being about 1 DN. Early in the WFPC observation program it was noticed that this difference changes sign when the WFPC electrical power is interrupted (i.e. during hardware safemode events, etc.). Figure 3 illustrates typical bias levels as a function of CCD column for three different dates.

In February 1992 a change was implemented in the pipeline, wherein separate bias levels are determined, and applied to, the even and odd columns. The two levels are determined from the CCD overscan lines in the .X0D file for each data set. These levels are then subtracted from the image, and recorded in the .C0D file binary header keywords BIASODD and BIASEVEN for each image group (CCD), and may be examined with IRAF task IMHEAD. Note that the name of the header files, .X0H and .C0H, must be specified in IRAF to examine the .X0D and .C0D files, respectively.

*Bias Image Subtraction.* The purpose of this step is to remove small pixel-to-pixel variations in the zero level, or bias level, which is caused by the CCD readout electronics. Typical features in the bias image include high regions (up to 12 DN high) near the CCD edges; broad bars extending in the row direction on the CCDs which are ~0.05 DN high; and faint ripples with an amplitude of a few times 0.01 DN which are at a small angle to the CCD row direction. Features in the bias frames

have been very stable with time; exceptions are a small region in the corner of WF1 which has varied by  $\sim 0.1$  DN, and a few new hot pixels which are intense enough to appear in the bias frames.

The bias calibration image is an average of a number of  $\sim 43$  second exposures taken with the shutter closed. Early during operation of the pipeline, an average of 18 such on-orbit bias frames was used for calibration. In August 1993 an improved bias calibration image was installed which was the average of 47 on-orbit frames for the WF, and 43 for the PC. These improved bias calibration frames have an RMS noise of about 0.25 DN, and will reduce the noise contributed by calibration, which may be significant if large numbers of science data frames are averaged together.

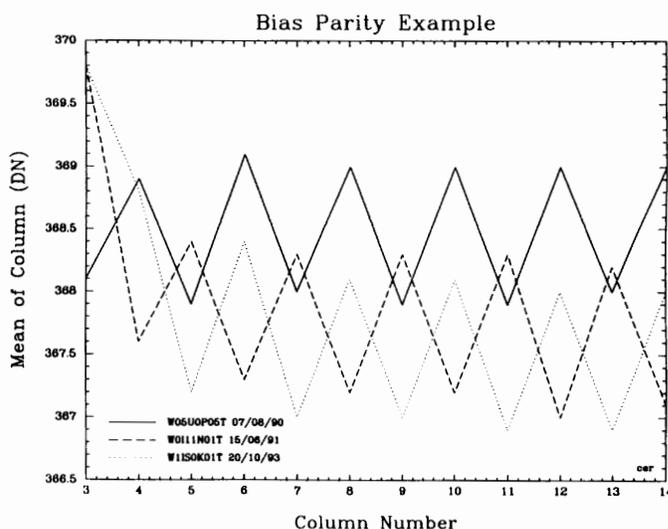


Figure 3: Bias level (in DN) as a function of column number in three typical .X0H files. Observation dates are shown.

*Preflash Image Subtraction.* Faint images ( $< 200$  electrons per pixel) have poor charge transfer during readout, which causes tails to appear on images in the column direction. To reduce this effect, images can be preflashed with a small amount of light using faint lamps shining on the back of the WFPC shutter blades. Typically images are preflashed to about 50 electrons per pixel, which is sufficient to reduce the tails while only slightly increasing the noise. The purpose of preflash calibration is to remove this faint illumination pattern from the science images.

The preflash illumination pattern is fairly uniform, but does contain a number of features. These include a broad pattern from non-uniform illumination of the shutter blades, and large features associated with markings on the shutter blades. There are also small numbers of hot pixels which are sufficiently intense to appear during the minute or so it requires to perform the preflash. The preflash images have been quite stable, with only a broad region on PC5 showing variations  $\sim 0.04$  DN. There are also new hot pixels which appear over time. Since the preflash is performed with a  $\lambda = 1 \mu\text{m}$  filter in place (F1042M or F1083N), they are relatively immune to variations in contamination and quantum efficiency.

The images used to calibrate and remove the preflash pattern are averages of on-orbit preflash exposures made without opening the shutter. Separate calibration images are made for the “A” and “B” shutter blades, since their reflectivities are slightly different. These calibration files are finally scaled to a preflash time (duration of preflash lamp being on) of 1 second.

