Chapter 26

WFPC2 Calibration

In This Chapter...

This chapter discusses the *calibration* of WFPC2 data, namely the routine processing that is required before detailed data analysis is performed. We begin by describing the pipeline calibration that occurs before the data are delivered to the original observer and stored in the Hubble Data Archive. We then detail possible reasons to repeat this routine calibration and the options available to do so. Finally, we mention a few additional steps that can be taken to enhance and complement the routine pipeline processing.

After WFPC2 observations have executed, the image data pass through the OPUS *pipeline*, where they are processed and calibrated. All of the steps performed by the pipeline are recorded in the trailer file for each dataset. Figure 26.1 shows an example of a trailer file and identifies comments made during the following pipeline steps:

1. The data are partitioned (separated into individual files, e.g., the engineering and science data are separated).
2. The data are edited to insert fill (an arbitrary assigned value given in the header) in place of missing data.
3. The data are evaluated to determine discrepancies between the subset of the planned and executed observational parameters.
4. The data are converted to a generic format and the header keywords populated.
5. The data are calibrated using a standard WFPC2-specific calibration algorithm and the best available calibration files.

Figure 26.1: Sample Trailer File

```
CECCCM-******************************************** OBSERVER COMMENTS FILE *****************************************************
CECCBN-*************************************************************************************************************************
     OSS quality/utility report - Wide Field/Planetary Camera II (WFII)

     Observation:    Object name:        Proposal ID:    Executed (UT):
     U28S0303        PSR1957+20          05390           94.242/ 21:57:17

                            Observation Specifics
                            ---------------------

              Science Data Mode:                  IMAGE
              CCDs Used:                          ALL
              Data Format:                        STDMODE
              Pointing Control:                   FINELOK
              Filter(s):                          F675W
              Analog gain:                        7.5 electrons/DN
              Exp. time (sec):                     600

 Comments: This observation appears to have executed as planned.

 OSS staff did not inspect the observation.

   No terminator crossings occurred during this observation.

 OSS_INFO1:   OK - no apparent problems
 OSS_INFO2:   NO-MON - obs not monitored (lack of eng data and/or OSS staffing)
DPPBAN-****************************************************** TRAILER FILE *****************************************************
DPPSTA--------------------------------------------- DATA PARTITIONING STARTED ---------------------------------------------
DPPSTR-DATA PARTITIONING STARTED: 31-AUG-94 16:15:55 .
DPPOBS-Observation Identification: Program Number 28S , Observation Set Number 03 , Observation Number 03
DPPCAT-Msg Artifacts Catalog: DCF Msg 7 contained data for Info Set File with Root Name of U28S0303P
DPPIST-Missing pkts processing is complete, processed 3200 science pkts, detected 0 as missing          1 Partitioning
DPVWM1-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 U28S0303P
DPPEND-DATA PARTITIONING ENDED: 31-AUG-94 16:23:06 .
DPPFIN--------------------------------------------- DATA PARTITIONING COMPLETED -------------------------------------------
CPE0ST-------------------------------------------- DATA EDITING STARTED ----------------------------------------------------
CPESTR-DATA EDITING STARTED 31-AUG-94 16:23:20 FOR U28S0303P.
DPE4PC- 0 fill source packets were inserted by PODPS.                                                  2 Editing
DPE4DC-In U28S0303P, 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 31-AUG-94 16:23:20 FOR U28S0303P.
CPE0EN--------------------------------------------- DATA EDITING COMPLETED ---------------------------------------------------
CPG0VS--------------------------------------------- DATA EVALUATION STARTED ----------------------------------------------
DPVSTR-DATA EVALUATION STARTED 31-AUG-94 16:23:39 FOR U28S0303P.
DPVEND-DATA EVALUATION ENDED 31-AUG-94 16:24:03 FOR U28S0303P.
DPVWM2-Weighted Quality Measure of 0 was calc for discrepancies between predicted & actual Flags & Indicators for Info S   3 Evaluation
DPVOKK-Info Set quality was OK as Weighted Quality Measure of 0 did not exceed Quality Threshold of 9
CPG0VE--------------------------------------------- DATA EVALUATION COMPLETED --------------------------------------------
CGAI00-
CGAI01--------------------------------WIDE FIELD AND PLANETARY CAMERA GENERIC CONVERSION BEGINNING----------------------------
CGAI00-
CGAT01-Routine CGWFP2, version 34.4.A , will perform generic conversion
CGAT02-GENERIC CONVERSION BEGINNING: processing information set U28S0303P
CGAT03-CGWFP2 START: 31-AUG-94, 16:24:04
CGAW06-No error values detected in flags and indicators                                                4 Conversion
CGAI06-SHP generic conversion has completed successfully
CGAC02-Generated new WFII reference file catalog : CCC:[SIS.WF2]U28S0303P.CTX
CGAI08-SCI generic conversion has completed successfully
CGAI22-DQM generic conversion has completed successfully
CGAT04-GENERIC CONVERSION TERMINATING: successful completion
CGAT09-CGWFP2 END: 31-AUG-94, 16:27:45
CPG0EN--------------------------------------------- GENERIC CONVERSION COMPLETED ---------------------------------------------
CCAI00-
CCAI07-CALIBRATION BEGINNING: processing information set 31-AUG-94
CGAI00-
CCAI07-CALIBRATION BEGINNING: processing information set U28S0303P                                      5 Calibration
CCAI11-CCWFP2 START: 31-AUG-94, 16:33:17
CCAIRI- --- WF/PC-2 Calibration Starting: CALWP2 Version 1.3.0.6
CCAIRI- --- Starting CALWP2: Input = U28S0303P Output = ucal:u28s0303p
CCAIRI- --- Starting processing of element 1
CCAIRI- photmode = WFPC2,1,A2D7,F675W,,CAL
CCAIRI- --- Starting processing of element 2
CCAIRI- photmode = WFPC2,2,A2D7,F675W,,CAL
CCAIRI- --- Starting processing of element 3
CCAIRI- photmode = WFPC2,3,A2D7,F675W,,CAL
CCAIRI- --- Starting processing of element 4
CCAIRI- photmode = WFPC2,4,A2D7,F675W,,CAL
CCAIRI- --- Computing image statistics of element 1
CCAIRI- --- Computing image statistics of element 2
CCAIRI- --- Computing image statistics of element 3
CCAIRI- --- Computing image statistics of element 4
CCAIRI- --- WF/PC-2 Calibration Ending for observation
CCAI10-CALIBRATION END: 31-AUG-94, 16:38:30
```

The calibration software used by the pipeline is the same as that provided within STSDAS (**calwp2**). The calibration files and tables used are taken from the Calibration Data Base (CDBS) at STScI and are the most up-to-date calibration files available at the time of processing. All CDBS files are available to you through the HST Data Archive. (See Chapter 1).

