

**PART X:**

# **WF/PC-1**

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**Chapter 43: WF/PC-1 Instrument Overview**

**Chapter 44: WF/PC-1 Data Structures**

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■ WF/PC-1

# WF/PC-1 Instrument Overview

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## 43.1 Historical Overview

The development and construction of the Wide Field and Planetary Camera (WF/PC-1) was led by Prof. J.A. Westphal, Principal Investigator, of the California Institute of Technology. The Investigation Definition Team (IDT) also included J.E. Gunn (deputy P. I.), W.A. Baum, A.D. Code, D.G. Currie, G.E. Danielson, T.F. Kelsall, J.A. Kristian, C.R. Lynds, P.K. Seidelmann, and B.A. Smith. The instrument was built at the Jet Propulsion Laboratory, California Institute of Technology. A general overview of the instrument is given by Westphal et al., 1982, "The Wide Field/Planetary Camera," in *The Space Telescope Observatory*, ed. by D.N.B. Hall, page 28, NASA CP-2244.

The WF/PC-1 was a dual two-dimensional spectrophotometer with rudimentary polarimetric and transmission-grating capabilities. The instrument was designed to operate from 1150 Å to 11,000 Å, with a resolution of 0.1 arcsec per pixel (Wide Field Camera,  $f/12.9$ ) or 0.043 arcsec per pixel (Planetary Camera,  $f/30$ ) using an array of CCD detectors.

Launched aboard the HST in April of 1990, the WF/PC-1 underwent an initial checkout period, obtained the HST's first light images, and was central to the discovery and characterization of the OTA spherical aberration. In December 1990, the WF/PC-1 detectors were conditioned (UV flood procedure) in preparation for the scientific observing program. During 1991, Science Verification (SV) tests and calibration data were obtained by the IDT concurrent with the Cycle 0 GTO science observations. Starting in mid-1991, GO science

observations became a significant part of the WF/PC-1 observing program. The engineering handover of the WF/PC-1 from JPL to STScI was completed in November 1991. Observations for the IDT's SV program were completed in January 1992 and the formal SV Report (Faber et al., 1991) delivered in February 1992. The GO science programs and the STScI calibration programs began during the fall of 1991 and continued successfully until December 1993, when WF/PC-1 was replaced by WFPC2 during the first maintenance and servicing mission.

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## 43.2 WF/PC-1 Documentation

In this section we list important STScI sources of documentation for WF/PC-1.

### 43.2.1 Instrument Handbook

The final version of the *WF/PC-1 Instrument Handbook* (version 3.0) is a useful description of the technical capabilities of the instrument and practical information for its use. Earlier versions contain little useful information not included in the final version. Version 3.0 is not available in electronic format.

### 43.2.2 Instrument Science Reports

Instrument Science Reports (ISRs) are technical reports issued by STScI that describe calibrations, anomalies, and operational capabilities of the instrument. ISRs are generally written for a technical audience, so we have tried to incorporate their results into this handbook as necessary. When an ISR may be particularly helpful, as in treatment of a topic beyond the scope of this volume, we provide the appropriate reference. For completeness we have included a listing of WF/PC-1 ISRs in the bibliography section at the end of this chapter. Paper copies of all ISRs are available from the STScI Help Desk; send E-mail to [help@stsci.edu](mailto:help@stsci.edu).

### 43.2.3 Previous Data Handbooks

This version of the *HST Data Handbook* replaces all previous data handbooks as we have tried to improve upon and slightly expand the treatments in the previous handbooks. Any updates to this handbook will be posted on the STScI WWW site.

### 43.2.4 WF/PC-1 WWW Resources

The top WF/PC-1 WWW page can be found among the STScI World Wide Web resources, in the Instruments section.<sup>1</sup> The STScI home page is at:

<http://www.stsci.edu/>

The WF/PC-1 pages are grouped into three major categories: memos, general documentation (more formal reports), and calibration products. We provide below a short summary of the items on these pages that may be of particular interest to an archival user, grouped by page, not in order of importance.

- WF/PC-1 Memos Page
  - Closure Flatfields
  - Reference File Memo
  - Super-sky Flatfields
  - Lick Group Flatfield Correction Frames
  - Deltaflat Corrections
  - Measles Contamination and Compensation
  - Hot Pixel List
  - Photometric Monitoring Results
  - PSF Library
- General WF/PC-1 Documentation Page
  - Online Data Handbook
  - WF/PC-1 Instrument Science Reports (see Bibliography below)
  - Calibration Workshop Proceedings
- Calibration Products page
  - WF/PC-1 Filter Scans, measured in the lab after the mission
  - Photometric Monitoring Results

Additionally, notices concerning any updates to WF/PC-1 documentation will be posted here, though none are presently planned.

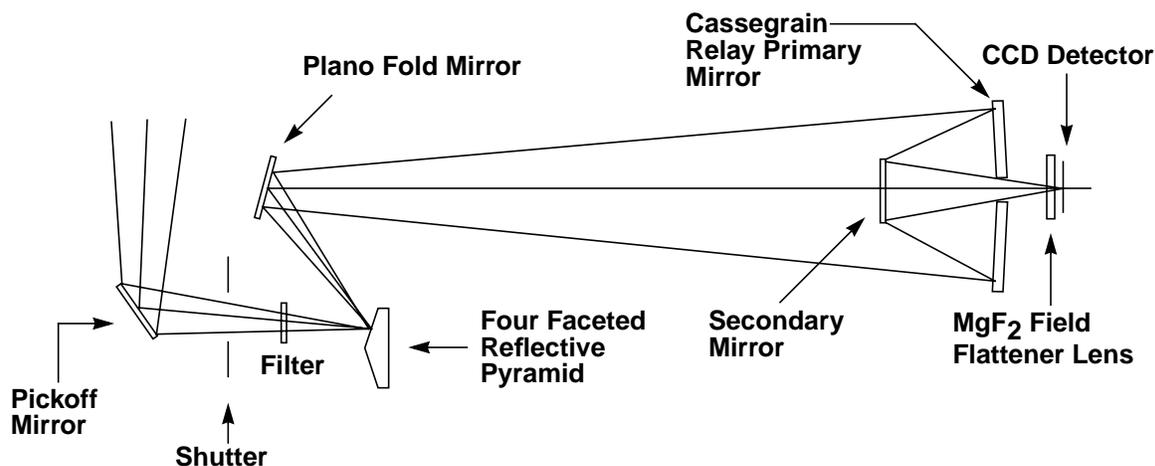
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## 43.3 WF/PC-1 Instrument Basics

Figure 43.1 shows a schematic of the optical arrangement of the WF/PC-1. The central portion of the optical telescope assembly (OTA)  $f/24$  beam was intercepted by a steerable pick-off mirror attached to the WF/PC-1 and diverted through an open port entry into the WF/PC-1. The beam then passed through a shutter and interposable filters. A total of 48 spectral elements and polarizers were contained in an assembly of 12 filter wheels. The light then fell onto a shallow-angle, four-faceted pyramid located at the aberrated OTA focus. Each face of the pyramid was a concave spherical surface. The pyramid divided the OTA image of the sky into four parts. After leaving the pyramid, each quarter of the full field-of-view was relayed by an optical flat to a Cassegrain relay that formed a second field image on a charge-coupled device (CCD) of 800 x 800 pixels. Each of these detectors was housed in a cell filled with 0.1 atmosphere of argon sealed by a  $\text{MgF}_2$  field flattener.

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1. A list of URLs is also provided in Appendix E.

**Figure 43.1:** WF/PC-1 Optical Configuration

In total, the WF/PC-1 contained eight relay mirror-repeater-CCD trains, four for the wide-field camera and four for the planetary camera. To place the desired camera into operation, the pyramid was commanded to rotate into one of two fixed orientations separated by 45 degrees. The Wide Field cameras (WF) produced a final focal ratio of  $f/12.9$  while the Planetary Cameras (PC) produced  $f/30$ .

Table 43.1 summarizes the configuration of the two cameras (also see the *OV/SV Report*, 1992 and the *WF/PC-1 Instrument Handbook*, 1992). The Wide Field chips are numbered 1 through 4, the Planetary Camera chips 5 through 8.

**Table 43.1:** Camera Configurations

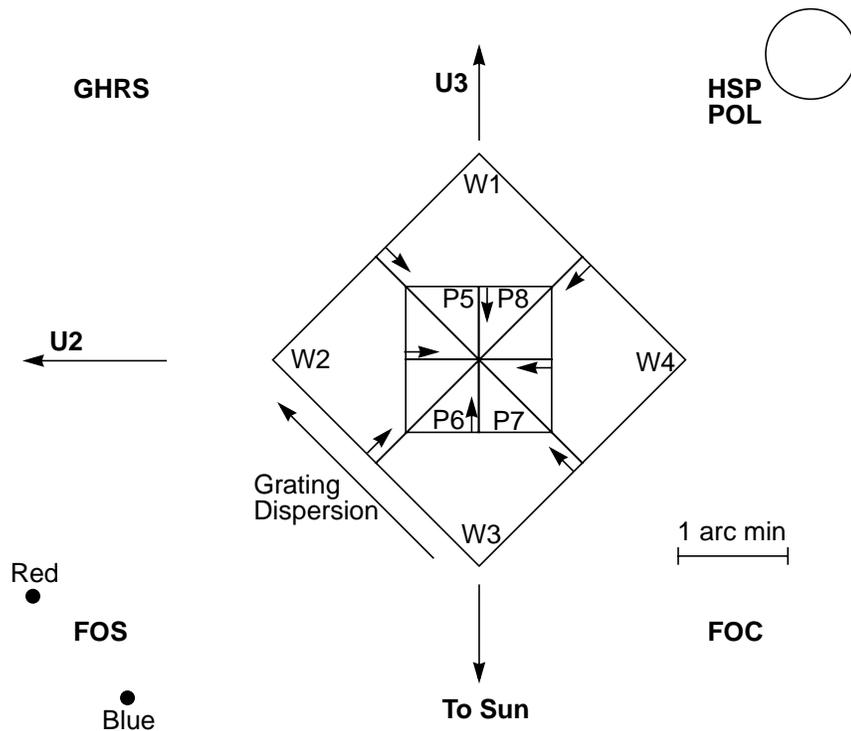
Camera	Pixels	Field of View	Scale	f/ratio
WFC	800 x 800 x 4 chips	2.6' x 2.6'	0.102"	12.9
PC	800 x 800 x 4 chips	66" x 66"	0.043"	30

Two readouts for each camera were available: FULL and AREA mode (given in the MODE header keyword). FULL mode was the default, with full single-pixel resolution. In full mode, each line of science data contained two 16-bit words of engineering data followed by 799 16-bit numbers as read from the chip, followed by 12 overclocked pixels which were used to determine the bias level (BLEV) correction (see "Calibration Details" on page 45-7. During the initial steps of the routine pipeline processing, the science data was reformatted and separated into the raw (.d0h/.d0d) science data (800 x 800 pixels) and the engineering data along with the 12 bias columns (.x0h/.x0d).

AREA mode—which was not used often (only 50 images, 35 of them externals, out of 15,746 total WF/PC-1 images)—was a 2 x 2 pixel summation. In this case, the two words of engineering data were followed by only 400 16-bit numbers read out from the chips; no overclocking was done. In this mode, the BLEV correction was determined from the second column of engineering data. The least significant bit (from odd rows only, even rows contained engineering data) was averaged, then multiplied by two.

The field of view of the WF/PC-1 charge-coupled devices (CCDs) on the sky is illustrated in Figure 43.2; some features of the chips are summarized below.

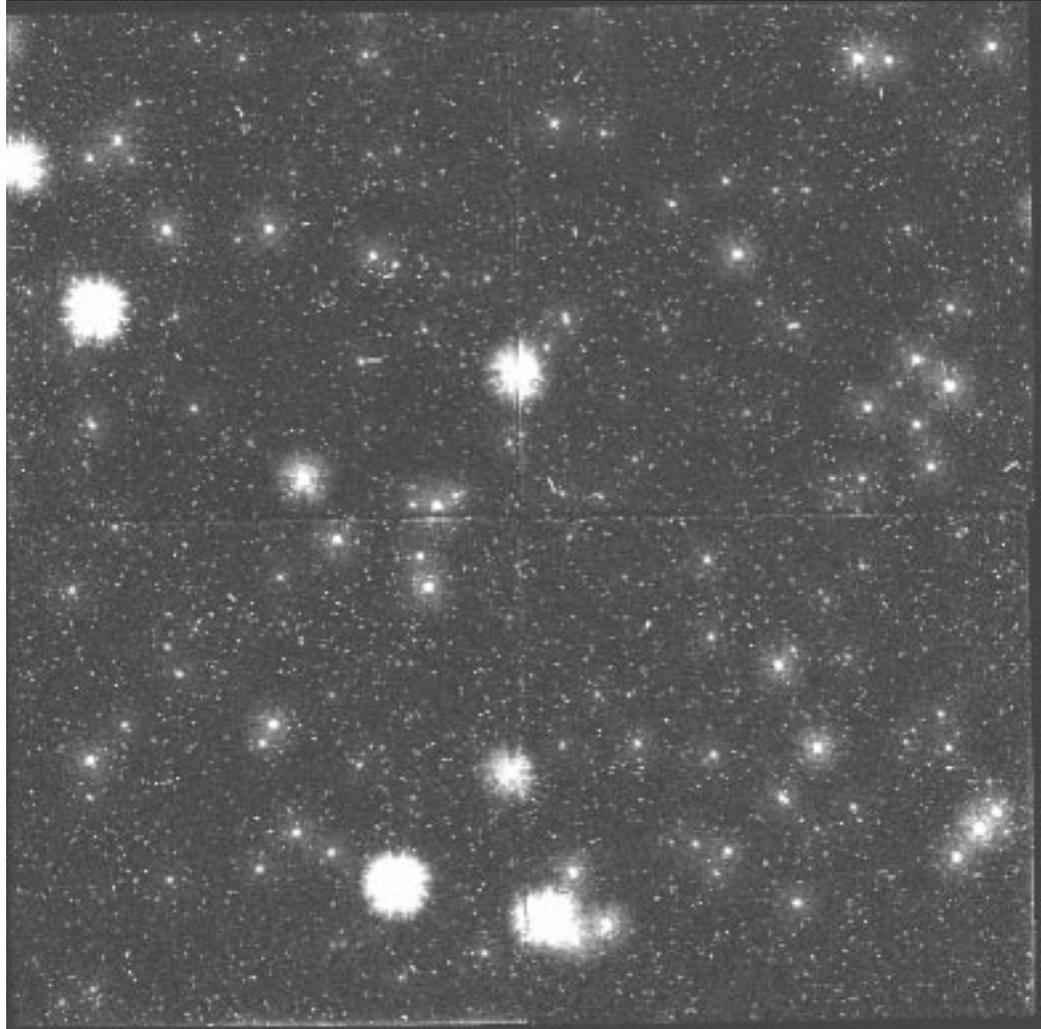
**Figure 43.2:** WF/PC-1 Field of View on Sky



- Each chip was read out from the corner nearest the central point where all chip corners meet; the arrows indicate the readout direction. The column and row (line) numbers increased from the center outwards; the direction of blooming (along columns) was parallel to the arrows.
- An optically inactive edge (about 25 pixels wide) bordered the two sides of each chip that were adjacent to another chip. The resultant area on the sky covered by all four chips was approximately 1543 x 1543 pixels for the wide field camera (WFC) (154.5" x 154.5") and 1531 x 1531 pixels for the planetary camera (PC) (65.8" x 65.8").