The science data images are preflash calibrated by first deciding which shutter blade was in place during the preflash. This information is usually stored in the SHUTTER keyword of the .D0H header file by PODPS. (Otherwise it can be determined by running STSDAS tasks ENGEXTR on the .X0H file to construct an IRAF table, which is then displayed with TPRINT, also in STSDAS. Rows 85 and 86 of the table contain the SHUTOPNB and SHUTOPNA keywords, with “open” indicating that shutter was in place at the *start* of the exposure, and hence used for the preflash. This only applies to external observations with one exposure per CCD readout. For exposures of 300 seconds or longer taken before November 1993, it is not possible to determine the preflash shutter blade from the image header information. Instead, this must be determined from the shutter motion in exposures prior to the one in question. Statistically speaking, shutter B is most often used to preflash these exposures, and this is what the pipeline assumes in routine processing.) The correct reference file for that shutter is then multiplied by the preflash duration in seconds (PREFTIME header keyword), and the scaled reference file is finally subtracted from the science data. The preflash durations are 30 seconds for WF images, and 8 seconds for the PC format.

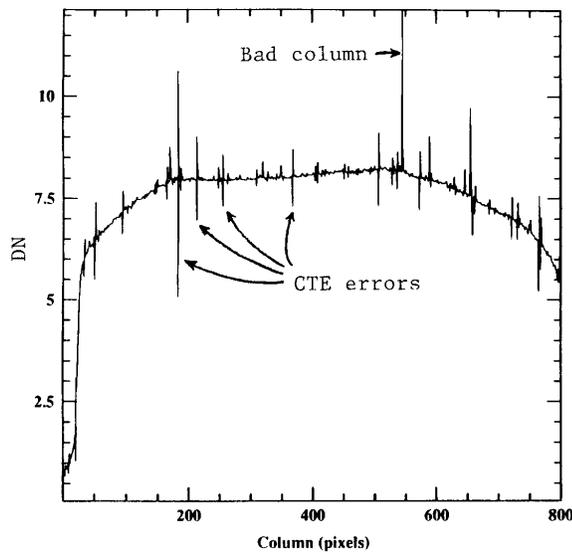


Figure 4: A preflash calibration file for WF1 which has been averaged along the columns, and which shows the typical pattern of adjacent low and high CCD columns.

For much of the WFPC history, the preflash calibration files were the averages of about 10 frames taken early in the mission. In August 1993 an improved, low-noise preflash calibration was installed. The improved WF calibration uses the average of 36 frames for the B shutter. For the A shutter, only 12 on-orbit frames were available, so a low-noise calibration reference file was constructed by using low spacial frequencies from the A blade, and high spacial frequencies from the B blade data.

The PC calibration frames were constructed in a similar manner. These improved files have about half the noise of the older files ( $\sim 0.35$  DN RMS), and will reduce the noise in situations where many science images are averaged together. We also removed the hot pixels, since they vary with time.

*Charge Transfer Error (CTE) Correction.* The WFPC CCDs have several columns where charge lags behind during the horizontal readout, due to charge transfer problems in the horizontal (or serial) readout register. These columns show a typical signature where the count levels are low by about 1 DN, with the following column being high by an equal amount. See Figure 4. The amount of charge which lags behind is insensitive to the exposure level, provided it exceeds a few DN, and is constant along the entire column.

For images which are preflashed, the preflash subtraction automatically corrects for this effect, since it is present in both the preflash calibration image and the science image. For images which are not preflashed, it is still useful to remove the column pattern caused by the CTE effect. In practice, the correction is derived from the preflash calibration images, by averaging along the columns, and then removing the broad illumination patterns, so that only column-to-column variations on scales of a few pixels remain. This correction is then stored in the first row of each preflash calibration frame. The CTE correction will be applied by the CALWFP when the control parameters are set as: PREFCORR = YES, PREFFILE = [normal preflash calibration file name], and PREFTIME = 0. For these settings, CALWFP will subtract the CTE correction from each image column, rather than the preflash image itself. This CTE correction is stored in the first row of the preflash reference file image.