26.1 Overview of Pipeline Calibration

In this section we provide an overview of the steps comprising the routine pipeline calibration. The flow of the data through the pipeline is presented in schematic form in Figure 26.2. The pipeline calibration software (which the user can find as **calwp2** in the STSDAS **hst_calib** package) takes as input the raw WFPC2 data file pairs (see Table 25.1) `.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 your 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 of the observation, and any special pre-specified constraints. They were initially set in the headers of the raw data file in the OPUS pipeline during generic conversion; if reprocessing is necessary, they can be redefined by editing the raw header (`.d0h`) using the task **chcalpar** and then running **calwp2** on the raw files.

The values of the calibration switches in the headers of the raw and calibrated data indicate what calibration steps the pipeline applied to the data and which calibration reference files were used. Calibration switches will have the value PERFORM, OMIT, or COMPLETE, depending on whether the step has yet to be performed, is not performed during the processing of this dataset, or was completed. For convenience, these keywords are reported in the dataset information page of the new-style paper products.

As with other header keywords, the calibration keywords can be viewed using, for example, **imhead** or **hedit**. Alternately, you can use the **chcalpar** task in the STSDAS **tools** package to view the calibration keywords directly.

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 **calwp2**, 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 26.2: Pipeline Processing by calwp2

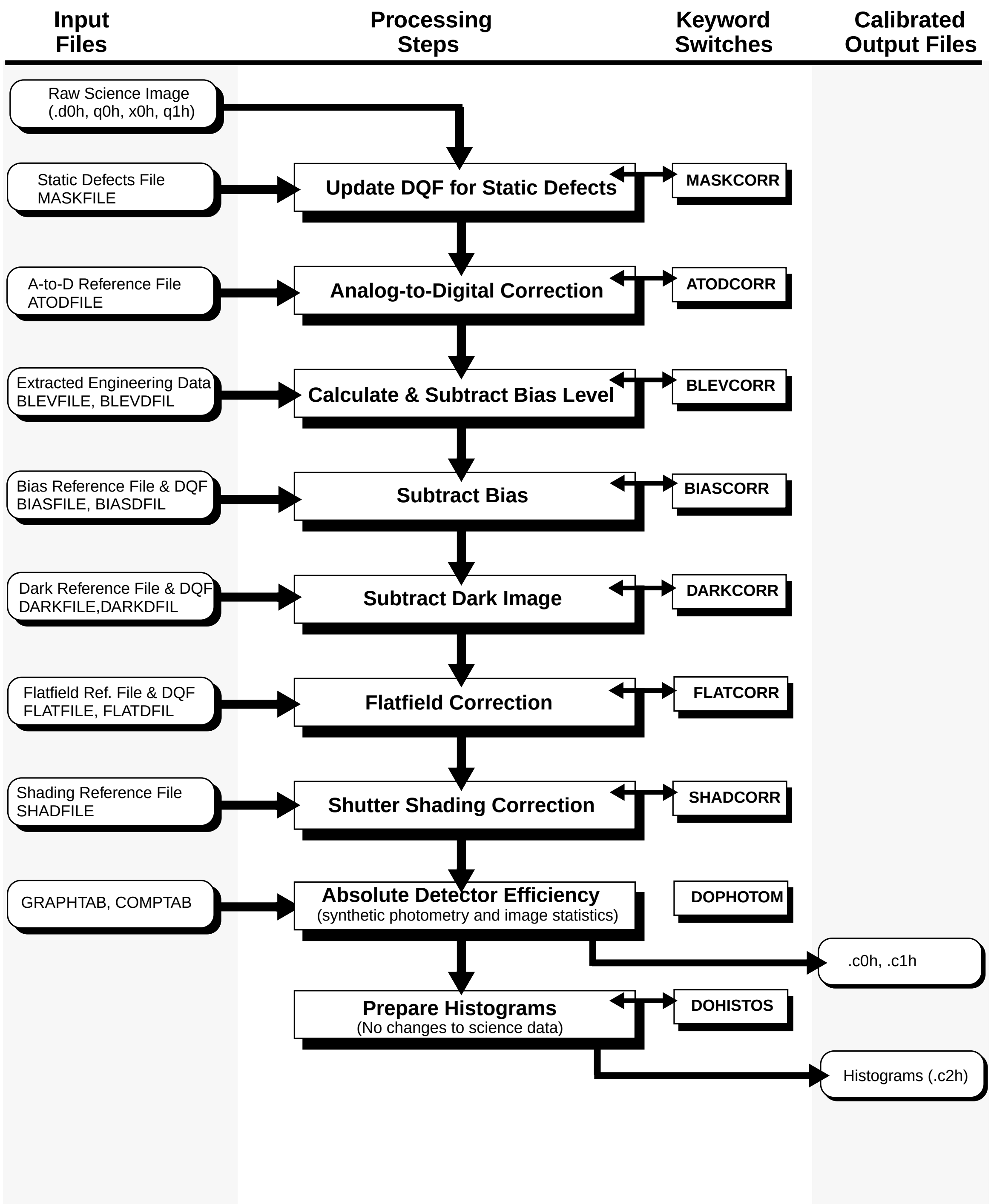


Table 26.1: Calibration Steps and Reference Files Used for WFPC2 Pipeline Processing

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.	maskfile (`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).	atodfile (`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 the bias level exhibits a column-wise pattern that changes over time.	blevfile, blevdfil (`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).	biasfile, biasdfil (`r2h`/`b2h`)
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).	darkfile, darkdfil (`r3h`/`b3h`)
FLATCORR	Correct for pixel-to-pixel gain variation by multiplying by flatfield image.	flatfile, flatdfil (`r4h`/`b4h`)
SHADCORR	Remove shading due to finite shutter velocity (exposures less than 10 seconds)	shadfile (`r5h`)
DOPHOTOM	Determine absolute sensitivity using throughputs in **synphot** tables identified in GRAPHTAB and COMPTAB. This step does not change science data values.	
DOHISTOS	Create 3-row image (`.c2h`) for each group. Row 1 is a histogram of raw science values, row 2 the A/D correction, row 3 the calibrated image. (Optional, default is not to produce them.)	

26.2 Standard Pipeline Calibration

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. Do analog-to-digital (A/D) correction.
3. Subtract bias level.

4. Subtract bias image.
5. Subtract dark for exposures longer than 10 seconds.
6. Multiply by flatfield.
7. Apply shutter shading correction to exposures of less than 10 seconds.
8. Calculate photometry keywords.
9. Calculate histograms.
10. Generate final science data quality file.