- A region of low reflectance on the pyramid (called the *Baum spot*) with 0.1% reflectance of the rest of the pyramid can be found in PC 8 ( $x=416$ ,  $y=417$ ) and in WF 4 ( $x=195$ ,  $y=197$ ), about 1.2" (~28 pixels) in diameter.
- The *Kelsall spots*, a series of eleven pinholes along each of the common pyramid edges used for image registration, were illuminated only during special calibration observations.
- *Read noise* was around 13 rms electrons per pixel; gain was approximately 7.5 electrons per digital number (DN) (see the *WF/PC-1 Instrument Handbook*, Version 3.0 page 34).

The images from each chip are oriented such that north shifts by roughly 90 degrees from chip to chip. The orientation of each chip (i.e., the direction of north) is stored in the ORIENTAT group keyword; the **north** task can be used to obtain the position angle of the image. Calibrated WF/PC-1 images retain a residual geometric distortion (about 1 pixel, corner to corner). The **wmosaic** task can be used to geometrically correct and align the four chip images (see Chapter 3 for more details). Figure 43.3 shows the image produced after **wmosaic** has been used to properly align and geometrically correct the four sub-images and produce a single mosaic image.

**Figure 43.3:** Aligned WF/PC-1 Mosaic Image

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## 43.4 WF/PC-1 Bibliography

### 43.4.1 WF/PC-1 Instrument Handbook

- MacKenty, J., R. Griffiths, W. Sparks, K. Horne, R. Gilmozzi, S. Ewald, C. Ritchie, S. Baggett, L. Walter, and G. Schneider, *WF/PC-1 Instrument Handbook*, version 3.0, 1992.

### 43.4.2 Calibration References

- Ratnatunga, K.U., et al., “Calibration of HST Wide Field Camera for Quantitative Analysis of Faint Galaxy Images,” , 1994, *AJ* **108**, 2362.
- Phillips, A.C., et al., “Flatfielding and Photometric Accuracy of the First Hubble Space Telescope Wide Field Camera,” 1994, *AJ* **107**, 1904.
- *Calibrating Hubble Space Telescope*, 1994 workshop proceedings, edited by J.C. Blades and S.J. Osmer.
- Lauer, T., “The Reduction of Wide Field/Planetary Camera Images,” 1989, *PASP*, **101**, 445.
- Faber, S. M., and the WF/PC-1 Investigation Definition Team, “Final Orbital/Science Verification Report,” 1991.

### 43.4.3 WF/PC-1 Instrument Science Reports<sup>2</sup>

- Contramination Correction in SYNPHOT for WFPC2 and WF/PC-1 (WFPC2 ISR 96-02), S. Baggett, W. Sparks, and J. MacKenty.
- WF/PC Observed PSF Library (93-03), S. Baggett and J. MacKenty
- WF/PC Photometric Monitoring Results (93-02), C. Ritchie and J. MacKenty
- The Evolution and Treatment of Hot Pixels in the WF/PC (93-01), J. Biretta and C. Ritchie
- PSF Calibration Plan (92-13), S. Baggett and J. MacKenty
- Currently Available Non-SV Flatfield Calibrations (92-12), C. Ritchie and J. MacKenty
- The Stability of Measles Features: an Autocorrelation Analysis (92-11), W. Sparks, C. Ritchie and J. MacKenty
- Deltaflat Corrections (92-10), S. Baggett and J. MacKenty
- Absolute Efficiency of the WF/PC (92-09), W.B. Sparks, C. Ritchie, J. MacKenty
- Numbers and Characteristics of PC “Measles” Features from February through April 1992 (92-08), S. Baggett and J. MacKenty
- WF/PC UV Calibration Following Decontamination (92-07), C. Ritchie and J. MacKenty
- A Library of Observed WF/PC Point Spread Functions (92-05), S. Baggett and J. MacKenty

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2. Paper copies of these reports are available from [help@stsci.edu](mailto:help@stsci.edu); only the titles and abstracts are on the WF/PC-1 WWW pages.

- WF/PC Measles Contamination and Compensation with Delta Flats (92-04), J. MacKenty and S. Baggett
- WF/PC Reference Files Currently in the Calibration Data Base (92-03), S. Baggett and J. MacKenty
- Estimation of the Current Status of the WF/PC UV Flood (92-02), J. MacKenty and C. Ritchie
- Determination of the Position Dependent Zero Point Magnitude Correction for the Core Aperture Photometry with WF/PC (not WFPC ISR but TS #92-02), Ellyne Kinney and Roberto Gilmozzi
- Position Changes for Standard Star Observations (92-01), C. Ritchie
- Exposure Times for G200L Images of AGK+81D266 during UV Flood (91-08), K. Horne and J. MacKenty
- Analysis of Stellar Monitor Proposal #3173 (91-07), C. Ritchie
- July 6 Decontamination Affected QE Slightly (91-05), S. Ewald
- WF/PC Photometric Calibration during Jan-May 1991 (91-04), K. Horne, L. Walter, C. Ritchie
- WF/PC II Contamination Control (91-03), J. Barengoltz, J. Millard, T. Jenkins, D. Taylor
- Spacecraft Jitter: Its Effect on the HST PSF and on the `Breathing`?) (91-02), R. Gilmozzi
- 91-01 Post-Flood PC quantum Efficiency (91-01), K. Horne and C. Ritchie
- Technical Report on Wide Field Camera Observations of 2237+0305 (SV 3068) (90-10), D. Schneider & J. Bahcall
- WF/PC Internal Molecular Contamination During System T-V Test (90-08), R. Griffith
- "Core" Aperture Photometry with WF/PC (90-07), R. Gilmozzi
- A Pre-Flood Checkup on WF/PC Quantum Efficiency Using the STSDAS SYNPHOT
- Software Package (90-06), K. Horne, E. Wyckoff, and D. Bazell
- A Pre-Flood Study of WF/PC Photometric Stability Using Aperture Photometry on NGC 188 Data Taken in August and September (90-05), E. Wyckoff, R. Gilmozzi, K. Horne
- Sensitivity at 9000A, (90-04), P. Seitzer
- The Take Data Flag (90-03), S. Ewald
- Filter F656N Anomaly I (90-02), S. Ewald
- Bias Change During TV6 (90-01), C. Ritchie and S. Ewald



# WF/PC-1 Data Structures

## In This Chapter...

Science Data Files / 44-1

Reference Files / 44-3

Header Keywords / 44-3

This chapter contains information about WF/PC-1 data formats and file types, and necessary reference files. This chapter does not include a discussion of paper products as no such products exist for WF/PC-1,

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## 44.1 Science Data Files

If **strfits** was used to convert the HST Archive's FITS files (as described in Chapter 3), the image data will be in GEIS format. A directory listing (type `dir` within IRAF), will show that the files all have a nine-character rootname and a three-character suffix.

By definition, a *dataset* is the collection of all files produced by the Routine Science Data Processing (RSDP) pipeline for a single HST exposure. The files in a dataset all share the same nine-character rootname or *IPPPSSOOT*. As defined in Appendix B, the rootname follows a specific naming convention that allows each executed observation to be uniquely tied to the scheduling information from which it originated.

Each file in a dataset has a three-character suffix. For each instrument, this suffix uniquely identifies the file contents. The WF/PC-1 science data file sizes and suffixes are listed in Table 44.1 below.

Files whose suffixes end with the letter "h" (e.g., `w01o0105t.c1h`) are ASCII *header files*. The header files contain keywords that describe the parameters used to take the observation, the processing of the data, and the properties of the image. Files whose suffixes end in the letter "d" (e.g., `w01o0105t.c1d`) are binary *data files*; these files contain the data as well as the group keywords. A single GEIS image is composed of a header and data *pair* (e.g., the files `w01o0105t.c1h` and `w01o0105t.c1d` together represent a single image, retrieved as `w01o0105t_c1f.fits` from the Archive).

**Table 44.1:** WF/PC-1 Dataset Suffixes and File Sizes

Suffix	File Contents	File Sizes (full mode) <sup>a</sup>
<i>Raw Data Files</i>		
.d0h/ .d0d	Raw science data	5 MB
.q0h/ .q0d	Data quality for raw science data	5 MB
.x0h/ .x0d	Extracted engineering data	90 KB
.q1h/ .q1d	Data quality for extracted engineering data	90 KB
.shh/ .shd	Standard header packet containing observation parameters	90 KB
<i>Calibrated Data Files</i>		
.c0h/ .c0d	Calibrated science data	10 MB
.c1h/ .c1d	Data quality for calibrated science data	5 MB
.c2h/ .c2d	Histogram of science data pixel values	
.c3h/ .c3d	Saturated pixel map	
.tr1	Trailer file	

a. Area mode files are ~1/4 the size of Full mode.



The data quality file (.c1h) flags bad pixels; see Table 45.2 for a description of the data quality values and their meaning.

A single WF/PC-1 exposure is obtained as four images (less if fewer than four chips were read out). GEIS files use group format to keep all of the data from a given HST exposure together in a single image file. The data corresponding to each sub-image for the WF/PC-1 are stored sequentially in the groups of a single GEIS image. The header file for an image contains the information that applies to the observation as a whole (i.e., to all the groups in the image), viewable by paging the header. The group-specific (that is, chip-specific) keyword information is stored with the group data in the binary data file; group keywords are only accessible via specialized software such as the STSDAS tasks like **hedit** or **imhead**.

WF/PC-1 images are normally four-group images, groups 1–4 representing CCD chips WF1–WF4 or PC5–PC8, depending on the camera used; if only a subset of chips were read out, only a subset of groups will be present. The group keyword DETECTOR provides the identification number of the chip (1 through 8) stored in that group, regardless of the number of chips read out.

## 44.2 Reference Files

The types of WF/PC-1 reference files, along with their suffixes, are listed in Table 44.2; the **b\*** suffixes refer to the associated data quality files. The rootname of the reference file is based on the time that the file was delivered to the Calibration Data Base System (CDBS); the file names and history of all WF/PC-1 reference files in CDBS (and retrievable from the HST Archive) are contained in the Reference File Memo on the WWW:

[http://www.stsci.edu/ftp/instrument\\_news/WFPC/wfpc1\\_memos.html](http://www.stsci.edu/ftp/instrument_news/WFPC/wfpc1_memos.html)

This memo is routinely updated with each new delivery. Any CDBS file is available for retrieval through the HST Data Archive.

**Table 44.2:** WF/PC-1 Calibration Reference Files

Suffix <sup>a</sup>	Reference File
r0h, r0d	Static mask
r1h, r1d	Analog to digital look-up table
r2h, r2d, b2h, b2d	Bias
r3h, r3d, b3h, b3d	Preflash
r5h, r5d, b5h, b5d	Dark frame
r6h, r6d, b6h, b6d	Flatfield
r7h, r7d	Extracted PSF images <sup>b</sup>
r8h, r8d, b8h, b8d	Delta flat images <sup>b</sup>
cw0	Photometry table

a. Suffixes .r4h and .r4d (superpurge) were not used.

b. PSFs and delta flats are additional CDBS files available from the Archive. They are intended for use separately from **calwfp**; more details on their use are provided in “Choosing and Generating Delta Flats” on page 45-18 and “PSFs” on page 46-11, as well as in the online WWW memos.

## 44.3 Header Keywords

Table 44.3 lists the header keywords found in a WF/PC-1 .c0h image header that many observers are likely to find useful; the STSDAS tasks **hedit** or **imhead** can be used to view any or all of the header and group keywords. WF/PC-1 keywords include items such as observing mode, integration time, and filters used, calibration steps performed and reference files used, and the properties of the data

itself (e.g., number of groups, coordinates, scale, flux units, image statistics, and more). In Table 44.3, the group keywords are GROUPS through PHOTBW; keywords INSTRUME through SEQNAME are the general keywords.

**Table 44.3:** WF/PC-1 Header Keywords

<b>Keyword</b>	<b>Description</b>
<i>Information about the groups</i>	
GROUPS	Multi-group image?
GCOUNT	Number of groups (number of detectors read out)
<i>Coordinate-related keywords</i>	
CRVAL1	RA of reference pixel (deg)
CRVAL2	Declination of reference pixel (deg)
CRPIX1	X coordinate of reference pixel
CRPIX2	Y coordinate of reference pixel
CD1_1	Partial of RA with respect to $x$
CD1_2	Partial of RA with respect to $y$
CD2_1	Partial of declination with respect to $x$
CD2_2	Partial of declination with respect to $y$
<i>Image Contents</i>	
ORIENTAT	Orientation of image (deg)
DETECTOR	CCD detector: WF 1-4, PC 5-8
<i>Bias level information (columns 3–14 of the .x0h/.x0d file)</i>	
DEZERO	Bias level from EED extended register
BIASEVEN	Bias level based on average of odd columns in x0h/x0d file
BIASODD	Average bias level based on average of even columns
<i>Pixel statistics</i>	
GOODMIN	Minimum value of “good” pixels (not flagged in DQF)
GOODMAX	Maximum value of “good” pixels
DATAMEAN	Mean value of “good” pixels
GPIXELS	Number of good pixels

**Table 44.3:** WF/PC-1 Header Keywords (Continued)

<b>Keyword</b>	<b>Description</b>
<i>Photometry keywords</i>	
PHOTMODE	Photometry mode
PHOTFLAM	Inverse sensitivity (units of erg/sec/cm <sup>2</sup> /Å for 1 DN/sec)
PHOTZPT	Zero point (currently -21.10, if DOPHOTOM = yes)
PHOTPLAM	Pivot wavelength (in angstroms)
PHOTBW	rms bandwidth of filter (in angstroms)
<i>Image keywords</i>	
INSTRUME	Instrument used; always WFPC for either WF or PC
ROOTNAME	Rootname of the observation set
FILETYPE	SHP - standard header packet EXT - extracted engineering file EDQ - EED data quality file SDQ - science data quality file SCI - science data file
CAMERA	Camera in use: WF (wide-field), PC (planetary)
MODE	Mode: FULL (full resol.) or AREA (2x2 pixel summation)
SERIALS	Serial clocks: ON, OFF
<i>Data type keywords</i>	
IMAGETYP	DARK/BIAS/INTFLAT/KSPOTS /EXTERNAL/EARTH-CAL
CDBSFILE	GENERIC/BIAS/DARK/PREF/FLAT/MASK/ATOD/NO Is the image a reference file and if yes, type is specified
<i>Reference file selection keywords</i>	
DATE	Date file written (dd/mm/yy)
FILTNAM1	First filter name
FILTNAM2	Second filter name; blank if none
FILTER1	First filter number (0-48) (Historical, but used in SOGS)
FILTER2	Second filter number (0-48)
PFILTER1	Preflash Filter 1 number (0-48); always 1=F122M
PFILTER2	Preflash Filter 2 number (0-48); always 47=F1083N (WF) 35=F1042M (PC)
SHUTTER	Shutter in place during preflash or INTFLAT (A, B, or Unknown)