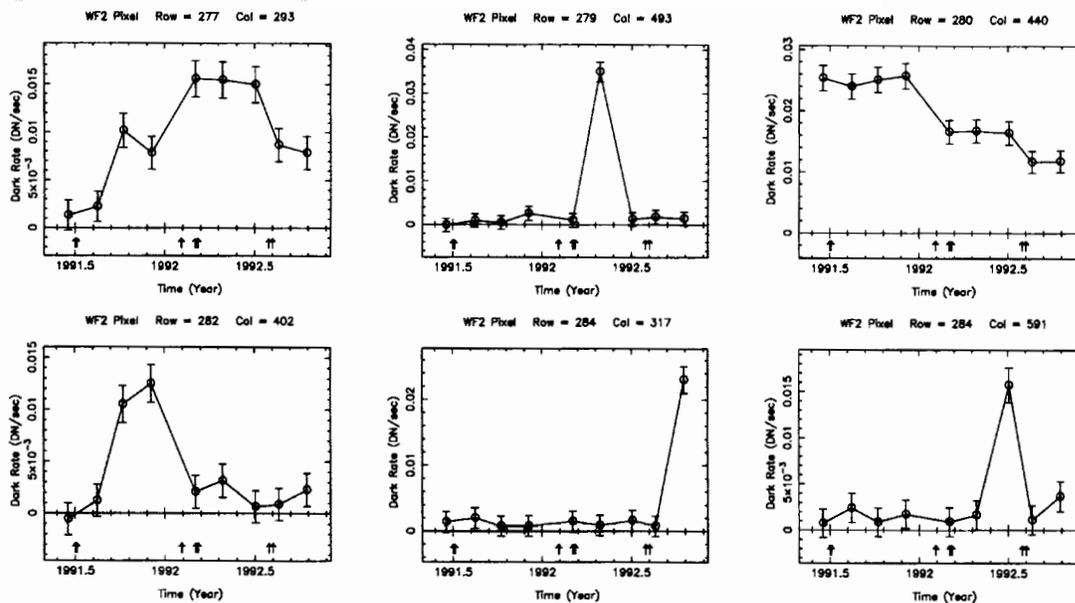


Figure 5: Evolution of dark count rate as function of year for six typical hot pixel pixels on CCD WF2. Vertical arrows indicate CCD decontaminations

Unfortunately, a bug in PODPS has caused PREFCORR to be set to NO for images which are not preflashed, so that, in effect, the CTE correction is never applied by the pipeline. Observers with non-preflashed images of faint targets may wish to perform the CTE correction themselves, by setting the preflash control parameters as above

in the .DOH files, and then running CALWFP again on their data.

*Residual Image Correction.* The pipeline contains a facility for removing residual images caused by prior over-exposures of the CCDs. This feature has not been used, both because the CCDs are operated above the originally proposed temperature, and because the spherical aberration has resulted in fewer extreme over-exposures.

*Dark Current Subtraction.* The purpose of this calibration is to remove dark current from long exposure science images. The dark current has several components: a quasi-uniform background around 0.001 DN/sec/pixel; large numbers of “warm” pixels; and several hundred “hot pixels” (>0.01 DN/sec). The pattern of hot pixels is known to vary with time; about 30 new hot pixels appear per CCD per month, while about 30 percent are abruptly lost during decontaminations (Figure 5). There are also a few hot pixels per CCD which flicker on time scales of hours, and cannot be calibrated.

The calibration reference files are constructed from either ~1440 or ~1740 sec duration on-orbit, pre-flashed exposures taken with the shutter closed, and through “crossed” filters to eliminate any light leaks. Typically about ten such frames are calibrated, averaged, and then scaled to 1 second of darktime, to form a dark calibration reference file.

These calibration reference files are then applied by computing the darktime of the science exposure, scaling the reference file by this darktime, and then subtracting the scaled reference file from the data. The darktime is defined as the period of time during which dark current collects, and in practice is the interval between the initial erase of a CCD and the start of its readout. PODPS uses an approximation which is accurate to about 1 minute, and stores this value in the DARKTIME keyword of the .DOH file:

$$\begin{aligned} \text{DARKTIME} &= (\text{exposure time}) + 1 \text{ min} \\ &+ 2 \text{ min (if preflashed)} + 1 \text{ min (if two filters used)} \end{aligned}$$

In situations requiring more accurate dark calibration, observers may wish to re-calibrate using a more accurate darktime estimate. (See Appendix 2 of Biretta, Ritchie, and MacKenty 1993). We note that science images taken with the serial clocks on (CLOCKS=YES; usually for very bright targets) will require a different dark calibration, since the serial clocks modify the dark pattern near the top and bottom of the CCDs, and alter the dark time, as well.

During 1993 we modified the strategy used for dark calibration. Before January 1993 a single dark calibration reference file was used for each CCD, without regard to the observation date. Beginning in January 1993, we went to a new strategy which attempts to minimize the time variations. We generated a new series of calibration reference files, with each file covering a 6 to 12 month period between decontaminations since launch. Further improvements were made in June 1993, when we increased the rate of on-orbit dark calibration exposures from 2 per month to 12 per month, and began delivering monthly dark calibration files.