26.2.1 Calibration Files

Table 26.2 lists the types (and related suffixes) of the WFPC2 reference files used in the pipeline calibration. Most suffixes have the form `r`*N*`h/r`*N*`d`, where *N* is a number that identifies the step in which the file is used. The related data quality file, if it exists, has the suffix `b`*N*`h/b`*N*`d`. The rootname of a 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 WFPC2 reference files in CDBS (and retrievable from the HST Archive) are contained in the Reference File Memo, available via the WFPC2 WWW pages. This memo is routinely updated with each new delivery. Any CDBS file is available for retrieval through the HST Data Archive (see Chapter 1). Some additional reference files generated by the WFPC2 IDT are listed in the IDT Reference File Memo, also available on the web. The WFPC2 web page can be found at:

`http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_top.html`

Table 26.2: WFPC2 Calibration Reference Files

Suffix	Reference File
`r0h, r0d`	Static mask
`r1h, r1d`	Analog-to-digital look-up table
`r2h, r2d, b2h, b2d`	Bias
`r3h, r3d, b3h, b3d`	Dark frame
`r4h, r4d, b4h, b4d`	Flatfield
`r5h, r5d`	Shutter shading
`c3f`	Photometry table (generated, not required)

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

26.2.2 Calibration Steps

Application of the Static Mask

The static mask reference file (`.r0h/.r0d`) contains a map of the known bad pixels and columns. If this correction is performed (MASKCORR=PERFORM), the mask is included in the calibration output data quality files. The mask reference file is identified in the MASKFILE keyword. The science data themselves are *not* changed in any way; the STSDAS task **wfixup** can be used on the final calibrated science image (`.c0h/.c0d`) to interpolate across bad pixels flagged in the final data quality file (`.c1h`).

A/D Correction

The analog-to-digital (A/D) converter takes the observed charge in each pixel in the CCD and converts it to a digital number. Two settings, or gains, of the A/D are used on WFPC2. The first converts a charge of approximately seven electrons to a single count (called a *Data Number* or *DN*), and the second converts a charge of approximately 14 electrons to a DN, also referred to as *gain 15* for historical reasons. A/D converters work by comparing the observed charge with a reference and act mathematically as a "floor" function. However, these devices are not perfect, and some values are reported more (or less) frequently than they would be by a perfect device. One can adjust statistically for this bias; fortunately the WFPC2 A/D converters are relatively well-behaved and this is a small correction. The largest correction is about 1.8 to 2.0 DN for bit 12 (thus 2048).

The best estimate of the A/D bias is removed when the ATODCORR keyword is set to PERFORM. The calibration file used to correct for the A/D errors has the suffix `.r1h`.

Bias Level Removal

The charges that are in each pixel sit on top of an electronic pedestal, or "bias" designed to keep the A/D levels consistently above zero. The mean level of the bias must be determined empirically using extended register (overscan) pixels which do not view the sky. The values of these pixels are placed in the extracted engineering files (`.x0h/.x0d`). The overscan area used to calculate the mean bias levels is [9:14,10:790], with BIASODD being determined from columns 10, 12, and 14 and a BIASEVEN being determined from columns 9, 11, and 13 (this surprising nomenclature is due to an offset in the `.x0h` file; even and odd are correctly oriented with respect to the data file columns). In observations before March 8, 1994, the pipeline used a larger part of the overscan region, resulting in oversubtraction of the bias level and possibly large negative pixel values. Separate even and odd bias levels were extracted only after May 4, 1994. See Chapter 27 for more information on how to deal with early WFPC2 data. The keyword BLEVCORR controls the subtraction of the bias in **calwp2**.

Bias Image Subtraction

The value of the bias pedestal can vary with position across the chip. Therefore, once the mean bias level correction has been completed, the pipeline looks at the keyword BIASCORR. If it is set to PERFORM, then a bias image (`.r2h`) is subtracted from the data to remove any position-dependent bias pattern. The bias reference file is generated from a large 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 data quality file (`.b2h`/`.b2d`).

Dark Image Subtraction

A dark correction is required to account for the thermally-induced dark current as well as a *glow* (see "Dark Glow" on page 27-4) from the field flattening lens. 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, and BIASCORR). In addition, each frame is examined and regions affected by image anomalies (such as residual images, see Figure 27.2) are masked out. If a dark correction is performed, the dark reference file (which was normalized to one second) is scaled by the DARKTIME keyword value and subtracted from the observation. The keyword DARKCORR controls the subtraction of the dark file (`.r3h`). By default, DARKCORR is set to "PERFORM" for all exposures longer than 10 seconds, and to "OMIT" for shorter exposures.

Flatfield Multiplication

The number of electrons generated in a given pixel by a star of a given magnitude depends on the individual quantum efficiency of the pixel as well as any large scale vignetting of the field-of-view caused by the telescope and camera optics. To correct these variations in total quantum efficiency, the image is multiplied by an inverse flatfield file, which is currently generated from a combination of on-orbit data, used to determine the large-scale structure of the illumination pattern, and data taken before launch to determine the pixel-to-pixel response function. The application of the flatfield file (extension `.r4h`) is controlled by the keyword FLATCORR.

Shutter Shading Correction

The finite velocity of the shutter produces a position-dependent exposure time. This effect is only significant for exposures of a few seconds or less, and is automatically removed from all exposures less than ten seconds. The keyword switch is SHADCORR, and the shutter shading file name is stored in the keyword SHADFILE.

Creation of Photometry Keywords

Photometry keywords, which provide the conversion from calibrated counts to astronomical magnitude, are created using the STSDAS package **synphot**. (More information on **synphot** can be found in this document, and in the *Synphot User's Guide*, which is available via WWW.) These keywords are listed in Figure 26.3, 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 Chapters 2 and 3 for more details). This calibration step uses the HST graph and component tables (`.tmg` and `.tmc`) to determine the throughput for the appropriate WFPC2 observing mode and filter. The keyword switch for this step is DOPHOTOM, and the reference file keywords are GRAPHTAB and COMPTAB.

Figure 26.3: Photometry Keywords

Header parameters

```
DOPHOTOM= 'YES ' / Fill photometry keywords: YES, NO, DONE
PHOTTAB = 'ucal$u27s0301n.c3t' / name of the photometry calibration table
```

Group parameters

```
'PHOTMODE' / Photometry mode      (for example, WFPC2,1, A2D7, F675W,CAL)
'PHOTFLAM' / Inverse Sensitivity (erg/sec/cm2/Å for 1 DN/sec)
'PHOTPLAM' / Pivot wavelength (angstroms)
'PHOTBW ' / RMS bandwidth of the filter (angstroms)
'PHOTZPT' / Photometric zeropoint (magnitude)
```

Histogram Creation

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 three-line image where the first row is a histogram of the raw data values, row two is a histogram of the A/D corrected data, and row three is a histogram of the final calibrated science data. This operation is controlled by the keyword DOHISTOS; the default is not to produce them.