**Table 44.3:** WF/PC-1 Header Keywords (Continued)

<b>Keyword</b>	<b>Description</b>
<i>Calibration switches</i>	
MASKCORR	Do mask correction: YES, NO, DONE
ATODCORR	Do A-to-D correction: YES, NO, DONE
BLEVCORR	Do bias level correction: YES, NO, DONE
BIASCORR	Do bias correction: YES, NO, DONE
PREFCORR	Do preflash correction: YES, NO, DONE
PURGCORR	Do purge correction—always NO
DARKCORR	Do dark correction: YES, NO, DONE
FLATCORR	Do flatfield correction: YES, NO, DONE
DOSATMAP	Output Saturated Pixel Map—always NO
DOPHOTOM	Fill photometry keywords: YES, NO, DONE
DOHISTOS	Make histograms: YES, NO, DONE
<i>Calibration reference files used<sup>a</sup></i>	
MASKFILE	Name of the input DQF of known bad pixels
ATODFILE	Name of the A-to-D conversion file
BLEVFILE	Engineering file with extended register data
BLEVDFIL	Engineering file data quality file (DQF) name
BIASFILE	Name of the bias frame reference file
BIASDFIL	Name of the bias frame reference DQF
PREFFILE	Name of the preflash reference file
PREFDFIL	Name of the preflash reference DQF
PURGFILE	Name of the purge reference file (dummy name)
PURGDFIL	Name of the purge reference DQF (dummy name)
DARKFILE	Name of the dark reference file
DARKDFIL	Name of the dark reference DQF
FLATFILE	Name of the flatfield reference file
FLATDFIL	Name of the flatfield reference DQF
PHOTTAB	Name of the photometry calibration table
SATURATE	Data value at which saturation occurs (always 4095 for WF/PC-1, which includes the bias)

**Table 44.3:** WF/PC-1 Header Keywords (Continued)

<b>Keyword</b>	<b>Description</b>
<i>Ephemeris data</i>	
PA_V3	Position angle of V3 axis of HST
RA_SUN	Right ascension of the sun (deg)
DEC_SUN	Declination of the sun (deg)
EQNX_SUN	Equinox of the sun
<i>Exposure Information</i>	
WEXPODUR	Commanded duration of exposure (seconds). For exposures less than 1/2 sec, WEXPODUR is set to 0.
PREFTIME	Predicted preflash time (sec); 30 for WFC and 8 for PC
DARKTIME	Estimate of darktime (in sec)
FGSLOCK	Commanded FGS lock (FINE, COARSE, GYROS, UNKNOWN)
<i>Timing information</i>	
DATE-OBS	UT date of start of observation (dd/mm/yy)
TIME-OBS	UT time of start of observation (hh:mm:ss)
EXPSTART	Exposure start time (Modified Julian Date)
EXPEND	Exposure end time (Modified Julian Date)
EXPTIME	Exposure duration (seconds)
EXPFLAG	How exposure time was calculated. (NORMAL, INTERRUPTED, INCOMPLETE, EXTENDED, UNCERTAIN, INDETERMINATE, or PREDICTED)
<i>Proposal information</i>	
TARGNAME	Proposer's target name
RA_TARG	Right ascension of the target (deg) (J2000)
DEC_TARG	Declination of the target (deg) (J2000)

a. Calibration reference file keywords are populated even when not used.



# Calibrating WF/PC-1 Data

### In This Chapter...

- Overview of Pipeline Processing / 45-1
- Calibration of WF/PC-1 Data / 45-3
- Calibration Details / 45-7
- Should You Recalibrate? / 45-12
- Improvements to Calibration Reference Files / 45-13
- Determining the “Best” Reference Files / 45-14
- Recalibrating WF/PC-1 Data / 45-20

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## 45.1 Overview of Pipeline Processing

The data were received from the Space Telescope Data Capture Facility by the Post Observation Data Processing System (PODPS). There they were passed to Routine Science Data Processing (RSDP)—referred to as the *pipeline*—to be processed and calibrated. All of the steps performed by the pipeline were recorded in the trailer file for the dataset. Figure 45.1 shows an example of a trailer file and identifies comments made during the following pipeline steps:

1. The data were partitioned (separated into individual files, e.g., the engineering and science data are separated).
2. The data were edited to insert fill values in place of missing data.
3. The data were evaluated to determine discrepancies between the subset of the planned and executed observational parameters.
4. A list of calibration reference files to be used in the calibration of the data was created based on the executed observational parameters. This step did not generate comments in the example trailer file.

5. The data were converted to a generic format and the header keywords populated.
6. The data were calibrated using a standard WF/PC-1-specific calibration algorithm (STSDAS task **calwfp**).

**Figure 45.1: Sample Trailer File**

```

DPPBAN-***** TRAILER FILE *****
DPPSTA----- DATA PARTITIONING STARTED -----
DPPSTR-DATA PARTITIONING STARTED: 23-AUG-93 14:12:38
DPP OBS-Observation Identification: Program Number 1DR , Observation Set Number 08 , Observation Number 06
DPPCAT-Msg Artifacts Catalog: DCF Msg 12 contained data for Info Set File with Root Name of W1DR0806T
DPPIST-Missing pkts processing is complete, processed 3200 science pkts, detected 0 as missing
DPVWML-Weighted Quality Measure of 0 was calc for errors reported in Quality & Acctg Capsule entries for Info Set
DPPNPR- 3201 packets expected, 3201 packets received ( 1 SHPs, 0 UDLs, 0 Bad pkts) for Info Set W1DR0806T
DPPEND-DATA PARTITIONING ENDED: 23-AUG-93 14:23:31 .
DPPFIN----- DATA PARTITIONING COMPLETED -----
CPEOST----- DATA EDITING STARTED -----
CPESTR-DATA EDITING STARTED 23-AUG-93 14:23:47 FOR W1DR0806T.
DPE4PC- 0 fill source packets were inserted by PODPS.
DPE4DC-In W1DR0806T, 0 source packets were found that contain fill data inserted by the ST DCF.
DPERSC-CP34SE: ...and 0 packets were found to have segments without Reed Solomon corrections
CPEEND-DATA EDITING ENDED 23-AUG-93 14:23:47 FOR W1DR0806T.
CPEOEN----- DATA EDITING COMPLETED -----
CPGOVS----- DATA EVALUATION STARTED -----
DPVSTR-DATA EVALUATION STARTED 23-AUG-93 14:23:55 FOR W1DR0806T.
DPVEND-DATA EVALUATION ENDED 23-AUG-93 14:24:22 FOR W1DR0806T.
DPVWML-Weighted Quality Measure of 0 was calc for discrepancies between predicted & actual Flags & Indicators for Info Set
DPVOKK-Info Set quality was OK as Weighted Quality Measure of 0 did not exceed Quality Threshold of 9
CPGOVE----- DATA EVALUATION COMPLETED -----
CGAI00-----
CGAI01-----WIDE FIELD AND PLANETARY CAMERA GENERIC CONVERSION BEGINNING-----
CGAI00-----
CGAT01-Routine CGWFPC, version 32.0.D , will perform generic conversion
CGAT02-GENERIC CONVERSION BEGINNING: processing information set W1DR0806T
CGAT03-CGWFPC START: 23-AUG-93, 14:24:22
CGAW06-No error values detected in flags and indicators
CGAI06-SHP generic conversion has completed successfully
CGAC02-Generated new WFPC reference file catalog : CCC:[SIS.WFPC]W1DR0806T.CTX
CGAI08-SCI generic conversion has completed successfully
CGAI22-DQM generic conversion has completed successfully
CGAT04-GENERIC CONVERSION TERMINATING: successful completion
CGAT09-CGWFPC END: 23-AUG-93, 14:29:08
CPGOEN----- GENERIC CONVERSION COMPLETED -----
#####
##### This observation was reprocessed through the RSDP pipeline
##### because they were unreadable on the DMF disks. This allows
##### the data to be ingested into DADS for later/future retrievals
#####
##### 26-APR-1995 Mk
#####
CPEOST----- DATA EDITING STARTED -----
CPESTR-DATA EDITING STARTED 26-APR-95 18:05:56 FOR W1DR0806T.
DPE4PC- 0 fill source packets were inserted by PODPS.
DPE4DC-In W1DR0806T, 0 source packets were found that contain fill data inserted by the ST DCF.
DPERSC-CP34SE: ...and 0 packets were found to have segments without Reed Solomon corrections
CPEEND-DATA EDITING ENDED 26-APR-95 18:05:56 FOR W1DR0806T.
CPEOEN----- DATA EDITING COMPLETED -----
CPGOVS----- DATA EVALUATION STARTED -----
DPVSTR-DATA EVALUATION STARTED 26-APR-95 18:16:57 FOR W1DR0806T.
DPVEND-DATA EVALUATION ENDED 26-APR-95 18:17:10 FOR W1DR0806T.
DPVWML-Weighted Quality Measure of 0 was calc for discrepancies between predicted & actual Flags & Indicators for Info Set
DPVOKK-Info Set quality was OK as Weighted Quality Measure of 0 did not exceed Quality Threshold of 9
CPGOVE----- DATA EVALUATION COMPLETED -----
CGAI00-----
CGAI01-----WIDE FIELD AND PLANETARY CAMERA GENERIC CONVERSION BEGINNING-----
CGAI00-----
CGAT01-Routine CGWFPC, version SOGS35.3.A , will perform generic conversion
CGAT02-GENERIC CONVERSION BEGINNING: processing information set W1DR0806T
CGAT03-CGWFPC START: 26-APR-95, 18:17:10
CGAW06-No error values detected in flags and indicators
CGAI06-SHP generic conversion has completed successfully
CGAC02-Generated new WFPC reference file catalog : CCC:[SIS.WFPC]W1DR0806T.CTX
CGAI08-SCI generic conversion has completed successfully
CGAI22-DQM generic conversion has completed successfully
CGAT04-GENERIC CONVERSION TERMINATING: successful completion
CGAT09-CGWFPC END: 26-APR-95, 18:20:33
CPGOEN----- GENERIC CONVERSION COMPLETED -----
CGAI00-----
CGAI01-----WIDE FIELD AND PLANETARY CAMERA CALIBRATION BEGINNING-----
CGAI00-----
CGAI07-CALIBRATION BEGINNING: processing information set W1DR0806T
CGAI11-CCWFPC START: 26-APR-95, 18:45:08
CCAIRI- --- Message From: CALWFP While Processing:
CCAIRI- --- Message: WF/PC Calibration Starting: CALWFP Version 1.2.1
CCAIRI- --- Message From: CALWFP While Processing: W1DR0806T
CCAIRI- --- Message: Starting CALWFP: Input = wcal:w1dr0806t Output = wcal:w1dr0806t
CCAIRI- --- Message From: CALWFP While Processing: W1DR0806T
CCAIRI- --- Message: Start Process Element 1
CCAIRI- --- Message From: CALWFP While Processing: W1DR0806T
CCAIRI- --- Message: Start Process Element 2
CCAIRI- --- Message From: CALWFP While Processing: W1DR0806T
CCAIRI- --- Message: Start Process Element 3
CCAIRI- --- Message From: CALWFP While Processing: W1DR0806T
CCAIRI- --- Message: Start Process Element 4
CCAIRI- --- Message From: CALWFP While Processing: W1DR0806T
CCAIRI- --- Message: WF/PC Calibration Ending for observation
CCAI10-CALIBRATION END: 26-APR-95, 18:54:35
    
```

**1** Partitioning

**2** Editing

**3** Evaluation

**4** Conversion

**5** Comments, if any

**6** Calibration

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The calibration software used by the pipeline is exactly the same as that provided within STSDAS (**calwfp**). The calibration files and tables used were taken from the Calibration Data Base (CDBS) at STScI and were the most up-to-date calibration files available at the time the data was processed. All CDBS files are available to users through the HST Data Archive.

---

## 45.2 Calibration of WF/PC-1 Data

WF/PC-1 science data was calibrated in the pipeline using **calwfp**, available under the **hst\_calib** package. By using this IRAF/STSDAS task, the data can be recalibrated using the same software used in the routine calibration pipeline.<sup>1</sup>

The calibration software takes as input the raw WF/PC-1 data file pairs (Table 44.1 on page 44-2) `d0h/d0d`, `q0h/q0d`, `x0h/x0d`, `q1h/q1d` and any necessary calibration reference images or tables. The software determines which calibration steps to perform by looking at the values of the calibration switches (e.g., MASKCORR, BIASCORR, etc.) in the header of the raw data (`.d0h`) file. Likewise, it selects the reference files to use in the calibration of the data by examining the reference file keywords (e.g., MASKFILE, BIASFILE, BIASDFILE, etc.). The appropriate values of the calibration switches and reference file keywords depend on the instrumental configuration used, the date when the observations were taken, and any special pre-specified constraints. They were initially set in the headers of the raw data file in the RSDP pipeline during generic conversion; for recalibrating, they can be redefined (using **hedit** for example) and **calwfp** run on the raw files.

To determine what calibration steps the pipeline applied to the data and which calibration reference files were used to calibrate the data, examine the values of the calibration switches in the header of the raw (or calibrated) data. Prior to calibration, the calibration switches will have the value YES, NO, or PERFORM. After calibration, the switches for completed steps will have been assigned the value COMPLETE in the header keywords of the calibrated data file.

As with other header keywords, the calibration keywords can be viewed using any of several tasks, for example, **imhead**, **hedit**, or **hselect**. Alternately, the **chcalpar** task in the STSDAS **tools** package can be used to view the calibration keywords directly.