A known problem with the PODPS dark calibration occurs for exposures which are

interrupted due to loss of guidance system lock, and the like. In these situations, the shutter closes for a brief period of time, but dark current continues to collect. The bug is that PODPS only used the shutter open time, in computing the darktime. Exposure interruptions may be indicated by the EXPFLAG header keyword (though a bug often caused this to be set to NORMAL instead of INTERRUPTED), by unequal values of the WEXPODUR and EXPTIME keywords, and by keyword NSHUTA17 being greater than one.

*Flat Field Correction.* The purpose of flat field correction is to bring all detector pixels to the same photometric response. This step removes pixel-to-pixel variations in the CCD response, patterns imposed by the filters, optical vignetting, etc.

Each filter / camera combination requires its own calibration reference files. These files are constructed from exposures of the bright earth taken through the filter in question, with a neutral density filter sometimes being used as well. These raw earth-cal frames contain streaks due to the combined effects of spacecraft motion and earth features. The STREAKFLAT code in STSDAS is used to remove the streaks by combining images taken at different streak angles. The combined de-streaked image is then normalized so that all CCDs average to unity, and is finally inverted (1 / image) before being installed in the pipeline. Science images are calibrated simply by selecting the reference file for the appropriate filter / camera, and multiplying the reference file into the data.

Most of the currently available (Dec. 1993) flats were observed between July 1991 and January 1992, and are referred to as either the SV flats or Cycle 1 flats, depending whether they were compiled by the IDT or STScI. In some cases more than one flat is available, where either different raw frames were used, or where earth-cals were taken both with and without a neutral density filter. We have just completed observing 1300 earth-cals as part of the closure calibration, and new flat field reference files should be available early in 1994.

The flat-field calibration, and its short-comings, are the topic of several other papers in this volume.

*Filling of Photometric Keywords.* This final step merely copies photometric information from a look-up table into the .COD file binary header, but does not alter the image itself. CALWFP examines the image header, sets the PHOTMODE keyword, searches the photometry look-up table (PHOTTAB) for a matching PHOTMODE, and copies this information into the photometry keywords. For example, PHOTMODE="PC,5,F,DN,F1042M,OPEN,CAL" indicates that detector PC5 was used, a calibration in flux units (F) is desired, the raw data are in DN, the filters were F1042M and OPEN (no second filter), and CAL indicates the data were flat-fielded. The matching PHOTMODE entry in the photometry table is then located, and the numbers are copied into the following keywords of the .COD binary header:

PHOTFLAM: inverse sensitivity, defined as  $F_{\lambda}$  in  $\text{erg cm}^{-2} \text{sec}^{-1} \text{Angstrom}^{-1}$  for a count rate of  $1 \text{ DN sec}^{-1}$ .

PHOTZPT: zero point magnitude (Space Telescope Magnitude at  $F_{\lambda}=1$ ).

PHOTPLAM: pivot wavelength for the filter in Angstroms.

PHOTBW: RMS filter bandwidth in Angstroms.

These keywords may be subsequently examined with IMHEAD in IRAF. Separate papers will present more discussion of WFPC photometry.

*Summary of Image Calibrations.* The above image calibrations may be summarized in a single equation:

$$\begin{aligned} \text{Calibrated image (.COD file)} &= (\text{flat field reference file}) \times \\ &[ \text{A-to-D (raw .DOD image file)} \\ &\quad - (\text{bias level correction}) \\ &\quad - (\text{bias reference frame}) \\ &\quad - (\text{preflash reference frame}) \times (\text{PREFTIME}) \\ &\quad - (\text{dark reference frame}) \times (\text{DARKTIME}) ] \end{aligned}$$

#### IV. Output of the Calibration Pipeline

The calibrated output from the pipeline consists of the headers and data files shown in Table 3. The calibrated data appear in the .COD files, and the data quality is indicated by the .C1D files. The histograms can be optionally output by setting the DOHISTOS keyword.

We also include a note regarding the data quality files, or DQF files. These are used to track problems occurring during the observations, data transmission, or calibration, which might adversely affect the science data. The DQF files are 16-bit integer images, and the pixel value bits are set to indicate problems. A setting of all bits to zero (i.e. pixel value zero) indicates good data. Setting of different bits indicates different problems, as shown in Table 4.