Data Quality File Creation

The **calwp2** software will combine the raw data quality file (`.q0h`, `.q1h`) with the static pixel mask (`.r0h`) and the data quailty files for bias, dark, and flatfield reference files (`.b2h`, `.b3h`, `.b4h`) in order to generate the calibrated science data quality file (`.c1h`). The flag values used are defined below. The final calibrated data quality file (`.c1h`) may be examined (for example, using SAOimage, ximtool, or **imexamine**) to identify which pixels in your science image may be bad.

The bad pixels flagged in the `.c1h` file have not been fixed in the `.c0h` file. You may wish to use the STSDAS task **wfixup** to interpolate across bad pixels in your science image or to use the `.c1h` file to determine which pixels to discard in various analysis programs.

The Image

After the completion of the standard pipeline processing the final image is placed in a real-valued image labelled `.c0h/.c0d`.

Table 26.3: WFPC2 Data Quality Flag Values

Flag Value	Description
0	Good pixel
1	Reed-Solomon decoding error. This pixel is part of a packet of data in which one or more pixels may have been corrupted during transmission.
2	Calibration file defect—set if pixel flagged in any calibration file. Includes charge transfer traps identified in static pixel mask file (`.r0h`).
4	Permanent camera defect. Static defects are maintained in the CDBS database and flag problems such as blocked columns and dead pixels. (Not currently used.)
8	A/D converter saturation. The actual signal is unrecoverable but known to exceed the A/D full-scale signal (4095).[a]
16	Missing data. The pixel was lost during readout or transmission. (Not currently used.)
32	Bad pixel that does not fall into above categories.
128	Permanent charge trap. (Not currently used.)
256	Questionable pixel. A pixel lying above a charge trap which may be affected by the trap.
512	Unrepaired warm pixel.
1024	Repaired warm pixel.

a. Calibrated saturated pixels may have values significantly lower than 4095 due to bias subtraction and flatfielding. In general, data values above 3500 DN are likely saturated.

26.3 Recalibration

In this section we discuss the *recalibration* of WFPC2 data, namely running the raw data again through the same pipeline calibration described thus far. We will first indicate when recalibration can be advisable, usually due to the availability of improved reference files and tables, and then go through the mechanics of how recalibration is performed. The next section will discuss some relevant post-pipeline calibration issues.

26.3.1 Why and When to Recalibrate

The main reason to recalibrate WFPC2 images is the availability of better or more up-to-date reference files and tables, especially darks, flatfields, and **synphot** component tables, and changes in the pipeline calibration task **calwp2**. The most recent reference files and tables appropriate to a given observation can be determined and retrieved via StarView. Note that, when recalibrating, **calwp2** must be run again in its entirety even if only one reference component has changed, and thus all reference elements need to be retrieved (see below).

In the following we give a brief summary of some relevant changes of reference elements and the pipeline task as of today. More details and up-to-date information can be found in the WFPC2 History Memo, and especially its section 5 for calibration details. We also give a quantitative account of the differences between various generations of reference files in Chapter 27. The WFPC2 History Memo is available at the following URL:

```
http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_memos/
wfpc2_history.html
```

Darks

The calibrated data originally delivered to the PI and to the Archive run through the pipeline calibration within a few days of the observation. At that time, the available dark reference file does not contain the most up-to-date information about warm pixels, which change on a weekly timescale (see “Warm Pixels” on page 26-16). Thus, dark files used in standard processing are *always* out of date, and the correction of warm pixels can be improved by recalibrating with a more appropriate dark file. However, another method to correct for warm pixels, the STSDAS task **warmpix** (described in “Warm Pixels” on page 26-16) can be used instead of recalibrating. Using **warmpix** is generally recommended because it gives the user more flexibility and control over the treatment of warm pixels.

Very deep observations taken before August 1996 can also benefit from recalibration with a different dark reference file. Until that date, dark reference files were produced by combining ten dark exposures taken during a two week interval surrounding the observation. For observations longer than about 20,000 s (10,000 s in the UV and in narrow-band filters), the noise in this dark frame is a significant contributor to the total noise in the final calibrated image. For this reason, if the science results are limited by the noise, it is advisable to recalibrate the image using a ‘‘superdark’’ reference file. Superdarks are generated from 120 individual dark exposures, compared to the ten exposures that go into a normal dark, and thus reduce significantly the noise associated with dark subtraction. If a superdark is used, the accompanying superbias must also be used, and warm pixels must be corrected independently by post-pipeline processing tasks such as **warmpix** (see “Warm Pixels” on page 26-16).

Starting August 1, 1996, the dark reference files have been generated using the appropriate superdark and adding the information on warm pixels from that week’s darks; thus, observations taken after that date do not require recalibration in order to use a superdark. (Recalibration may still be appropriate in order to use the dark reference file with up-to-date information on warm pixels.)

A description of available superdarks and how to retrieve them via the Archive can be found in sections 2 and 5 of the WFPC2 History Memo on the WFPC2 Web page.

Flatfields

Very early observations, before March 9, 1994, used interim flat fields based on pre-launch data. These flat fields did not have good large-scale properties, with peak errors of about 10%, and thus WFPC2 observations before that date most likely need to be recalibrated. After that date, in-flight flatfields have been used. Their quality has steadily improved, and the flatfields currently in the pipeline are believed to be good to about 0.3% on small scales, and 1% or less on large scales. See Chapter 27 for a detailed discussion of the differences between various generations of flatfields.

If you are in doubt about the quality of the flatfielding in your observations, check the PEDIGREE and DESCRIP keywords of the flatfield file, also reported (after December 1994) in the HISTORY comments at the end of the header of the calibrated image. If PEDIGREE is GROUND, the data will need to be recalibrated. If the PEDIGREE is INFLIGHT, the flatfield was obtained from on-orbit data, and the DESCRIP keyword gives some information on its quality. INFLIGHT flatfields are of sufficient quality for most scientific goals, but for especially demanding applications and data with very high signal-to-noise ratio, it may be advisable to recalibrate with the most recent flatfields.

Photometric Tables

The photometric component tables are used by **synphot** to determine the photometric calibration, namely the photometric header parameters PHOTFLAM and PHOTPLAM (see Chapter 28). These component tables have been updated several times, most recently on May 16, 1997, in order to contain the most up-to-date information on the throughput of WFPC2. If the photometric tables have changed, users can either recalibrate their observations or, more simply, run **synphot** directly to determine the header parameters. Users can also use the alternate methods given in “Photometric Zero Point” on page 28-1 to calibrate their observations, thus avoiding recalibration altogether.