---

1. Online details about the WF/PC-1 calibration pipeline are available from within the IRAF help system using the `opt=sys` argument, type: `help wfpc opt=sys`



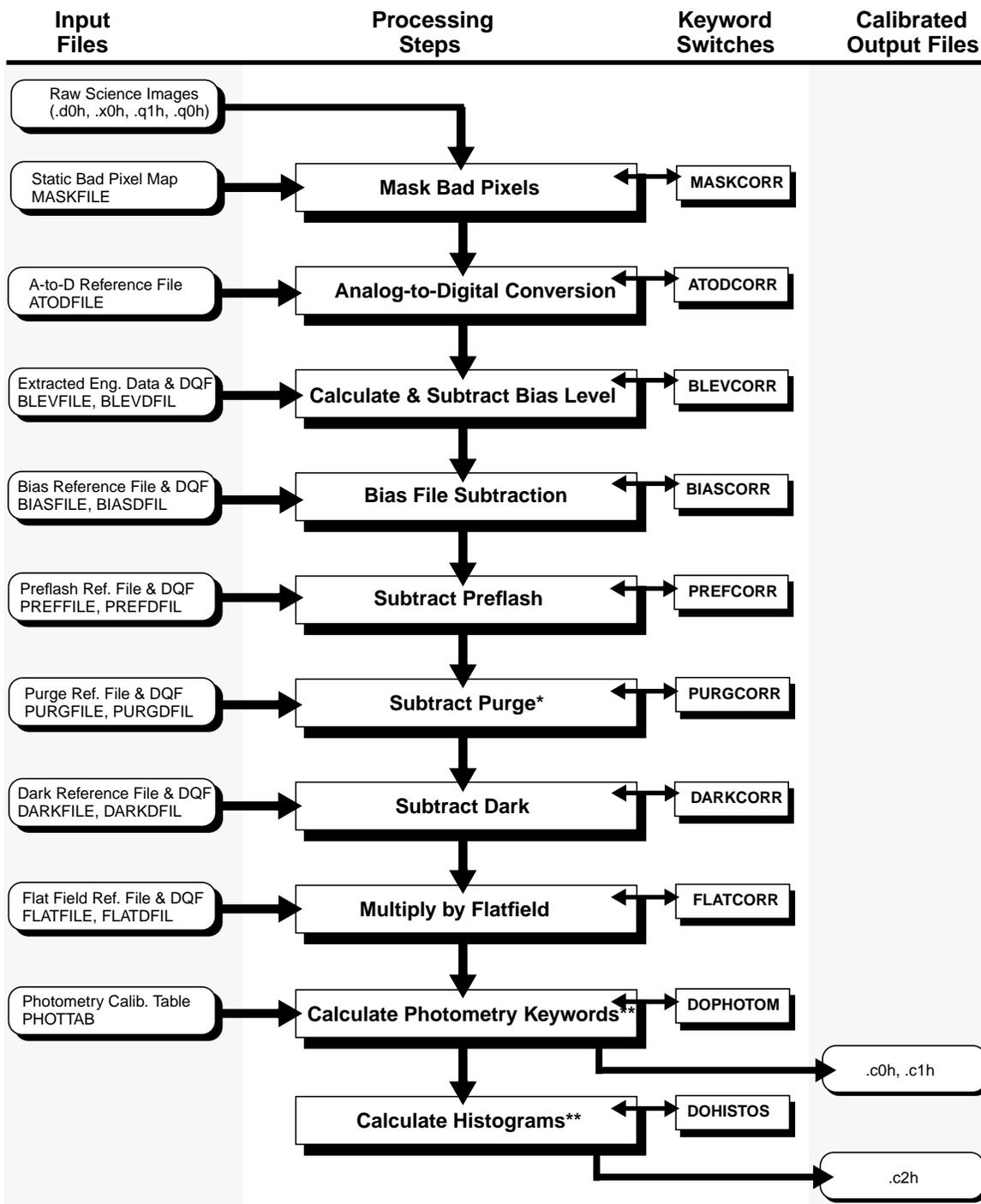
---

There are history records at the bottom of the header file of the calibrated data (as well as the calibration reference file headers). These history records sometimes contain important information regarding the reference files used to calibrate the data in the pipeline.

---

The flow chart below summarizes the sequence of calibration steps performed by **calwfp**, including the input calibration reference files and tables, and the output data files from each step. The purpose of each calibration step is briefly described in the accompanying table; a more detailed explanation is provided in the following section.

Figure 45.2: Pipeline Processing by calwfp



\* Purge subtraction was never implemented  
 \*\* This step does not change the science data

**Table 45.1:** Calibration Steps and Reference Files Used for WF/PC-1 Pipeline Processing

Switch	Processing Step	Reference File
MASKCORR	Update the data quality file using the static bad pixel mask reference file (MASKFILE), which flags defects in the CCD that degrade pixel performance and that are stable over time.	mask file (r0h)
ATODCORR	Correct the value of each pixel for the analog-to-digital conversion error using information in the A/D lookup reference file (ATODFILE).	atod file (r1h)
BLEVCORR	Subtract the mean bias level from each pixel in the science data. Mean values are determined separately for even column pixels (group parameter BIASEVEN) and odd column pixels (BIASODD) because bias levels exhibit column-wise pattern that changes over time.	extracted engineering file (x0h/ q1h)
BIASCORR	Subtract bias image reference file (BIASFILE) from the input science image and update output data quality file with bias image data quality (BIASDFIL).	bias file, bias DQF file (r2h/b2h)
PREFCORR	Correct for uneven illumination pattern produced by preflash by subtracting preflash reference file (PREFFILE) scaled by preflash lamp exposure (PREFTIME keyword). If no preflash was done, a correction called CTE fixup is done to correct charge transfer problem across gate.	preflash file, preflash DQF file (r3h/b3h)
PURGCORR	Remove residual effects of superpurge, which removes residual image from highly overexposed source. This step was not implemented in pipeline.	purge file (r4h/b4h)
DARKCORR	Correct for dark current by scaling dark image reference file and subtracting it from science data. Dark image is multiplied by total dark accumulation time (keyword DARKTIME).	dark file (r5h/b5h)
FLATCORR	Correct for pixel-to-pixel gain variation by multiplying by inverse flatfield image.	flatfield file (r6h/b6h)
DOSATMAP	Create an output data quality file (.c3h) that flags pixels that saturated the A/D converter. This is redundant because saturated pixels are flagged in the DQF (.c1h).	
DOPHOTOM	Determine absolute sensitivity using throughputs in photometry calibration table (PHOTTAB). This step does not change science data values.	phottab (cw0)
DOHISTOS	Create 3-row image (.c2h) for each group. Row 1 is a histogram of raw science values, row 2 the A/D corrected data, row 3 the calibrated image.	

---

## 45.3 Calibration Details

Each calibration step (and the keyword switches used to turn the step on or off) is described in detail in the following sections; the steps are performed in the following order:

1. Flag static bad pixels.
2. Flag saturated pixels.
3. Do analog-to-digital (A/D) correction.
4. Subtract bias level.
5. Subtract bias file.
6. Subtract preflash.
7. Subtract dark.
8. Multiply by inverse flatfield.
9. Calculate photometry keywords.
10. Calculate histograms.
11. Generate final science data quality file.

### 45.3.1 Static Mask

The static mask reference file contains a map of the known bad pixels and blocked columns. If this correction is performed (MASKCORR=YES), the mask is included in the calibration output data quality files. The mask reference file is identified in the MASKFILE keyword. The science data itself is not changed in any way; the STSDAS task **wfixup** can be used to interpolate across bad pixels flagged in the final data quality file (.c1h). Note, however, that the fixup is generally only done for image presentation; the interpolation can cause large errors in any photometry involving the flagged pixels.

### 45.3.2 Saturated Pixels

Pixels at the maximum level of the analog-to-digital (A/D) converter are automatically flagged in the calibration output data quality files (.c1h/.c1d). If the DOSATMAP correction is requested, an additional calibration output file is generated (.c3h/.c3d), containing a map of the saturated and missing pixels. Note, however, that this output file is redundant, since the same information is stored in the .c1h/.c1d.

### 45.3.3 A/D Fixup

All WF/PC-1 observations should have the analog-to-digital (A/D) correction performed. Due to a problem in the WF/PC-1 sample and hold circuitry, certain DN values are statistically more likely to occur than adjacent values. For this reason, a statistical correction is applied to the data using the A/D fixup file; there is no associated data quality file with the A/D reference file. Note that the correction is a statistical one—there will be some information that is not recoverable.

The A/D reference files may contain multiple look-up tables, which depend on the Bay 3 temperature (stored as degrees Celsius in the WBA3PCTM keyword of the observation). The first row in the A/D reference file consists of temperatures, while subsequent rows contain the lookup tables. That is, the second pixel in row one is the Bay 3 temperature associated with the second row A/D fixup values, the third pixel in row one is the Bay 3 temperature for the lookup table in the third row, and so on. However, since the Bay 3 temperature remained stable, only one lookup table is contained with the A/D reference file.

Note that the STSDAS task **mka2d** can be used to generate a lookup table. However, a table of the 48-bit errors are required as input (see *OV/SV Report*, Faber et al., 1992, Chapter 1).

### 45.3.4 Bias Level

The bias level is determined to first order from the extended register pixels which are in columns 3 through 14 of the extracted engineering files (.x0h/.x0d; if the image was done in area mode, the bias level is determined from the good pixels in column 1). Since the odd and even columns are at slightly (~0.6 DN) different levels (whose parity occasionally changes with a decontamination procedure), the bias level is separately determined and removed for even and odd columns (in **calwfp** versions after and including February 1992). The levels removed are stored in the group parameters BIASEVEN and BIASODD in the calibrated file, which can be examined with the IRAF task **hedit**. Note that the BIASEVEN keyword contains the average of the extracted engineering data (EED) columns 3, 5, 7, 9, 11, and 13 while the BIASODD keyword contains the average of EED columns 4, 6, 8, 10, 12 and 14.

### 45.3.5 Bias File

Once the bias level correction has been completed, any remaining bias pattern is removed by applying a bias file correction. The bias reference file is generated from a set of A/D and bias-level corrected zero-length exposures. The correction consists of subtracting the bias file from the observation and flagging in the .c1h/.c1d file any bad pixels noted in the bias file data quality file (.b2h/.b2d). Due to charge transfer problems, the bias calibration files do not make suitable corrections for dark current during readout, and this overhead time should be included in the DARKTIME used for dark correction.<sup>2</sup> (See *WF/PC-1 ISR 93j-01*).

### 45.3.6 Preflash/CTE File

A preflash was applied to circumvent the low level non-linearity in the CCDs: during readout, very low-level charge ( $< 250 e^-$  /pixel) was inefficiently transferred, smearing faint images. In addition, some charge ( $\sim 50e^-$ ) was completely lost, which adversely affected the photometry of even uncrowded fields. The preflash, which was requested by the observer, was done by imaging the shutter through a red filter, thereby imposing a low-level signal ( $\sim 30$  to  $40 e^-$ /pixel) on the image before the science exposure began.

The preflash reference files were generated from sets of bias files which were preflashed; the final reference files were scaled to 1 second. Since the two possible shutters (A or B) had different reflection patterns, there were separate preflash reference files for each shutter configuration (see note below). If the preflash time (PREFTIME) was larger than zero, the preflash reference file was multiplied by PREFTIME and subtracted from the image. The first row of each preflash file contains the charge transfer efficiency (CTE) correction (offsets for columns with poor charge transfer); if the preflash time was zero, the CTE fixup was done. Note that for preflashed images, the preflash reference file effectively includes the CTE fixup, so that the CTE correction is done during the subtraction of the preflash reference file.

For an external image, the SHUTTER keyword should indicate which shutter was in place during the preflash. The shutter used can be verified by extracting the engineering data to a table using the STSDAS **engextr** task and then using the **tdump** task to examine the table, for example:

```
st> engextr w0ts0n02t.x0h outtable=.
st> tdump w0ts0n02t row=77-78
```

The example above would write to the screen the values stored in rows 77-78 of the file `w0ts0n02t.tab` which contain the shutter status at the *end* of the image readout. Assuming that 1) there were no interruptions or multiple exposures before the readout, 2) SERIALS=NO, and 3) the observation is shorter than 300 seconds, the preflash shutter is the one opposite the shutter marked as closed in the table (e.g., if A is marked as closed in the extracted engineering table, B was used during the preflash).




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For exposures longer than 300 seconds, shutter B always closed the end of the exposure, regardless of the shutter used for preflash, so that the above algorithm fails—however, the difference between the A and B shutter blade preflashes was relatively small, less than about 0.5 DN. Shutter B was usually used to preflash long exposures, and that is the assumption used in calibrations. If the shutter blade is likely to be important for the observations, contact the STScI help desk ([help@stsci.edu](mailto:help@stsci.edu)) for help in determining the preflash shutter.

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2. See *WF/PC-1 Instrument Science Report 93-01*.

### 45.3.7 Dark File

A dark correction is required to account for the thermally-induced dark current which occurred during the image exposure; many of the hot pixels are corrected with the dark file as well (however, see “Hot Pixels” on page 46-5). Usually, the dark reference file is generated from ten or more individual dark frames (long exposures taken with the shutter closed) that have each had the standard calibration corrections applied (ATODCORR, BLEVCORR, BIASCORR, and PREFCORR). In addition, each frame is examined and residual images are excluded by a mask. If the dark correction is requested, the dark reference file (which has been normalized to 1 second) is scaled by the DARKTIME keyword value and subtracted from the observation.




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Note that the DARKTIME used in pipeline processing is only an approximation. For long exposures or data requiring very accurate dark correction, the darktime should be recalculated (see *WF/PC-1 Instrument Science Report 93-01*), inserted into the DARKTIME keyword, and then the images should be recalibrated. There was a problem in older data with the DARKTIME being improperly set for interrupted exposures; in these cases, the darktime must be manually computed from the WEXPODUR keyword and the DARKTIME keyword updated before recalibrating (see “Recalibrating WF/PC-1 Data” on page 45-20).

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### 45.3.8 Flatfield

The data are multiplied by a normalized, inverted flatfield in order to remove any pixel-to-pixel variations in the cameras. Flatfields used in the pipeline calibration were generated from sets of *earthcals* (observations of the bright earth). The general procedure for creating a pipeline flatfield was to combine a chosen set of earthcals using the STSDAS task **streakflat**, then normalize and invert using **normclip**. The code allows for the fact that some of the earthcals had streaks due to features on the earth being smeared by HST motion in the images.

Acquiring enough properly exposed earthflats was time-consuming, primarily due to the large variation in the earth’s albedo. In addition, the earth is too bright for some broadband filters, requiring the use of a neutral density filter (either the F8ND or F122M), which added features of their own which must then be removed. For these reasons, only two complete flatfield calibrations were planned, the first was completed during Science Verification (“SV”) and early Cycle 1 (“non-SV”), and the second was obtained during the second half of Cycle 2 through Cycle 3 (dubbed *closure flats*).



Care must be taken in choosing the best flatfield to use; flatfields generated from earthcalcs taken with the neutral density filters (F122M or F8ND) can contain gradients of 20-30%. See “Choosing Among Available Flats” on page 45-15 and “Flatfield Anomalies” on page 46-7 for details on the available flatfields.

### 45.3.9 Photometry Keywords

The photometry keywords are listed in Figure 45.3, below; the first two keywords are in the ASCII header (both `d0h` and `c0h`) while the last five keywords are group parameters (use the IRAF tasks **imheader** or **hedit** to examine the group keywords). (See “Converting Counts to Flux or Magnitude” on page 3-15).

**Figure 45.3:** Photometry Keywords

<b>Header parameters</b>	<pre>DOPHOTOM= 'YES ' / Fill photometry keywords: YES, NO, DONE PHOTTAB = 'wtab\$cbj15281w.cw0' / name of the photometry calibration table 'PHOTMODE' / Photometry mode      (for example, PC,5,F,DN,F1042M,OPEN,CAL) 'PHOTFLAM' / Inverse Sensitivity (erg/sec/cm<sup>2</sup>/Å for 1 DN/sec) 'PHOTPLAM' / Pivot wavelength (angstroms) 'PHOTBW ' / RMS bandwidth of the filter (angstroms) 'PHOTZPT' / Photometric zeropoint (magnitude)</pre>
<b>Group parameters</b>	

The PHOTTAB keyword is set by the PODPS pipeline during generic conversion; all other photometry keywords are blank or contain values of zero in the `.d0h` files. If the image is being recalibrated, use the StarView Calibration screens and consult the Reference File Memo on WWW for a listing of new photometry tables available for use.

Setting DOPHOTOM to “YES” instructs **calwfp** to populate the photometry-related keywords; no operations are performed on the actual images. The first step is to form the PHOTMODE keyword based on the values of other keywords (CAMERA, DETECTOR, FILTNAM, etc.) in the header. The **calwfp** task then searches the photometry table specified in PHOTTAB for the matching mode; the PHOTFLAM, PHOTZPT, PHOTPLAM, and PHOTBW values in the table are written into the `c0h` group keywords (see Table 44.3). If no matching PHOTMODE is found in the table specified by PHOTTAB, the keywords remain blank or zero. For more information about improving the photometric calibration, see “Improving the Photometric Calibration” on page 46-17.