**Table 3: Calibrated WFPC Data Files**

Suffix	File Contents	Size (Data Type)
.C0H	Header for calibrated image	(ASCII)
.C0D	Calibrated image	800x800x4pixels(R*4)
.C1H	Data quality file for calibrated image (header)	(ASCII)
.C1D	Data quality file for calibrated image	800x800x4 pixels (I*2)
.C2H	Histograms of calibrated images (header)	(ASCII)
.C2D	Histograms of calibrated images	4096x3x4 pixels(I*4)
.CGR	ASCII copy .C0D binary header info. (group parameters keywords)	(ASCII)
.TRL	PODPS history text	(ASCII)

**Table 4: DQF pixel bit settings and problems they indicate**

Image Bit	Problem indicated
1's bit	Reed Solomon corrected pixel
2's bit	Poor calibration (variable hot pixel, bias, or preflash level; not enough preflash, poor flat fielding, etc.)
4's bit	Permanent CCD defect.
8's bit	A-to-D converter saturated (>4095 DN in raw image).
16's bit	Data lost during transmission to ground. These pixels are usually filled with value -100 DN
32's bit	Data bad for other reason.

## **V. When is the Post-Pipeline Re-Calibration Useful?**

There are many situations where observers may be able to improve upon the standard pipeline calibration. Whether it is worthwhile to perform such re-calibration will depend on the nature and science goals of the observations. Observations of bright targets (planets, bright galaxy nuclei, star clusters) are likely to be limited by the accuracy of the flat fielding. On the other hand, very deep exposures of faint stars of galaxies are likely to be limited by the dark current and noise, including readout noise and noise in the bias and preflash calibration files.

The centers of the default detectors, WF2 and PC6, are already relatively flat, so for small targets there, the pipeline flat fielding is probably good to a few percent, and very little improvement beyond this can be expected. For larger targets covering all four CCDs, there are various problems limiting the accuracy of flat fielding, with errors in the most serious cases near 20 percent. One major problem is that many broadband pipeline flats are taken through neutral density (ND) filters, which impose their own pattern on the flattened data. For some filters, flats have been taken both with and without neutral density filters, and it might be worthwhile to re-flatten using alternate flats lacking the ND filter. Another approach is to flatten the data with narrow band filter flats at nearby wavelengths, which are taken without ND filters, because of their lower throughput. Or alternatively, to derive the ND filter pattern using narrow band filter flats, and then to remove this pattern from the science data.

At short wavelengths (<5000 Angstroms), the measles contamination pattern can cause localized flat field errors exceeding 5 percent. The measles are perhaps best dealt with by using DELTAFLATS (MacKenty and Baggett 1992) to locate these artifacts, and then deciding whether they impact the location of the science target on the CCDs. The DELTAFLATS can also be multiplied into the science data as a correction, but they are likely to make only a partial correction due to differing illumination patterns of the flat and science data.

We hope to remedy some of these problems in creating the closure flats, which will be available in early 1994, so that re-calibration at that time might give some improvement in the flat fielding.

In order to obtain an optimal dark current calibration, it is necessary to know the dark current both before and after the science observation, so that a reasonable interpolation can be made to eliminate the time variations. Hence, the dark reference files used for pipeline calibration immediately after the observations are never quite optimal. In cases where the dark current is a serious limiting factor, it would be worthwhile to re-calibrate later, when a better reference file is available for that epoch. It would also be possible to tailor-make a dark calibration to the exact observation date, though that task is left to the observer.

In situations where large numbers of science exposures are averaged ( $\geq 4$  frames), the new low-noise bias and preflash calibration files should give an appreciable reduction in noise. For example, an average of 4 preflashed exposures will have the noise reduced by ~15 percent, and for 10 exposures reduced by ~28 percent. In these cases it may be worthwhile to re-calibrate with the new reference files.

## **VI. Further Information**

Additional information regarding the WFPC calibration pipeline may be found in:

- Calibration reference file header history texts. These contain descriptions of how the reference files were derived.
- Selected WFPC Instrument Science Reports and Memos, available from STScI Science Instruments Branch.
- Space Telescope Electronic Information Service (STEIS) Memos, which are available by anonymous FTP to internet node stsci.edu. These contain up-to-date information on calibration reference files, and the like.
- STSDAS Calibration Guide, available from STScI User Support Branch.
- WFPC Handbook, available from STScI User Support Branch.
- WFPC Final Orbital / Science Verification Report, 1992, ed. S. Faber, available from STScI User Support Branch.
- WFPC Instrument Science Reports and Memos, available from STScI Science Instruments Branch.
- HST Data Handbook, available from STScI.
- WFPC Data Products Guide, available from STScI Research Support Branch.

## **VII. References**

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