Pipeline Calibration Task calwp2

Another possible reason for recalibration is to use a more recent version of the calibration pipeline task **calwp2**. This task has seen several minor revisions, mostly to add information to processed data; the current version, as of this writing, is 1.3.5.2. Only three of the **calwp2** revisions since WFPC2 operations began actually affect the calibrated data. The first two were changes in how the bias level is computed: starting in March 8, 1994 (version 1.3.0.5), columns 3 through 8 of the overscan data were no longer used, because they could be affected by the image background; and starting in May 4, 1994 (version 1.3.0.6), separate bias levels were computed for even and odd columns, resulting in a slightly better image flatness for about 1% of all WFPC2 images (see *WFPC2 ISR* 97-04).

The third update (version 1.3.5.2, January 3, 1997) corrects a bug introduced in December 1994 (1.3.0.7) in the calibration of WFPC2 single-chip, two-chip, or three-chip observations that do not include the PC (about 1% of all archived observations). We recommend that such observations archived between December 1994 and January 1997 be recalibrated with the most recent version of **calwp2**.

26.3.2 Assembling the Calibration Files

In order to recalibrate a WFPC2 dataset, you need to retrieve *all* of the reference files and tables used by the calibration steps set to PERFORM. See “Identifying Calibration Reference Files” on page 1-19 for a description of how to obtain the appropriate reference files from the STScI Archive using StarView. Standard pipeline processing uses those files listed by StarView as the best reference files. We suggest copying the raw data files and the required reference files and tables to a subdirectory used for recalibration. This precaution will preserve all original files.

26.3.3 Setting Calibration Switches

The next step in recalibrating HST data is to set the calibration switches and reference keywords in the header of your raw data file (`.d0h`). These switches determine which calibration steps are performed and which reference files are used at each step in the process.

To change the calibration header keywords in a dataset, we recommend using at first use the **chcalpar** task in the STSDAS **hst_calib.ctools** package. The **hedit** task provides more detailed control over individual keywords and is preferred by some users experienced with calibration of WFPC2.

The **chcalpar** task takes a single input parameter—the name(s) of the image files to be edited. When **chcalpar** starts, it automatically determines the instrument used to produce that image and opens one of several parameter sets (*pset*) that loads it with the current values of the header keywords. The WFPC2 pset is named `ckwwfp2`. Typing **ckwwfp2**, as a task name, at the `cl>` prompt will also edit this pset.

A detailed description of the steps involved in changing header keywords follows:

1. Start the **chcalpar** task, specifying the image(s) in which you want to change keyword values. If you specify more than one image, for example using wildcards, the task will take initial keyword values from the first image, but it will substitute only the keywords that are actually typed in. For example, you could change keywords for all WFPC2 raw science images in the current directory (with initial values from the first image), using the following command:

```
wf> chcalpar u*.d0h
```

2. When **chcalpar** starts, you will be placed in **epar**—the IRAF parameter editor, and will be able to edit the parameter set of calibration keywords. Change the values of any calibration switches, reference files or tables to the values you wish to use for recalibrating your data. Remember that **no** processing has been done on the raw datasets. Therefore, even if you wish to correct, for instance, only the flatfielding, you will need to redo the bias and dark current subtraction as well. Therefore the switches for all these steps must be set to PERFORM.

3. Exit the editor by typing `:q` two times (the first `:q` to exit the pset editor; the second to exit the task). The task will ask if you wish to accept the current settings. If you type "`y`", the settings are saved and you will return to the IRAF prompt. If you type "`n`", you will be placed back in the editor to re-define the settings. If you type "`a`", you will return to the IRAF prompt and any changes will be discarded. For additional examples of updating the calibration keywords, check the on-line 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., `uref$` for calibration images and `utab$` 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, you will need to set these variables to the path where your reference files (and `.x0h`/`.q1h` raw data files) are located. For WFPC2 data, you would use something like the following:

```
to> set uref = "/nemesis/hstdata/caldir/"
to> set mtab = "/nemesis/hstdata/caldir/"
to> set ucal = "/nemesis/hstdata/rawdir/"
```

where `caldir` is the subdirectory for the reference files and `rawdir` is the subdirectory for the uncalibrated images.

While in VMS, to set the `uref`, for instance, one would type instead

```
to> set uref = "DISK$SHARE:[HSTDATA.CALDIR]"
```

where `HSTDATA.CALDIR` is the directory where you have stored the calibration reference files and tables.

Once you have correctly changed the values of the calibration keywords in the header of the raw data file, you are ready to recalibrate your data. The WFPC2 calibration software, **calwp2**, is run by typing the name of the task followed by the *rootname* of the observation dataset. For example, to recalibrate the dataset `u0w10e02t` and write the log of the results to the file `calwp2.log` (rather than to the screen), you would type:

```
wf> calwp2 u0w10e02t > calwp2.log
```

Note that the calibration routine will not overwrite an existing calibrated file. If you run the calibration tasks in the directory where your calibrated data already exist, you will need to specify a different output file name, for example:

```
wf> calwp2 u00ug201t wfpc_out > wfpc.log
```

For more information about how these routines work, use the on-line help by typing `help calwp2`.

Calculating Absolute Sensitivity for WFPC2

If you set DOPHOTOM=OMIT before running **calwp2**, then the values of inverse sensitivity (PHOTFLAM), pivot wavelength (PHOTPLAM), RMS bandwidth (PHOTBW), zeropoint (PHOTZPT), and observation mode (PHOTMODE) will not be written to the header of the recalibrated data file.

Remember that 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 in the header of the file. Therefore, unless you wish to recalculate the absolute sensitivity for your observation (e.g., because a more recent estimate of the throughput exists for your observing mode), there is no need to recompute these values and you can simply use the keyword values from your original calibrated file and apply them to your recalibrated data. However, new estimates of WFPC2 transmission and absolute sensitivity were obtained in September 1995, May 1996, and May 1997. If your data were processed in the pipeline before May 1997, you may wish to re-create the absolute sensitivity parameters using the latest version of **synphot**, which contains tables based on the most recent photometric calibration of WFPC2.

If you wish to recalculate the absolute sensitivity, set DOPHOTOM=YES in the `.d0h` file before running **calwp2**, or alternately, use the tasks in the **synphot** package of STSDAS.

The section titled “synphot” on page 3-16 has more information about how to use **synphot**.

To calculate the absolute sensitivity, **calwp2** 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). A more detailed discussion of photometric calibration can be found in “Photometric Corrections” on page 28-6.

You *must* have retrieved the **synphot** tables in order to recalculate absolute sensitivity for WFPC2 data using **calwp2** or **synphot**.