### 45.3.10 Histograms

If this operation is requested (by setting DOHISTOS=YES), histograms of the raw data, the A/D corrected data, and the final calibrated output data are created and stored in the `.c2h/.c2d` image. This is a multigroup image with one group for each group in the calibrated data file. Each group contains a 3-line image

where row 1 is a histogram of the raw data values, row 2 is a histogram of the A/D corrected data, and row 3 is a histogram of the final calibrated science data.

### 45.3.11 Data Quality Files

Each calibrated science dataset contains a *data quality file* (.c1h for WF/PC-1). The **calwfp** software will bit-wise OR all of the raw data quality files (.q0h, .q1h) with the reference file data quality files (.b2h, .b3h, etc.), in order to generate the calibrated science data quality file (.c1h). The flag values used are defined in Table 45.2. The final calibrated data quality file (.c1h) should be examined (for example, using SAOimage or **imexamine**) to identify which pixels may be bad in the science image.



The bad pixels flagged in the .c1h file are not fixed up in the .c0h file. The STSDAS task **wfixup** can be used to interpolate across bad pixels in the science image; note however, that this results in a loss of information and can have adverse effects on any photometry using those pixels.

**Table 45.2:** WF/PC-1 Data Quality Flag Values

Flag Value	Description
0	Good pixel
1	Reed-Solomon decoding error
2	Calibration file defect
4	Permanent camera defect
8	A/D converter saturation
16	Missing data
32	Bad pixel

## 45.4 Should You Recalibrate?

Although some users will find that the calibrated data produced by the RSDP pipeline—the standard calibration—are adequate, most users will want to consider recalibrating. The pipeline calibrated the data with the most up-to-date, WF/PC-1-specific calibration reference files available at the time the data was pipeline processed. However, updated or timely reference files frequently did become available after the data were processed (e.g., new dark reference files and

the “closure” flatfields). Certainly if there are unusual features in the data or if the analysis requires a high level of accuracy, recalibration is necessary.

Finding that a calibration reference file has changed since the data were calibrated doesn’t always mean that recalibration is necessary. The decision depends very much on which calibration image or table changed, and whether that kind of correction is likely to affect the analysis. Retrieving and comparing the recommended and used calibration files to examine any differences can help in the decision to recalibrate. (The table tools in the STSDAS **ttools** package can be used to manipulate calibration tables; the images can be manipulated in the same ways as the science data.)

---

## 45.5 Improvements to Calibration Reference Files

All of the installed reference files contain HISTORY keywords at the end of the header which can be viewed using the IRAF **imhead** task. These keywords contain more detailed information about how the file was created and installed in the database.

Several types of reference files and their associated calibration processes have been improved substantially. The following lists types of calibrations that may benefit from recalibration due to the improvements:

- Improved BLEV correction, as of February 1992. **calwfp** determines and removes odd and even column levels separately.
- Bias reference files for PC and WF were improved in August 1993: 40% lower noise than previously.
- Preflash reference files for PC and WF also improved in August 1993: noise was reduced by a factor of two.
- Since the WF/PC-1 darks were found to be time-variable (see *WF/PC-1 Instrument Science Report 93-01*), additional calibration observations were obtained and dark reference files generated for specific time intervals. There are now more than a dozen dark reference files for each camera, covering the time period July 1991 through November 1993. Please refer to the WWW Reference File Memo to identify the best dark to use for the data based on the date the science observation was taken (DATE-OBS keyword in .d0h file).
- Many new and improved flatfields were generated and installed in the Archive after the end of the WF/PC-1 mission (see sections “Choosing Among Available Flats” on page 45-15, and “Improving the Flatfield Correction” on page 46-15); the WWW Closure Flatfield and Reference file memos offer more details about these files and their use. Note that many of the early flatfields were generated from earthcals taken with a neutral density filter (F122M or F8ND); these flats can have residual intensity gradients of up to 20–30% across the field of view.



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See the following sections and Chapter 46 for information on the various error sources in WF/PC-1 calibrated data and suggestions for further improving the calibration, particularly the flatfielding.

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## 45.6 Determining the “Best” Reference Files

We refer to a “best” reference file for a given dataset. This section explains what “best” means and how the best files can be determined for WF/PC-1 data, using both the WWW memos and StarView.

Calibration reference files are specific to each instrument configuration and observing mode; in addition, monitoring has shown that some instrumental properties change with time. Therefore, calibration reference files can be time-tagged, indicating that they should be used with data taken within a specific range of dates. The best set of reference files for calibrating the observation (according to the pipeline) will therefore depend on the instrument configuration and observing mode that was used and the date when the observation was taken.

StarView, the interface to the HST catalog and Archive, can be used to determine the current best available reference files for any dataset and to retrieve those files from the HST Archive (Chapter 1 describes how to use StarView to access the HST catalog and archive). The Calibration Reference screens (one per instrument) in StarView can be used to obtain a listing of the current best reference files for any dataset and a listing of the files that were originally used to calibrate the dataset by the RSDP pipeline. Figure 45.4 shows StarView being used to determine the best and used calibration reference files for one particular WF/PC-1 observation. Either the used or the recommended (or both) reference files can be marked for retrieval and fetched from the Archive using FTP, as shown in the StarView tutorial in Chapter 1.

### 45.6.1 When is “Best” Not the Best?

The current limitation of StarView, and the reference files chosen automatically by the pipeline, is that only one “best” reference file can be specified. Frequently, there are several possible reference files that are appropriate and the files used may not be the optimal calibration files for some purposes, depending upon the scientific objectives.

For this reason, we highly recommend checking the Reference File and other memos on WWW, at:

```
http://www.stsci.edu/ftp/instrument_news/WFPC/  
wfpc1_memos.html
```

This memo suggest possible alternate reference files that can be used for recalibration. These memos summarize the file names and histories of available

reference files, as well provide more detailed information about the nature and quality of each reference file. For high accuracy in the science analysis, it is best to try using several different reference files to calibrate the data, to see which ones give the best results and to empirically determine the degree of uncertainty in the data attributable to the choice of reference file.

**Figure 45.4:** Finding Best Reference File Using StarView

< WFPC Reference Files – Search Results >

File Searches Constraint View Retrieve Customize Options Comments Help

PI : WESTPHAL Proposal ID : 4769

Target : 3C273-OFFSET

Rootname: W19C0101T Filter1: 29 Camera: PC Mode: FULL

Filter2: 0 Clock: OFF Shutter: B

Orien,A : -15,528 Orien,B: 74,383d Orien,C: 165,483 Orien,D: -105,02

	USED	RECOMMENDED	PERFORMED
A-to-D Correction:	WREF#C261402TW,R1H	C261402TW,R1H	DONE
Bias Correction:	WREF#C261403LW,R2H	D8C0826NW,R2H	DONE
Dark Current Correction:	WREF#C6116491W,R5H	D9G1345QW,R5H	NO
Flat Field Correction:	WREF#C191643EW,R6H	C191643EW,R6H	DONE
Static Pixel Mask:	WREF#BB61518LW,R0H	BB61518LW,R0H	DONE
Preflash Correction:	WREF#C8E0940GW,R3H	D8C08267W,R3H	DONE
Purge Reference File:	WREF#9CK10279W,R4H	9CK10279W,R4H	NO
Engineering File:	WCAL#W19C0101T,X0H		DONE
Photometry Cal. Table:	WTAB#CBJ15281W,CW0	CBJ15281W,CW0	DONE

Step Forward Step Back Mark USED Files for One Dataset

Scan Forward Scan Back Mark RECOMMENDED for One Dataset

Edit Search Constraints Mark USED Files for All Datasets

Write Search Results to File.. Mark RECOMMENDED for All Datasets

Retrieve Data Strategy Unmark All Files for One Dataset

Record 1 of 1 (in progress) Unmark All Files for All Datasets

Exit Screen ^Z

Use up/down arrow keys in data area to scroll full list of calibration files.

MESSAGE: More records available. Use record controls to view search results

## 45.6.2 Choosing Among Available Flats

A history of all flatfield reference files generated and delivered to the HST Archive is maintained in the Reference File memo on WWW, at:

[http://www.stsci.edu/ftp/instrument\\_news/WFPC/wfpc1\\_memos.html](http://www.stsci.edu/ftp/instrument_news/WFPC/wfpc1_memos.html)

This file is updated as new files are added. The flatfields listed in the memo include those used in the pipeline as well as some alternate flatfields, which were never used in the pipeline but which may be of use in recalibration. The Reference File memo provides a single one-line history comment for all files; for example, some reference file changes only involved keyword changes to the header and do not affect the data. On the other hand, some flatfield reference files were mere placeholders until data could be obtained and a flatfield generated and delivered. These placeholder flatfield files contained only values of 1 in order to prevent the routine pipeline processing from crashing yet avoid applying an improper correction. The same wfpc1\_memos WWW site also provides links to more detailed memos concerning specific reference files listed in the Reference File memo, such as the Closure Flatfields, the Super-Sky (MDS) Flatfields, and the Delta Flat Corrections.



See Chapter 1 for information about how to retrieve the flats (and other reference files) from the HST Archive. See Chapter 46 for more information on improving the calibration of WF/PC-1 data.

There were two main epochs of flatfields, dubbed “SV” and “non-SV” (Science Verification), and “closure” flats. The SV flats were generated from data taken between July 1991 and January 1992 and delivered to STScI in early 1992 by the WF/PC-1 Investigation Definition Team (IDT) (see *OV/SV Report*). All of these flats were reformatted and installed in CDBS (the Calibration Data Base); camera and filter combinations are given in Table 45.3. The STScI WF/PC-1 group generated and installed into the pipeline, flatfields for the non-SV camera and filter combinations (also referred to as “Cycle 1”); these are listed in Table 45.4.

**Table 45.3:** SV Flatfield Camera and Filter Combinations

Camera	Filters						
WF	F230W	F284W	F336W	F375N	F439W	F487N	F502N
	F547M	F555W	F622W	F631N	F656N	F658N	F673N
	F702W	F785LP	F889N				
PC	F230W	F284W	F336W	F469W	F487N	F502N	F517N
	F555W	F656N	F658N	F664N	F673N	F702W	F718M
	F785LP	F889N					

**Table 45.4:** Non-SV Flatfield Camera and Filter Combinations

Camera	Filters						
WF	F492M	F502N	F569W	F588N	F606W	F673N	F675W
	F725LP	F791W	F814W	F850LP	F875M	F889N	F1042M
	F1083N						
PC	F368M	F413M	F517N	F569W	F588N	F606W	F631N
	F648M	F664N	F675W	F718M	F725LP	F791W	F814W
	F850LP	F875M	F1042M				

Earthcal observations for the final Cycle 2 and 3 closure flatfield set were taken after August 2, 1993. The closure flats were generated in the same manner as previous cycles, using the IRAF/STSDAS tasks **streakflat** and **normclip**. In addition, the STSDAS **wfixup** task was used to interpolate across known bad pixels (the fixed pixels are flagged in the flatfield DQF file, suffix b6h/b6d). As for all reference files, users are encouraged to refer to the HISTORY records in the file headers for details about the generation of the file. The closure flats were installed in CDBS, the Reference File Memo updated, and a detailed Closure Flats Memo posted on WWW; filter and camera combinations are given in Table 45.5.



Closure flatfields are not only useful for 1993 WF/PC-1 data, but along with an appropriate delta flat, are useful for recalibrating older data as well.

**Table 45.5:** Closure (Cycle 3) Flatfield Camera and Filter Combinations

Camera	Filters						
WF	F336W <sup>a</sup>	F368M <sup>b</sup>	F375M <sup>ab</sup>	F413M <sup>cd</sup>	F439W <sup>d</sup>	F487N <sup>ab</sup>	F502N <sup>ab</sup>
	F517N <sup>c</sup>	F547M <sup>cd</sup>	F555W <sup>c</sup>	F569W <sup>cd</sup>	F588N <sup>ab</sup>	F606W <sup>d</sup>	F622W <sup>cd</sup>
	F631N	F648M <sup>c</sup>	F673N <sup>b</sup>	F702W <sup>d</sup>	F785LP <sup>d</sup>	F791W <sup>c</sup>	F850LP <sup>d</sup>
	F889N <sup>ab</sup>	F1042M <sup>ab</sup>					
PC	F336W	F368M <sup>a</sup>	F413M <sup>a</sup>	F439W <sup>a</sup>	F492M <sup>cd</sup>	F517N <sup>ab</sup>	F547M <sup>b</sup>
	F555W <sup>cd</sup>	F569W <sup>c</sup>	F606W <sup>cd</sup>	F622W <sup>cd</sup>	F648M <sup>c</sup>	F664N <sup>b</sup>	F673N
	F675W <sup>cd</sup>	F702W <sup>cd</sup>	F718M <sup>c</sup>	F725LP <sup>c</sup>	F785LP <sup>c</sup>	F791W <sup>c</sup>	F814M <sup>c</sup>
	F875M <sup>ab</sup>	F889N <sup>cd</sup>	F1042M				

a. Multiple versions of flatfields available: one taken without the F8ND filter and one taken with F8ND.

b. Multiple versions of flatfields available: one taken without the F122M filter and one taken with F122M.

c. Flatfield generated from data taken only with neutral density filter F122M.

d. Flatfield generated from data taken only with neutral density filter F8ND.

Particularly for science data taken in the same epoch as the streakflats (August 2, 1993 to December 1993), the closure flats will generally be the best choice for flatfielding. For data taken between the August 7, 1992 and August 2, 1993 decontaminations, the closure flatfields may be the better choice, as long as an appropriate delta flat is used as well. The older Cycle 0 and 1 flatfields may be most appropriate for data taken before February 1992, before the appearance of the “permanent measles”, since the closure flats do contain the measles features. Delta flats, discussed in the next section, may be used to correct any epoch of flatfield to any science data epoch.

In addition, some of the closure flats are considered to be “high-fidelity”, that is, they are flatfields where various features (such as the 30% intensity gradient due to the F122M filter) in the input earthcals have been removed; in addition, an attempt was made to remove the ~5% artifacts present in some earthcals due to short exposure reciprocity failure. Filter and camera combinations for high fidelity flatfields available from the HST Archive are given in Table 45.6. Please refer to the Closure Flat memo on WWW for names and details of specific flatfields; the memo outlines the history of all closure flatfields as well as the procedure for creating additional high fidelity flatfields if needed:

[http://www.stsci.edu/ftp/instrument\\_news/WFPC/wfpc1\\_memos.html](http://www.stsci.edu/ftp/instrument_news/WFPC/wfpc1_memos.html)

**Table 45.6:** Closure “High Fidelity” Flatfield Camera and Filter Combinations

Camera	Filters						
PC	F336W	F368M	F413M	F439W	F492M	F517N	F547M
	F555W	F569W	F606W	F622W	F648M	F664N	F673N
	F675W	F702W	F718M	F725LP	F785LP	F791W	F814W
	F875M						

### 45.6.3 Choosing and Generating Delta Flats

Observations taken during one epoch (time period between decontamination events) and processed with flatfield reference files created from data taken during a different epoch may require a delta flat correction to correct for QE changes that occurred during the decontaminations<sup>3</sup>. A delta flat, generated from ratios of INTFLATs, can also be used to reduce, although not eliminate, the effects of the measles contamination. In practice, since the pipeline flatfields are inverse flats (**calwfp** multiplies the science data by the FLATFILE specified in the .d0h header), the delta flat correction is the ratio of an INTFLAT of the same epoch as the flatfield calibration file divided by an INTFLAT taken close in time and wavelength to the science observation to be corrected. The calibrated pipeline image is multiplied by the appropriate delta flat:  $F = C \times D$  where  $F$  is the final

3. Decontamination events occurred January 1991, May 1991, July 1991, February 1992, March 1992, August 1992, and August 1993 (see Table 46.1 for details).

image, C is the calibrated pipeline product image (.c0h) which has had the flatfield reference file applied, and D is the delta flat.

The INTFLATs were taken by illuminating the backside of one of the two shutter blades (A or B) with internal lamps. Due to variations in the shutter blade reflectivities, all INTFLATs used in a delta flat must have been taken with the same shutter blade (given by SHUTTER keyword). Since the flatfields and measles features have been found to depend on wavelength, the delta flat (or INTFLATs) closest in filter to the observation will provide the best possible correction. Note that prior to the development of the persistent measles in February 1992, regular INTFLATs were being obtained using a relatively small number of filters; therefore, INTFLATs for the baseline epoch, and thus the resulting delta flats, are available for only a small number of filters. However, after February 1992, the delta flat proposals were greatly expanded in order to obtain INTFLATs in nearly 20 filters in each camera; these may allow the correction of the closure flatfields to data taken prior to August 1993.

Delta flats that have been generated were archived into CDBS and can be retrieved from the HST Archive; delta flat file suffixes are r8h/b8h for the data file and its data quality file, respectively. Listings of the file names can be found in the delta flat memo that is currently available through the World Wide Web at:

[http://www.stsci.edu/ftp/instrument\\_news/WFPC/wfpcl\\_memos.html](http://www.stsci.edu/ftp/instrument_news/WFPC/wfpcl_memos.html)

For some epochs, there are two types of delta flats available for use, *average delta* and *individual delta flats*. The average delta flats were created by averaging all the individual delta flats taken between decontaminations (dates of all decontaminations are listed in the delta flat file). These average delta flats are partially corrected for cosmic rays, and therefore, should be used whenever possible. The closure delta flats, generated from INTFLATs taken August 8, 1992 through November 1993, have all been cosmic ray corrected using the STSDAS **crrej** task and **wfixup** to average across questionable pixels. Note that a subset of the closure flats already include the appropriate delta flat correction; the Closure Flat Memo flags these appropriately.




---

Custom delta flats can be generated from internal flats observations retrieved from the HST Archive using StarView.

---

One use of the delta flats is to back-correct the Closure flats for use with earlier Cycle science data. For example, to adjust a hi-fi Cycle 3 flat for use with Cycle 1 data, find 2-3 INTFLATs for a nearby filter near the time of the science observations, and find 2-3 INTFLATs taken during Cycle 3 (after Aug 2, 1993). After retrieving and recalibrating these INTFLATs with the best reference files, removing cosmic rays and combining (e.g., with STSDAS **crrej**), the Cycle 1 “high-fidelity” flatfield is created by simply multiplying the Cycle 3 hi-fi flatfield by the ratio of the cleaned internals (e.g., with IRAF **imcalc**). Since the flatfields used by calwfp are inverse flats, the ratio is Cycle 3 divided by Cycle 1, that is:

$$\text{Hi-Fi (Cycle 1)} = \text{Hi-Fi (Cycle 3)} * (\text{clean Cycle 3 intflat}) / (\text{clean Cycle 1 intflat})$$

## 45.7 Recalibrating WF/PC-1 Data

This section describes the mechanics of doing a recalibration. The steps in recalibrating a dataset include choosing and assembling any necessary reference files or tables and the raw data files, setting the desired switches and updating the calibration reference file names in the header of the `.d0h` (raw data) file, and finally, running the calibration software, **calwfp**.

In order to recalibrate the data, *all* of the reference files and tables that are used by the calibration steps to be performed should be retrieved (see previous section for advise on choosing reference files). We suggest copying the raw data files required for input to the calibration routines and the required reference files and tables to a subdirectory to be used for recalibration. This will preserve the original files. How to identify and retrieve the calibration reference files necessary to recalibrate the data was described in the previous section.

The next step is to set the calibration switches and reference keywords in the header of the raw data file (`.d0h`); these control how the data is recalibrated and which reference files are used at each step in the process. The switches and keywords are changed with the **chcalpar** task but can also be done with **hedit**.

The **chcalpar** task in the STSDAS **hst\_calib.ctools** package takes a single input parameter—the name(s) of the image files to be edited. When the **chcalpar** task is started, it will automatically determine the instrument used to produce that image and will open one of several parameter sets (psets) that will load it with the current values of the header keywords. The WF/PC-1 pset is **ckwwfpc**.

For example, one method of editing the calibration keyword values would be:

1. Start the **chcalpar** task, specifying the image(s) in which the keyword values require changing. If more than one image is specified, for example using wildcards, the task will take the initial keyword values from the first image. For example, to change keywords for all WF/PC-1 raw science images in the current directory (with initial values from the first image), use the following command:

```
wf> chcalpar w*.d0h
```

2. When **chcalpar** begins, it will bring up **epar**—the IRAF parameter editor, which can be used to edit the pset of calibration keywords. Any of the values of the calibration switches, reference files or tables to the values can be changed as desired for recalibration.
3. To exit the editor, type `:q` two times. The task will inquire whether the current settings are correct. Typing “y” will save the settings and return the IRAF CL prompt. Typing “n” will bring back the editor, to re-define the settings. Typing “a” will return the IRAF CL prompt without saving any changes. For additional examples of updating the calibration keywords, check the online help by typing `help chcalpar`.

The calibration reference file names in the header of the raw data (i.e., the `d0h` file) are typically preceded by five characters (e.g., `wref$` for calibration images and `wtab$` for calibration tables) which are pointers to the location on disk where

the files are to be found by the calibration software. Before running the calibration routines, these variables must be set to the location of the reference files (and x0h/q1h raw data files). For WF/PC-1 data, the variables to set are:

```
to> set wref = "/nemesis/hstdata/"
to> set wtab = "/nemesis/hstdata/"
to> set wcal = "/nemesis/hstdata/"
or, on VMS
```

```
to> set wtab = "DISK$SHARE:[HSTDATA]"
```

where the directory name in double quotes is the local directory where the calibration reference files and tables reside.

Once the calibration keywords in the header of the raw data file are set properly, the data can be recalibrated. The WF/PC-1 calibration software, **calwfp**, is executed by typing the name of the task followed by the *rootname* of the observation dataset. For example, to recalibrate the dataset w0w10e02t and write the log of the results to the file calwfp.c.log (rather than to the screen), type:

```
hr> calwfp w0w10e02t > calwfp.c.log
```



To avoid overwriting existing calibration files, specify a different output file name, for example:

```
wf> calwfp w0w10e02t wfpc_out > wfpc.c.log
```

For more information about how these routines work, use the on-line help:

```
cl> help calwfp
```

### 45.7.1 Calculating Absolute Sensitivity for WF/PC-1

If DOPHOTOM is set to NO before running **calwfp**, then the values of the inverse sensitivity (PHOTFLAM), pivot wavelength (PHOTPLAM), RMS bandwidth (PHOTBW), zero point (PHOTZPT), and observation mode (PHOTMODE) will not be written to the header of the recalibrated data file. The DOPHOTOM calibration step does not alter the values of the data (which are always counts or data numbers in the calibrated file), but only writes the information necessary to convert counts to flux into the header file. Therefore, unless the absolute sensitivity for the observation must be recomputed (e.g., because a more recent throughput table exists for the observing mode), the keyword values from the original calibrated file can be used.

To recalculate the absolute sensitivity, set DOPHOTOM=YES in the .d0h file before running **calwfp**, or alternately, use the tasks in the **synphot** package of STSDAS.



---

See “Improving the Photometric Calibration” on page 46-17 for suggestions on improving the WF/PC-1 photometric calibration.

---

To calculate the absolute sensitivity, **calwfp** and the **synphot** tasks use a series of component lookup and throughput tables. These tables are not part of STSDAS itself, but are part of the **synphot** dataset, which can be easily installed at your home site (see “Getting the synphot Database” on page A-15 for information about how to do this).



---

The **synphot** dataset *must* be installed in order to recalculate absolute sensitivity for WF/PC-1 data using **calwfp** or **synphot**.

---

Table 46.4 provides a summary of the expected accuracy of calibrated WF/PC-1 data produced by the pipeline. For a more in depth discussion of the origin of these accuracies, of problems which can prevent these levels of accuracies from being obtained, and of ways to achieve higher accuracy than those routinely obtained, see Chapter 46.

# WF/PC-1 Error Sources and Data Analysis

### In This Chapter...

Effect of Decontaminations / 46-2
Scattered Light / 46-2
Persistent Measles / 46-2
Hot Pixels / 46-5
Cosmic Rays / 46-6
Flatfield Anomalies / 46-7
Photometry / 46-9
PSFs / 46-11
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Data Accuracies and Problem Solving / 46-13
Improving Bias, Preflash, and Dark Calibration / 46-14
Improving the Flatfield Correction / 46-15
Improving the Photometric Calibration / 46-17

In this chapter, we provide details about residual effects that may be affecting the robustness of the calibrated WF/PC-1 data, including:

- Effect of Decontaminations.
- Scattered light.
- Persistent measles.
- Hot pixels.
- Cosmic rays.
- Flatfield anomalies.
- Photometry.
- Plate distortion.

Additionally, we provide information for deconvolving WF/PC-1 images.

Further, these sections contain suggestions for further improving upon the calibration and analysis of WF/PC-1 data. A more general discussion of various image plotting and manipulation tasks is described in the STSDAS chapter of this book; please refer to that section for details on how to work with the positional information in the image, use metric, use **synphot** to re-derive the flux scale, and remove cosmic rays and image defects.

---

## 46.1 Effect of Decontaminations

The structure of the WF/PC-1 flatfields and the UV throughput was changed by any decontamination (decon) procedure. Decontaminations were normally done to:

- Improve blue performance.
- Reduce internal scattered light.
- Temporarily restore UV transmission and reduce contaminations.

See “Flatfield Anomalies” on page 46-7 below and “Photometry” on page 46-9 for corrections to apply to the data to compensate for the decons; note, too, that **synphot** can be used to determine and apply a contamination correction (use the CONT keyword in the OBSMODE; see *WF/PC-1 ISR 96-02* ).

Decons were performed under either of two conditions: 1) after every WF/PC-1 or HST safe mode entry which turns off the WF/PC-1 Thermal Electric Coolers (TECs) or 2) after about 9 or more months of continuous cold operation. Table 46.1 summarizes the WF/PC-1 decon activities.

---

## 46.2 Scattered Light

The WF/PC-1 cameras are known to suffer from a time-dependent loss of throughput as well as an increase in scattered light during the time periods following a decontamination procedure. Both effects are believed to be due to the slow growth of contaminants on the field flattening windows in front of the CCDs. The scattered light changes are estimated from internal flatfields, by determining the ratio of the intensity beyond the pyramid vertex to the intensity at chip center. The figure below summarizes the scattered light behavior of all eight chips since early 1991; decontamination episodes are marked with the vertical dotted lines.

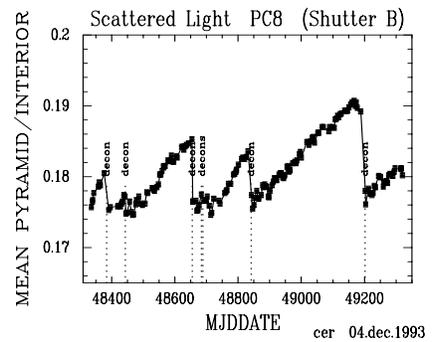
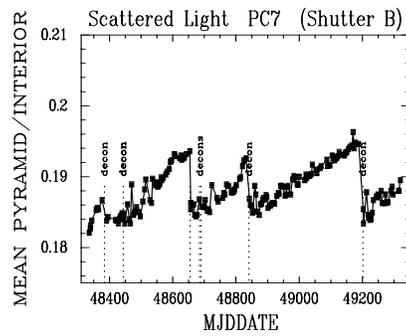
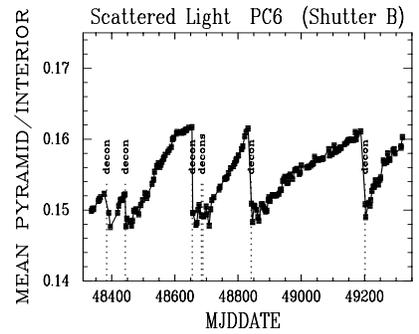
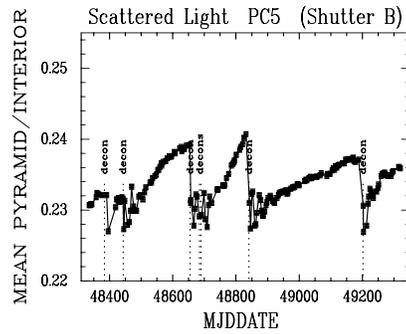
---

## 46.3 Persistent Measles

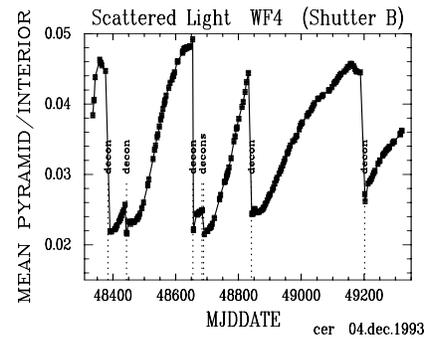
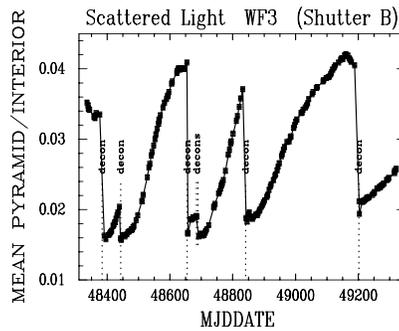
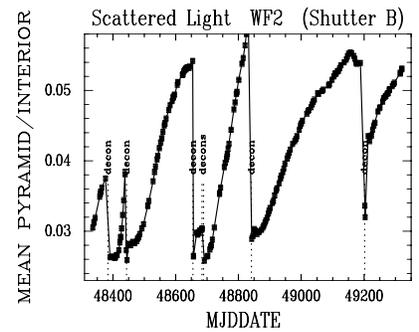
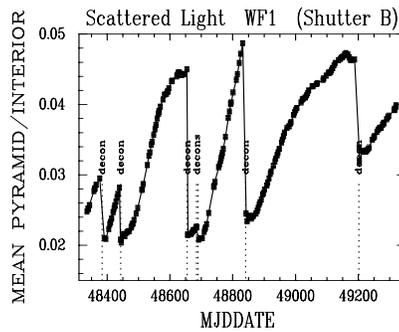
The WF/PC-1 camera heads were decontaminated on February 3, 1992 (day 034), following a long period of continuous cold operation of the WF/PC-1 CCD