26.4 Post-Pipeline Calibration

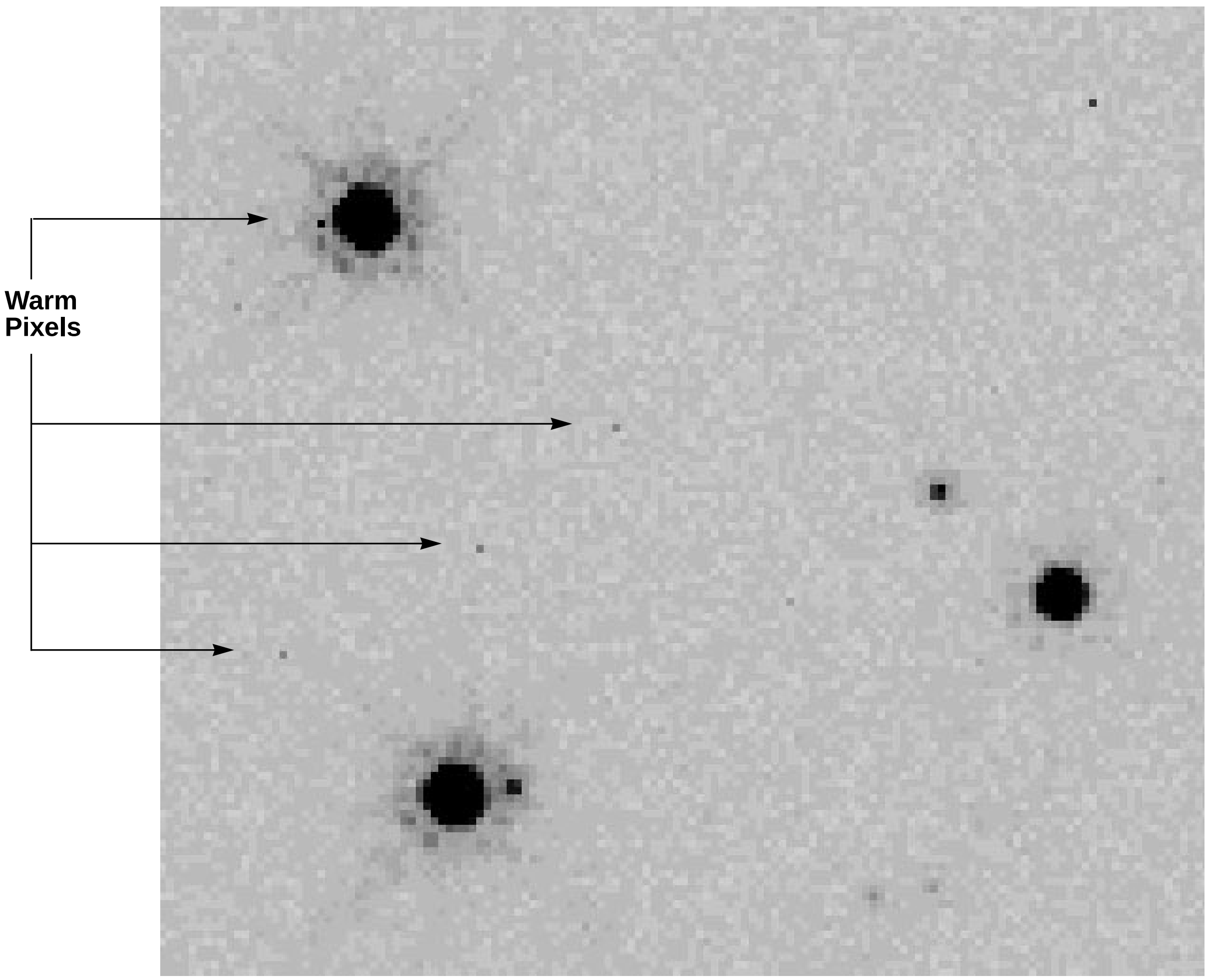
The calibrated individual images produced by the standard pipeline processing are, in most respects, as good as our knowledge of the instrument can make them. The usefulness of post-pipeline calibration is in general limited to two areas: improving the correction of pixels with elevated dark current (warm pixels), which are known to vary with time; and removing cosmic rays by comparing multiple images of the same field.

The treatment of warm pixels and cosmic rays can be quite different in the case of *dithered* data. This case is discussed in “Dithering” on page 28-19; the present discussion refers to co-aligned data only.

26.4.1 Warm Pixels

Figure 26.4 shows a section of a PC image of a stellar field. Cosmic rays have been removed through comparison of successive images. Nonetheless, individual bright pixels are clearly visible throughout the field.

Figure 26.4: PC Image of Stellar Field Showing Warm Pixels



These bright pixels are *warm* pixels, or pixels with an elevated dark current. The vast majority of WFPC2 pixels have a total dark current of about 0.005 e^{-}/s^{-1} (including the *dark glow*, discussed in “Dark Glow” on page 27-4). However, at any given time there are a few thousand pixels in each CCD, called warm pixels, with a dark current more than 0.02 e^-/s^{-1}, up to several e^-/s^{-1} in a few cases (see Figure 26.5). Some of these pixels are permanently warm, but most become warm during the course of the month, probably as a consequence of the on-orbit bombardment by heavy nuclei. STIS, the other instrument currently aboard HST that uses CCDs, exhibits a similar behavior. Most warm pixels return to normal after the CCDs are brought to room temperature for a few hours.

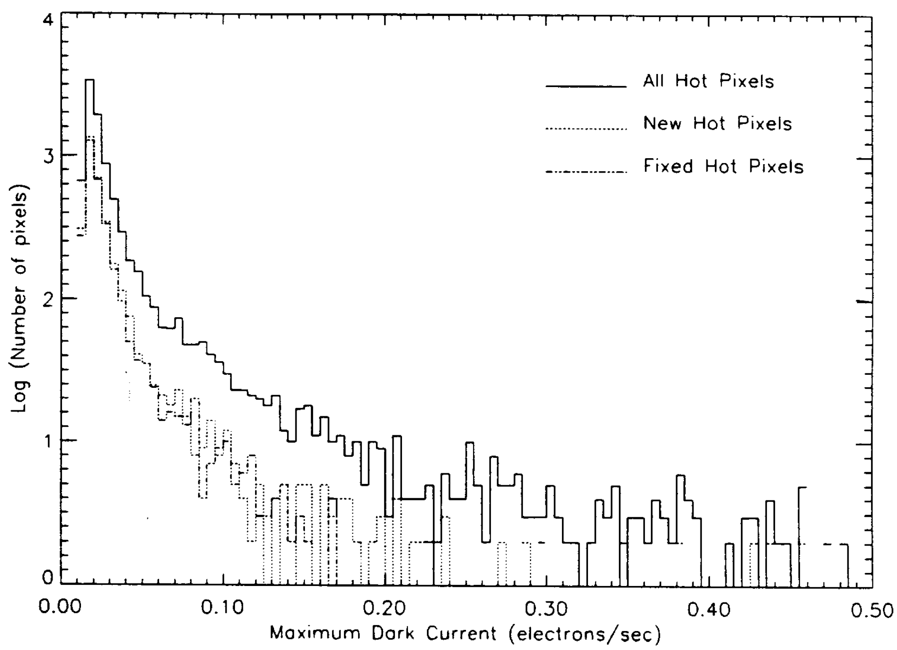
To repair warm pixels we run monthly decontaminations, in which the instrument warms up to about 22 C for a period of six hours. (Longer decontaminations do not appear to improve the fraction of pixels fixed.) Decontaminations are also needed to let UV-blocking contaminants that build up on the CCD windows evaporate, thus temporarily restoring the UV throughput of the camera. For more detailed information, see the *WFPC2 Instrument Handbook*.