Figure 46.1: Scattered Light Versus Time

**Planetary Camera Chips**



**Wide Field Camera Chips**



WFPC-1/ 46

**Table 46.1:** WF/PC-1 Decontamination Events

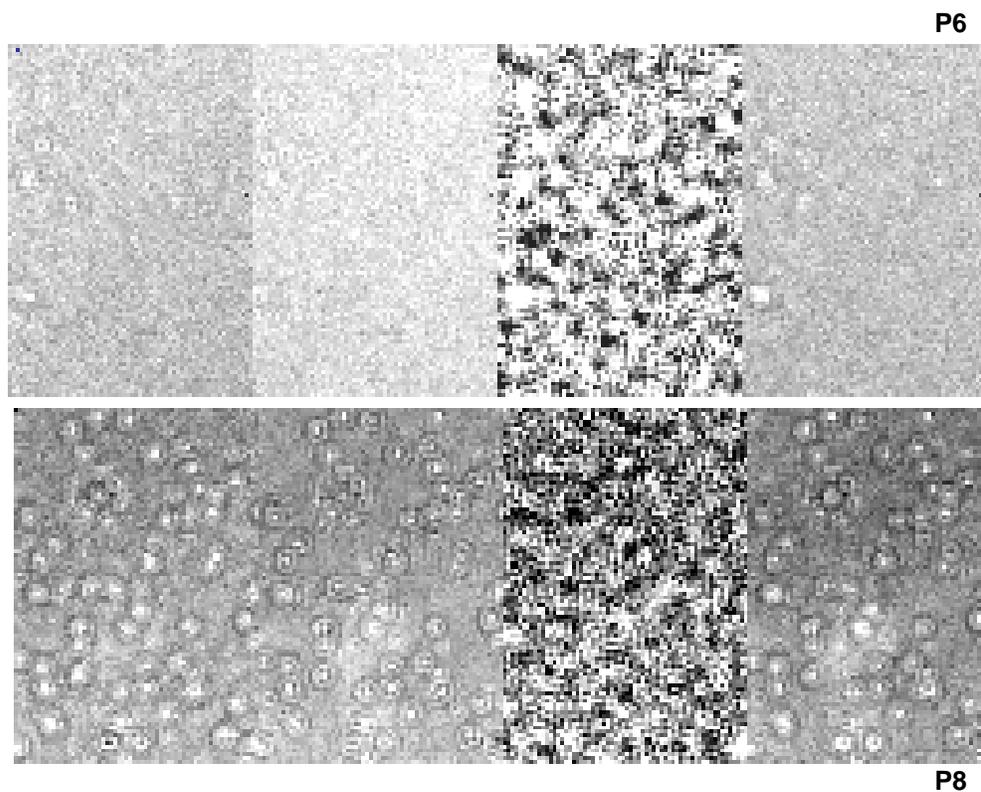
Date	DOY	Activity	
1990	Dec 31	365	Telescope safes (FGE 3 bit flip); UV flood
1991	Jan 2	002	Mini-low-temp decon
	Jan 26	026	De-ice decon (-82C)—failed to remove daisies
	Jan 28	028	Mini-low temp (-20C)—removed daisies, created measles
	Jan 29	029	Low-temp decon (-15C)—removed measles
	May 2	122	PSEA hardware safe mode, CCDs at -35 for 80 hours, created measles
	May 8	128	Hot-junction decon (+12C)—removed measles
	Jul 3	184	WIDLE turned WFC TEC off for 7 hours WFC reached -25C, created measles
	Jul 5	186	Flash decon (+6C)—removed measles
1992	Feb 3	03/4	Flash decon—restored UV transmission, removed scattering but made persistent measles
	Feb 4	035	Flash decon (same as day 034)—p.measles still present
	Mar 3	063	Hot junction decon—p. measles still present
	Mar 8	68	Flash decon—persistent measles still present
	Aug 7	220	Flash decon (CCDs +3.5C to +8.5)
1993	Aug 2	214	Modified flash decontamination

detectors during which many science observations were obtained. The decontamination procedure restored UV transmission (temporarily), blue performance, and reduced the internal scattered light. It also made the expected small changes in the flatfield structure but did not re-introduce QEH.

However, unlike previous decontaminations, the February 3, 1992 procedure caused the re-appearance of the measles contaminant. These permanent spot-like features, dubbed *persistent measles*, are generally a few pixels in radius; some have light cores, some have dark cores but all appear surrounded by one or more weaker rings. On an uniformly illuminated source (i.e., flatfield) they produce a 1.1% rms modulation with a 4 to 5% peak amplitude in their cores. Optical modelling finds them to be consistent with 10–15  $\mu\text{m}$  sized particles on the field flattening windows. A likely cause of persistent measles is the usage of the pyramid motor without a sufficient cool down period between motions. This often occurred during the SV flatfield observations (fourth quarter of 1991); the waiting period between pyramid motions was increased after the problem was recognized.

Detectors WFC2 and PC6 were the least affected CCDs while PC7 and PC8 were probably the most affected. Figure 46.2 shows a 100 x 100 region of the PC6 and PC8 detectors (divided by a flat taken before the measles problem appeared) at 4 epochs. The third from the left is after an HST safing event and illustrates the *post-safing measles* which the decontamination procedures regularly removed. The display range in Figure 46.2 is about  $\pm 10\%$  about the mean.

**Figure 46.2:** Persistent Measles



Precision photometry and astrometry of images with measles will be degraded. Applying an appropriate delta flat may partially correct for the measles; however, because the measles are out-of-focus features, a delta flat will not completely remove their effect. In addition, image deconvolution can actually enhance the measles, since they are roughly the same size as the PSF. In this case, delta flats may prove useful as a template, to allow differentiation of target features and measles.

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## 46.4 Hot Pixels

A hot pixel has been defined as a pixel whose dark current exceeds 0.01 DN/sec (usually few hundred per chip). Time variability has been seen in the hot pixels (*Instrument Science Report 93-01*) with the following characteristics:

- The number of hot pixels gradually increases over time (about 30 new pixels per month per CCD).
- The number of hot pixels decreases (by 10–30%) after decontamination procedures.
- Individual pixels evolve: some undergo large variations in count rate, others remain constant in time, a very few decrease at times other than decons.

The pipeline calibrates the data with time averaged dark files: these files have improved signal-to-noise, but don't correct for time variations in the hot pixels. If hot pixels are more of a concern than signal-to-noise, a custom dark file could be generated from dark frames taken close in time to the observation, and that alternate dark used to recalibrate the data. Some alternate dark reference files have been generated and are listed in the WWW WF/PC-1 Reference File Memo. It is also possible to generate a more appropriate reference file from a set of individual dark frames available through the STScI Archive; this can be done using **crrej**.

Through April 1993, two dark frames were usually obtained each month. As of May 1993, additional darks were taken, for a total of about 12 per month for each camera. By calibrating with a reference file generated from dark frames taken within one month of the science observation, it is possible to reduce the number of residual hot pixels by nearly an order of magnitude. Suspect pixels can be compared with new lists of known hot pixels which are kept on WWW.

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## 46.5 Cosmic Rays

The WF/PC-1 Investigation Definition Team (IDT) (*OV/SV Report*, 1992) analyzed several different cases, based on specific pixel threshold levels; two of these are summarized in the short table below.

**Table 46.2:** Cosmic Ray Events by Threshold Level

Threshold	Count Rate of Cosmic Ray Events Above Threshold	Average Number per Event
9 DN	4.7 pixels/sec/CCD	2.7 pixels
20 DN	3.2 pixels/sec/CCD	1.88 pixels

The event rate is estimated at about 1.7 events per second per CCD. As expected, long observations are most affected by cosmic ray events. Generally any exposure longer than 10 minutes is split into multiple integrations unless it was specified otherwise by the observer. The STSDAS task **crrej** may be used to correct a series of images for cosmic rays.

## 46.6 Flatfield Anomalies

The photometric accuracy of the data is often limited by the quality of the flatfield used to calibrate the data (see “Determining the “Best” Reference Files” on page 45-14 as well as the WWW Reference File and Closure Flat Memos). Details of the flatfields and delta flats available for calibration were discussed in “Determining the “Best” Reference Files” on page 45-14. In this section, we summarize residual features that may remain; we recommend experimenting with different flatfields to determine which are best for the data (see “Improving the Flatfield Correction” on page 46-15).

- ***Changes due to decontaminations.*** The flatfields are relatively stable between decontamination procedures; however, they do undergo some incremental changes across decontaminations. These changes are usually at the few percent level and so, may not be important for some observations<sup>1</sup>; if necessary, the changes may be corrected using an appropriate delta flat (see “Choosing and Generating Delta Flats” on page 45-18).
- ***Time variability due to scattered light changes.*** Following a decontamination, the gradual buildup of contaminants causes an increase in the scattered light (see “Scattered Light” on page 46-2); the corners of the internal flatfields used to monitor the instrument performance are seen to droop relative to the chip centers. Note also that the dust features change character in response to the increase in scattered light.
- ***UV throughput decreases over time.*** The buildup of contaminants responsible for the increase in scattered light also causes a corresponding decrease in throughput (see “Photometry” on page 46-9 and *WF/PC-1 Instrument Science Report 93-02*).
- ***Persistent measles after February 1992.*** These features are at the ~1% rms level, although the cores can deviate by up to 5% or more. See “Persistent Measles” on page 46-2 for more details.
- ***Large gradients caused by F122M.*** Due to the Earth’s albedo, some broadband filters had to be taken in conjunction with a neutral density filter (either F8ND or F122M) to obtain sufficient numbers of unsaturated earth-flat observations for creating reference files. The F122M filter, designed as a short wavelength pass filter, had a red leak that was used to provide neutral density at long wavelengths. The filter consisted of a very weak MgF lens, with a dielectric short pass filter deposited on the side closest to the pick-off mirror. However, the dielectric coating was non-uniform, resulting in a 25-30% *brightness gradient* running across the WF field, which is very weakly dependent on wavelength within the visual range. There were also several small pinholes in the F122M filter, which caused wavelength dependent “doughnuts” (images of camera relay optics pupils) to appear in the flats with strengths of 2% to 5%.

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1. *WF/PC-1 ISR 92-4.*

- **Anomalies due to the F8ND filter.** In other flatfields, the F8ND filter was used as the neutral density filter; it consisted of a strongly curved, thin meniscus whose center of curvature was at the pyramid apex. The surface was coated with a highly reflective metal film, which provided a neutral density uniform to less than 1% in intensity. The problem was that strong reflections could occur when F8ND was crossed with certain other filters. The strongly curved surface, together with its high reflectivity, caused light reflected from other filters to be strongly concentrated in a circular pattern centered near the pyramid apex. These reflections were formed by light passing through F8ND, reflecting off the other filter, reflecting from the curved surface of F8ND, and then passing through the other filter and onto the CCD. The strength of the circular reflection depended on the filter composition, and varied from <1% to ~30%. These reflections caused the F8ND filter to be dismissed as unusable early in the mission, though more recent tests show it is capable of giving near-perfect flats in certain filters. For filters which consist only of anti-reflection coated colored glass (polarizers, F555W, F569W, F725LP, F785LP, and F850LP), the intensity of the filter reflection is less than 1%. Certain other filter constructions gave very weak reflections, such as F336W, where the UG-11 colored glass component had a low throughput and was between F8ND and the F336W thin film component; in this case, the filter reflection is reduced to 1-2% in intensity (depending on field position).




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Note that the neutral density filter effects have not been removed from the SV and the non-SV epoch flatfields; to avoid the problem, use a flatfield close in wavelength that was not generated with the F122M filter or use a *closure* or a high fidelity flat<sup>2</sup>. For further suggestions on improving the flatfields, see “Data Accuracies and Problem Solving” on page 46-13 (see also *OV/SV Report*, Faber et al., 1992, Chapter 6, and Closure Flatfield Memo on WWW).

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- **Individual filter anomalies - short exposure reciprocity effects.** For exposures shorter than 1 second, the sensitivity of the CCD corners tends to increase. The effect is largest in the blue (~5%), and diminishes towards red wavelengths. The effect is strongest for 0.11 second exposures, and is nearly gone for exposure times of over 1 second. Hence it is useful to optimize the exposure times of the flats to match the data being flat-fielded; the Closure Flatfield Memo lists flats optimized to short and longer exposures.

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2. Note that the use of a different flat will affect the photometric calibration.

## 46.7 Photometry

The photometry keywords (PHOTFLAM, PHOTZPT, PHOTPLAM, PHOTBS, and PHOTMODE) in the .c0h header are populated by the **calwfp** task; the header keywords are updated but the data are not changed (see “Converting Counts to Flux or Magnitude” on page 3-15). There are four effects that to be aware of when converting from DN to flux:

- The time-dependent throughput.
- The effect of the source spectrum.
- Use of an alternate flatfield.
- Gradients (~20-30%) in broadband flats taken through neutral density filters.

The absolute sensitivity does not account for the temporal variations in throughput which follow each decontamination. Contamination is—as discussed on page 21-2—the gradual buildup of contaminants after a decontamination procedure and gives rise to a corresponding decrease in photometric throughput over time. On-orbit observations indicate that the attenuation is apparent to at least 5000 Å. Figure 46.3 summarizes the photometric monitoring of BD+75D325 done in WF 2 and PC 6; counts for each date are normalized to those from a set of observations taken in February 1992 immediately following a decontamination procedure (except for WFC, F230W, which is ratioed to July 1991, which was about 10 days after a decontamination). Decontaminations are indicated with vertical, dotted lines.

Users should correct their fluxes for the decrease in sensitivity that may have occurred during the time between the observation and the decontamination done before the observation was taken.<sup>3</sup> (See the list of decontamination events in Table 46.1). The necessary correction can be estimated from Figure 46.3 or by using **synphot** (e.g., the **calcphot** task), which can now accommodate the time-dependent throughput via the CONTAM keyword which is specified as part of the OBSMODE (*WF/PC-1/WFPC2 Instrument Science Report 96-02*).

The absolute sensitivity calculation in WF/PC-1 is done assuming a flat spectrum (constant flux per wavelength); if the spectrum of the source is not flat, the STSDAS **synphot** package can be used to recalibrate the flux (see Chapter 3). Finally, corrections to the conversion factors (PHOTFLAM) may need to be applied if an alternate flatfield is used; use the photometry appropriate for the filter through which the observation was taken, regardless of the flatfield filter.

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3. For more information about photometric modeling, see *WF/PC-1 ISR 93-02*.



## 46.8 PSFs

When dealing with the spherical aberration, point spread function (PSF) images are often an important element in the deconvolution of WF/PC-1 data. Characteristics of the WF/PC-1 PSF include:

- A sharp, 0.1 arcsecond radius core which contains about 15% of the energy.
- Broad, extended wings out to about 4".
- Strong position dependence due to camera vignetting.
- Wavelength dependence due to diffraction effects.
- Time variability due to dependence on the telescope's focus position.
- Shutter diffraction effects for exposures of less than 1/2 second.
- OTA focus variations and image motion on short time scale (< 1 hour).
- Spacecraft jitter.

Ideally, PSFs should be observed in a variety of positions on each chip, in all filters used and close in time to the observation, a time-consuming process. In addition, the shorter exposures needed to avoid saturating the PSF cores generally provide insufficient S/N in the wings. For these reasons, model PSFs will generally be needed to supplement the available observed PSFs. The Tiny Tim software package, which can be used to generate model PSFs, is available at:

<http://scivax.stsci.edu/~krist/tinytim.html>

### Observed PSF Library

Deconvolution of WF/PC-1 observations is supported through a library of observed WF/PC-1 point spread function (PSF) images that can be found in the STScI Calibration DataBase (CDBS). Rather than storing entire WF/PC-1 datasets that already reside in the HST Archive, the library consists of smaller (typically 256 x 256) sub-sections, usually centered on the PSF star. Any PSF can be retrieved from StarView in the same manner as reference files (the file type is CDB). A complete PSF image name consists of the PSF rootname as provided in DATA\_FILE column of the tables in the WWW memo plus the suffixes .r7h for the ASCII header and .r7d for the binary data file. The memo listing all available observed PSFs in the library is regularly updated on WWW.

Header keywords from a typical PSF image are described in Table 46.3. The secondary mirror actuator position keywords were populated using the results presented in the *OTA Instrument Science Report #7*.

**Table 46.3:** PSF Header Keywords

Keyword	Sample Value	Definition
<i>Keywords Listed in WWW Memo</i>		
filtnam1	F785LP	First STSCI filter name
camera	PC	WF or PC
detector	6	1–4 for WF, 5–8 for PC
rootname	W0MN0A02T	Rootname of observation with PSF image
data_fil	C3U1428IW.R7H	Name of the PSF image file
targname	SAO107200	Target name
spectral	unknown	Spectral type of source, if known
exptime	0.23	Exposure time in seconds
date_obs	23/06/91	UT date
xcorner	502	X pixel of (1,1) corner in PSF image
ycorner	38	Y pixel of (1,1) corner in PSF image
xcenter	630	X coordinate of PSF center on the chip
ycenter	166	Y coordinate of PSF center on the chip
<i>Keywords in Headers, but not Listed in WWW Memo</i>		
filtnam2	F122M	Second STScI filter name
mode	FULL	Full or area
origin	HST	Data source, e.g., HST, TIM or other
mjd	48430.	Modified Julian date (JD-2400000.5)
calibrat	T	Was image calibrated (see Chapter 45)?
flatfile	c1916444w	Name of flatfield image (or INDEF)
psfscale	1.	Divisor used to normalize PSF (1 if none)
obsmode	PC,6,F,DN,F785LP	Observation mode (for <b>synphot</b> )
refspec	CRCALSPEC: AGK_81D266_002.TAB	Reference spectrum
actuat25	-1492	Position of secondary mirror actuator 25 (and actuator keywords 26 through 30)

### PSF Limitations and Effect of Jitter

Due to the limited dynamic range of the WF/PC-1, observed PSFs that are properly exposed in the core will have low signal-to-noise in the wings and will not reflect the true PSF. In addition, exposures shorter than 0.17 second (*OV/SV Report*, Chapter 9, Faber et al., 1992) suffer from diffraction effects which are caused by the shutter obscuring some of the light beam during flight time.

Except for very short exposures, both the observed and modeled PSFs will not perfectly match WF/PC-1 images due to the *jitter* in the HST pointing. The jitter is primarily caused by the motion of the telescope in response to the solar array oscillations, and possibly oscillations of the aperture door and the high gain

antennas as well (*SESD Report* 92-15). The effect is greatest during earth terminator crossings, but is present at other times as well. On April 12, 1992, software called *SAGA II* was installed to correct for some of the jitter, effectively reducing it by about 50%. That is, the rms jitter dropped from 17 mas to 7 mas entering orbital day and fell from 12 mas to 6 mas entering orbital night.

The effects of the remaining 5–10 mas jitter, while not predictable, can be partially determined for observations taken in Fine Lock, via some of the associated engineering data. (Note that this is engineering data which is not part of the standard WF/PC-1 image set; users must submit a special request to [help@stsci.edu](mailto:help@stsci.edu) to obtain more information on a particular observation from the Observation Monitoring System<sup>4</sup>.) For images obtained on Coarse Track, the effects of jitter can only be estimated.

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## 46.9 Plate Distortion

Calibrated WF/PC-1 data from the pipeline are left with a residual geometric distortion; across a chip, from corner to corner, there is roughly a 1 pixel distortion in positional accuracy. This distortion can be removed, using the **wmosaic** task, which joins the four images into a single, correctly aligned and geometrically rectified, image; the residual distortion is about 0.1 pixels in both cameras. Note however, that **wmosaic** uses linear interpolation so the photometric accuracy of the image it produces is reduced. Thus, we recommend using the unrectified images for accurate photometry wherever possible. The task **metric** can be used to determine accurate RA and Dec for sources (correcting for the geometric distortion) directly from the uncorrected single chip images which make up the groups of the .c0h file. See “Basic Astrometry” on page 3-9 for more details.

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## 46.10 Data Accuracies and Problem Solving

In this section we characterize the accuracy obtainable with WF/PC-1 data and suggest steps to take to achieve the best accuracy from the data. The table below summarizes the estimated calibration accuracies and the following sections offer some final suggestions on improving the calibration.\*

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4. This information became part of the standard pipeline products delivered with science data after June 1994.

**Table 46.4:** Estimated WF/PC-1 Calibration Accuracies

Attribute	Estimated Accuracy	Comments
Bias	0.2–0.3 DN	Files d8c08261w, d8c0826nw
Dark	~0.0006 DN/sec	Files dac14274w, dae14273w; worse on hot pixels
Preflash	~0.5 DN	Assuming 8 sec preptime for PC, 30 sec for WF (files d8c0*)
Flatfields, in general	~3%	Small scales (<<1")
	~25–30%	scales > 1" if flat contains F122M or F8ND (includes most broad band filters)
	~5–10%	scales > 1" if flat contains no ND filter (includes most narrow band filters)
	~1–2%	scales > 1" if high-fidelity flat used
Flatfields, additional effects	up to 5–7%	Short exposure reciprocity problem, if flat and data have very different exposure times. To minimize, use flat with same exptime as data.
	~1% rms (4–5% peak) few percent	Measle effects, partially correctible (see text) changes caused by decon; reduced with deltaflats
Relative photometry	5–30%	Depending on flat used
Absolute photometry	5–30%	<i>Strongly</i> dependent on flat used (see “Flatfield Anomalies” on page 46-7 and “Improving the Flatfield Correction” on page 46-15)
Plate Scale	WFC: 0.1016" +/- ~0.0001" PC: 0.0439" +/- ~0.0001"	

### 46.10.1 Improving Bias, Preflash, and Dark Calibration

- Near the end of the WF/PC-1 mission, high quality bias and preflash files were generated and installed in the archive; these are listed in the WWW Reference File memo. We suggest verifying that these were used in the calibration (e.g., BIASFILE, PREFFILE keywords) and if not, recalibrating.
- Check that the CTE correction was correctly applied for observations that were not preflashed. That is, the header keywords should be set as follows: PREFCORR=YES, PREFTIME=0, and PREFFILE=FILENAME. Note that the CTE correction was sometimes not applied where it should have been due to a bug in the PODPS pipeline. Use the preflash files that contain the updated versions of the CTE correction.
- Review the HISTORY records in the dark file used for calibration: Was it generated from individual dark frames taken close in time to the science image? If not, recalibrate with a more appropriate dark reference file from the Archive. If necessary, a new dark reference file can be generated for recalibration, by identifying dark frames that were taken close in time to the science data (e.g., with StarView), retrieving them from the Archive, then combining and normalizing them into a reference file for use in **calwfp**.

- If hot pixels are a concern, check the WWW memo for the locations of hot pixels or see the *WF/PC-1 Instrument Science Report 93-02* for a discussion of the evolution and treatment of WF/PC-1 hot pixels.
- Verify the DARKTIME keyword value; for more accurate dark calibration, darktime value can be recomputed (*WF/PC-1 Instrument Science Report 93-01*). Also note that for interrupted observations (perhaps due to loss of lock), the dark current continues to accumulate even when the shutter was closed. A bug in the PODPS pipeline caused only the shutter open time to be used to compute the darktime.

## 46.10.2 Improving the Flatfield Correction

### *Apply a Delta Flat*

A delta flat correction may be necessary if there was a decontamination procedure between the epoch of the flatfield and the epoch of the science data, particularly for PC8 data. One of the archived delta flats could be used or a new one created from individual internal flatfield exposures (see “Choosing and Generating Delta Flats” on page 45-18).

### *Experiment with Flatfields*

After the end of the WF/PC-1 mission, Closure and high-fidelity flatfields, as well as deltaflats, were generated and archived; these flats cover ~85% of the nearly 8000 external WF/PC-1 science images in the archive. Any of these flats may be retrieved from the Archive and used for recalibrations; the reference file memo on WWW lists all of the WF/PC-1 reference files available from the archive. Small scale errors in the flatfields are normally around 3% (the high-fidelity flatfields are generally good to nearly 1%) while 10% errors can be expected on larger scales. In addition, those flatfields which were generated from Earth calibration observations taken with the neutral density filter F122M are known to have 25% gradients across the four WF CCDs. The following suggestions may improve the flatfielding.

- Select an alternate version of the flatfield used; many filter / camera combinations have more than one possible flatfield. Look for the *closure or high fidelity flatfields* (Cycle 2 and 3) which have been generated and installed in the Archive in 1994 or try the “Super-Sky Flatfields” from the MDS (Medium Deep Survey) group. The WWW memos provide pointers to all these files. Closure flatfields can be *back-corrected* with a delta flat and applied to data taken before August 1993. WWW memos are available at:

[http://www.stsci.edu/ftp/instrument\\_news/WFPC/wfpcl\\_memos.html](http://www.stsci.edu/ftp/instrument_news/WFPC/wfpcl_memos.html)

- Try a flatfield close in wavelength to the science observation; for example, use narrow band flatfields to flatfield images of emission line targets taken with broadband filters.

- Remove the neutral density filter pattern if the flatfield was taken with F122M or F8ND (or use high-fidelity flats). Alternatively, if a high signal to noise target is small and close to the center of particularly WF2 or PC6, the neutral density filter gradient may not be significant.
- Generate high-fidelity flatfields for those observation modes lacking such a flatfield; these would include WF in F439W, F702W, F547M, and others, as well as PC in F889N, F850LP, and F502N (the prospects for improving the UV flats are not good, since there are few or no on-orbit earthflats). For example, a F555W, WF high fidelity flat (accuracy better than 2%) can be computed by correcting the Closure F569W flatfield reference file for wavelength dependent effects; the correction is obtained from F122M filter Earth flats, since the F122M pattern varies slowly with wavelength. That is:

$$\text{newflat (F555W)} = \text{flat(F569W+F8ND)} * [\text{flat(F555W+F122M)} / \text{flat(F569W+F122M)}]$$

In this case the flats are Cycle 3 flats taken through the indicated filters. The ratio of the flats crossed with F122M corrects for any wavelength dependent effects between 555nm and 569nm, and is applied to the F569W+F8ND Earth flat, which is known to be quite good. In practice, this can be done by identifying the appropriate filenames using the WWW Closure Flatfield memo, retrieving them from the archive, and using **imcalc** to perform the computation. For example:

```
imcalc input=e751348dw.r6h,e6d10291w.r6h,e6d1028sw.r6h output=newflat.r6h
equals="im1*im2/im3" pixtype="real"
```

The flatfield data quality file may be updated as well:

```
imcalc input=e751348dw.b6h,e6d10291w.b6h,e6d1028sw.b6h output=newflat.b6h
equals="max(max(im1,im2),max(im2,im3))" pixtype="short"
```

- Account for exposure time dependencies in the flatfields, which can be a significant effect; for example, we have found that flatfields based on Earth flats with exposures shorter than 1 sec, when applied to science exposures much longer than 1 sec, will result in 5–7% errors. As noted in their header HISTORY records, the input flats used in the example above (e75\*, e6d\*) were generated from Earth flat exposures which were ~8 sec long and so, the resulting flat is optimized for long exposures. The flatfield can, however, be optimized for short exposures by including a wavelength-independent correction factor; in this case, the factor can be determined from the F588N+F122M Closure flatfield (generated from 400 sec Earth flats) and the F588N Closure flatfield (generated from 0.18 sec F588N Earth flats). That is:

$$\text{newflat(F555W,short)} = \text{newflat(F555W)} * [\text{flat(F588N)} * \text{flat(F569W+F122M)}] / [\text{flat(F588N+F122M)} * \text{flat(F569W+F8ND)}]$$

In this case, newflat(F555W,short) is the new flatfield appropriate for short exposures, newflat(F555W) is the flatfield computed in the previous step,

and the other flatfields are Closure flatfields taken through the noted filters. This final high-fidelity flatfield can then be used directly in calwfp. In a similar manner, Closure flatfields based on short exposure times could be optimized for longer exposure times.

- Also be aware that many of the raw earth observations (from which the flatfield reference files are generated) and the INTFLATs (from which the delta flats are generated) contain small numbers of cosmic rays.
- Check for features in the flatfield which could degrade the science data; the delta flats may be used to identify the positions of measles.

### 46.10.3 Improving the Photometric Calibration

The resultant relative photometry at visible and far-red wavelengths should be good to 5–15% in the PC and WF2, and 10–30% for the full field of the WFC. Somewhat better accuracy is possible for narrow and medium band filters if the flats were not observed through neutral density (ND) filters; in these cases, the accuracy will be around 5–10% for all cameras. If core photometry is used in conjunction with a linear magnitude correction (*WF/PC-1 ISR 92-02*), and corrections are made for throughput variations and flatfield problems (ND filter gradients, edge droop, measles, etc.), an accuracy around 3–5% should be possible. The accuracy for absolute photometry will ultimately be limited by the accuracy of the absolute calibration, which is around 5% (see *WF/PC-1 ISR 92-09*).

- The uniform contamination layer has been shown to decrease the throughput in F555W by 10–15% about 6 months after a decontamination procedure; the degradation is worse toward blue. The effects can be corrected one of two ways:
  - Read the correction from the plots of the stellar monitoring results. (See Figure 46.3 and *WF/PC-1 ISR 93-02*).
  - Use the CONTAM keyword in **synphot**, which uses the date of the science observation to interpolate between data points in the CDBS stellar photometry table to arrive at the correction (see *WFPC ISR 96-02*).
- The uniform layer of contamination is also known to scatter and absorb light. This scattered light effect is particularly evident in the Earth observations (from which the flatfield reference files are generated) and in the internal flats (from which the delta flats are generated) as an edge-droop. Due to the different illumination pattern, the edge-droop is not likely to be present to the same extent in the science observation.
- The non-uniform contamination (persistent measles) will have small scale effects (2–5%) which may be partially corrected with the application of a delta flat.
- Note that the WF/PC-1 photometric calibration, in the form of the STSDAS Synphot tables, is based on the Cycle 1 (SV) flats and standard star observations made during Cycle 1 (the contamination correction tables *have* been updated through the end of the mission and may be used to estimate the

effect of the contamination layer). If the data has been recalibrated with the improved reference files discussed in previous sections, and the photometric information in the header keywords (e.g., PHOTFLAM) will be used, the synphot tables should be updated in order to make them consistent with the closure flatfields. The updates would require measuring statistics on all the final flatfields and adjusting the tables accordingly, before running **calwfp** or **synphot**. An ideal set of calibration data with which to verify any changes made would be the photometric sweep (proposal #4785), which was taken near the end of the WF/PC-1 mission.