Because of the time variability of warm pixels, standard dark correction does not deal with them adequately. Even dark frames taken within a day of the observation will contain some warm pixels that vary significantly from those in the observation. We have developed a task, known as **warmpix**, that will allow a user to either flag, or attempt to correct, pixels which are known to be warm, or which have varied near the time of the observation.

Will Warm Pixels Hurt my Science?

The impact of warm pixels on the scientific results obtained from WFPC2 images depends on a number of factors: the exposure length, the number of objects, and the science goals. If the principal goal of the program is to acquire morphological information on well-resolved targets, warm pixels are usually not a serious concern, as they are easily recognizable. If the goal is accurate photometry of point sources, the probability that uncorrected warm pixels will influence the measurement at a given level can be computed on the basis of the distribution of warm pixels (Figure 26.5). In general, warm pixels are a concern in two cases: accurate photometry of faint sources in crowded fields, where warm pixels can easily be confused with cores of faint sources, or aperture photometry with very large apertures and/or of extended objects. In the latter case, warm pixels cause a positive tail in the count distribution that is not included in the background determination, but—depending on the software used—could be included in the integrated source flux, which will then be positively biased.

Figure 26.5: Distribution of Dark Current for Warm Pixels



Can Warm Pixels be Corrected?

There are two levels of possible correction for warm pixels. The first is to identify and flag the warm pixels. Depending on the software used, the flagged pixels can either be ignored (PSF fitting software generally allows this) or be interpolated from nearby pixels (for software that requires a valid value for all pixels, such as most aperture photometry tasks). The identification of warm pixels can be accomplished by taking advantage of the fact that they are the only WFPC2 feature to extend across only one pixel; both cosmic rays and photons, in the form of point sources, involve more than one pixel. The IRAF task **cosmicrays**, written originally to remove single-pixel cosmic rays in ground-based data, has been used with some success to identify warm pixels in WFPC2 data. Identification of warm pixels is also possible using information from dark frames taken before and after the observations were executed, as described below.

The second level is to attempt subtraction of the dark current that existed at the time of the observations. This has the advantage that the information that exists in the measured signal in the pixel is retained, but it requires independent timely information on the dark current. WFPC2 takes several darks every week, thus information on warm pixels is available with a time resolution of about one week. While the user can in principle retrieve and process the darks taken at the time of observation, we provide a task and a set of tables to facilitate this process. The task is called **warmpix** and is part of the standard STSDAS release; the tables, in IRAF table format, are made available via the STScI Web pages at URL:

`http://www.stsci.edu/ftp/instrument_news/WFPC2/wfpc2_warmpix.html`

In order to use **warmpix** to identify or correct WFPC2 observations for the effect of warm pixels, perform the following steps:

- Obtain the relevant warm pixel tables from the URL previously mentioned. Each table name reflects its applicability dates; for example, the table named `decon_951214_960111.tab.Z` applies to all observations between December 14, 1995 and January 11, 1996.

These tables are in Unix-compressed format. On some systems, the retrieved table will not have the `.Z` extension, but they still need to be renamed to add the `.Z` extension and uncompressed by the Unix task `uncompress`. Please contact the Help Desk at `help@stsci.edu` if you have a non-Unix system or if you encounter difficulties in retrieving the tables.

- To correct the warm pixels, retrieve the calibration files used for dark subtraction and flatfielding in the calibrated image. The filenames are in the header parameters DARKFILE and FLATFILE, respectively. Redefine the IRAF variable `uref$` to point to the directory where the dark and flatfiles are stored. This step is required for **warmpix** to undo the dark current subtraction done in the pipeline, and substitute its own. If **warmpix** cannot find these files, it will not be able to correct the dark current subtraction, and will flag all warm pixels as bad.
- Run **warmpix** to correct and/or flag warm pixels. There are a number of user-adjustable parameters to decide which pixels should be corrected and which should be flagged as uncorrectable. Please see the **warmpix** help file for more details.

At the end of this process, pixels that exceed the user-defined thresholds will be either corrected for the dark current measured in the darks, linearly interpolated to the date of the observation, or be flagged as uncorrectable. An option is available to set the uncorrectable pixels to a specified value or to set the data quality values in the associated data quality files to reflect the fact that pixels have been corrected or rejected.

This procedure will generally correct for 90% to 95% of the warm pixels found in typical user data. There are some uncertainties in the results, associated with the intrinsic variability of hot pixels and the time span between darks. We have recently started a program to obtain dark frames daily, resulting in better warm pixel information. These darks are taken as a service to users, and they are not currently part of our delivered calibration files. Users who wish to use this information can recalibrate their data (see “Recalibration” on page 26-10) using a dark made from darks taken within one or two days of their observations.

Non-STSDAS tasks generally ignore the data quality files, and thus may not properly use the information indicating which pixels need to be rejected. Users should propagate this information by the appropriate method, which will depend on the specifics of the task.

26.4.2 Removing Cosmic Rays from Co-aligned Images

WFPC2 images typically contain a large number of *cosmic ray* events, which are caused by the interaction of galactic cosmic rays and protons from the Earth's radiation belt with the CCD. Hits occur at an average rate of about 1.8 events s^{-1} per CCD (1.2 s^{-1} cm^{-2}), with an overall variation in rate of 60% (peak-to-peak) depending upon geomagnetic latitude and position with respect to the South Atlantic Anomaly (see also the *WFPC2 Instrument Handbook*, v. 4.0, pages 74-79).

Unlike events seen on the ground, most WFPC2 cosmic ray events deposit a significant amount of charge in several pixels; the average number of pixels affected is 6, with a peak signal of 1500 e^{-} per pixel and a few tens of e^{-} per pixel at the edges. About 3% of the pixels, or 20,000 pixels per CCD, will be affected by cosmic rays in a long exposure (1800 s). Figure 26.6 shows the impact of cosmic rays in an 800 second exposure with WFPC2. The area shown is about 1/16th of one chip (a 200 x 200 region); pixels affected by cosmic rays are shown in black and unaffected pixels are shown in white. A typical long WFPC2 exposure (2000 s) would have about 2.5 times as many pixels corrupted by cosmic rays.

Cosmic rays are noticeable even for very short exposures. The WFPC2 electronics allow activities to be started only at one-minute intervals; thus a minimum-length exposure will collect at least one minute's worth of cosmic rays, the interval between camera reset and readout, and will be affected by about a hundred cosmic rays per CCD.

As a result of the undersampling of the WFPC2 PSF by the WF and PC pixels, it is very difficult to differentiate stars from cosmic rays using a single exposure. If multiple co-aligned images are available, cosmic rays can be removed simply and reliably by comparing the flux in the same pixel in different images, assuming that any differences well above the noise are positive deviations due to cosmic rays. STSDAS tasks such as **crrej** and **gcombine** can identify and correct pixels affected by cosmic rays in such images. (The task **crrej** has been significantly improved since the previous edition of the *HST Data Handbook* and is now the recommended choice.) If the images are shifted by an integral number of pixels, they can be realigned using a task such as **imshift**. As each CCD is oriented differently on the sky, this operation will need to be done on one group at a time, using the pixel shift appropriate for each CCD in turn.

Another consequence of the undersampling of WFPC2 is that small pointing shifts will cause measurable differences even between images at the same nominal pointing. These differences are especially noticeable in PC images, where pointing offsets of only 10 mas can cause a difference between successive images of 10% or more near the edges of stellar PSFs. We recommend that users allow for such differences by using the multiplicative noise term included in the noise model of the task used for cosmic ray rejection (`scalenoise` for **crrej** and `snoise` for **gcombine**). For typical pointing uncertainties, a multiplicative noise of 10% is adequate; note this is specified as 10 for `scalenoise`, and 0.1 for `snoise`. It is also strongly recommended that an image mask be generated for each image, to verify if there is an undue concentration of cosmic rays identified near point sources—usually an indication that the cores of point sources are mistaken for cosmic rays. Detailed explanations of **crrej** and **gcombine** can be found in the on-line help.

Figure 26.6: WF Exposure Showing Pixels Affected by Cosmic Rays

Because sub-pixel dithering strategies are now very common, the image combination tasks in the **drizzle** package (see “Dithering” on page 28-19) now include a script that can remove cosmic rays from images taken at multiple pointings, without repetitions.

How many Images for Proper CR Rejection?

Cosmic rays are so numerous on WFPC2 images that double hits are not uncommon. For example, the combination of two 2000 s images will typically contain about 500 pixels per CCD that are affected by cosmic rays in both images; in most of these cases, the hit will be marginal in one of the two images. If the science goals require a high level of cosmic ray rejection, it will be desirable to conduct a more stringent test in pixels adjacent to detected cosmic rays (see the parameter `radius` in **crrej**). Even better would be, in the planning stage, to break the observation into more than two exposures; the WFPC2 Exposure Time Calculator gives specific recommendations on the number of exposures necessary as a function of the number of pixels lost. In general, three exposures are sufficient for non-stringent programs, and four exposures for any program. The Exposure Time Calculator is available via the WWW at:

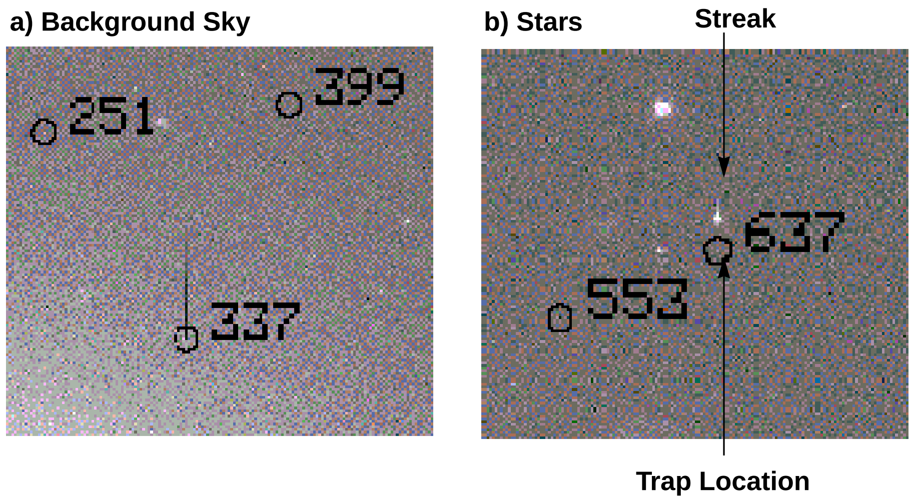
```
http://www.stsci.edu/ftp/instrument_news/WFPC2/Wfpc2_etc/
wfpc2-etc.html
```

26.4.3 Charge Traps

There are about 30 pixels in WFPC2 which do not transfer charge efficiently during readout, producing artifacts that are often quite noticeable. Typically, charge is delayed into successive pixels, producing a streak above the defective pixel. In the worst cases, the entire column above the pixel can be rendered useless. On blank sky, these traps will tend to produce a *dark* streak. However, when a bright object, or cosmic ray, is read through them, a bright streak will follow the object. Figure 26.7 shows examples of both of these effects. (Note that these “macroscopic” charge traps are different from the much smaller traps believed to be responsible for the charge transfer effect discussed under “Charge Transfer Efficiency” on page 28-11.)

The images in Figure 26.7 show streaks (a) in the background sky and, (b) stellar images produced by charge traps in the WFPC2. Individual traps have been cataloged and their identifying numbers are shown.

Figure 26.7: Streaks in a) Background Sky, and b) Stars



Bright tails have been measured on images taken both before and after the April 23, 1994 cool down. The behavior of the traps has been quite constant with time, and fortunately there is no evidence for the formation of new traps since the ground system testing in May 1993. The charge delay in each of the traps is well characterized by a simple exponential decay which varies in strength and spatial scale from trap to trap.

The positions of the traps, as well as those of pixels immediately above the traps, are marked in the `.c1h` data quality files with the value of 2, indicating a chip defect. These pixels will be obviously defective even in images of sources of uniform surface brightness. However, after August 1995 the entire column above traps has been flagged with the value of 256, which indicates a “Questionable Pixel.” An object with sharp features (such as a star) will leave a trail should it fall on any of these pixels.

In cases where a bright streak is produced by a cosmic ray, standard cosmic ray removal techniques will typically remove the streak along with the cosmic ray. However, in cases where an object of interest has been affected the user must be more careful. While standard techniques such as **wfixup** will interpolate across affected pixels and produce an acceptable cosmetic result, interpolation can bias both photometry and astrometry. In cases where accurate reconstruction of the true image is important, modelling of the charge transfer is required. For further information on charge traps, including the measured parameters of the larger traps, users should consult *WFPC2 ISR* 95-02, available on the WPFC web pages.