Chapter 27
WFPC2 Error Sources

In This Chapter...

This chapter discusses some of the error sources associated with WFPC2 data. Most of the chapter focuses on specific calibration errors, complementing and partially overlapping the discussion given in “Post-Pipeline Calibration” on page 26-15. Other subtle errors and problems which appear in WFPC2 data, but which are not directly related to data calibration, are discussed at the end of this chapter and in Chapter 28.

Keep in mind that many of the error sources affecting calibrated WFPC2 data can be greatly reduced, or even corrected entirely, by either recalibration with newer calibration reference files or post-pipeline calibration. The routine pipeline calibration initially performed on a dataset before it is deposited in the Archive and delivered to the observer uses the most current, WFPC2-specific calibration reference files available at the time of processing. If there appear to be unusual features in the data, or if the analysis requires a high level of accuracy, it is important to determine if a better set of later calibration reference files can be used to recalibrate the data. Finding that a calibration reference file has changed since the data were calibrated doesn’t always mean that recalibration is necessary. The decision to recalibrate depends very much on which calibration image or table changed, and whether that kind of correction is likely to affect the analysis. Chapter 26 gives more details on the required procedures.

27.1 Bias Subtraction Error

Very early on, it was discovered that the first few columns of the overscan region of WFPC2 CCDs, used for bias subtraction, can be positively offset if a strong signal is present in the image itself. The consequence was oversubtraction of the bias level. The sky background level in such images is incorrect, and in a few cases a significant part of the calibrated image has negative pixel values. The problem was fixed in **calwp2** version 1.3.0.5 (March 1994).

Slightly later, it was also realized that proper bias subtraction occasionally requires the use of separate bias values for odd and even columns. WFPC2 data taken before May 4, 1994 did not use this form of bias subtraction. As a result a striated pattern with a typical amplitude of a few electrons (a fraction of a DN) may remain in these images. These data will benefit from recalibration with **calwp2**, version 1.3.0.6 or later, unless the signal of the observation is so large that the noise statistics are dominated by Poisson noise. A recent study of the properties of bias frames throughout WFPC2 operations can be found in the *WFPC2 ISR* 97-04. From their results, it appears that large differences between the bias level in the even and odd columns have been rare after 1995, thus it is unlikely that recent WFPC2 data suffer from this problem to any measurable degree.

27.2 Flatfield Correction Errors

Early WFPC2 data were flattened using flatfields that did not take into account the large-scale structure of the flatfield. The offending flats have names that begin with “d” or “e1”.

Some special-purpose filters (such as the polarizers) did not have flats made until well after the installation of WFPC2. Some, such as the Woods filter (F160BW), still do not have an accurate flatfield. In these cases, the PEDIGREE and DESCRIP keywords for the flatfield file, reported at the end of the header of the calibrated image in HISTORY records, will indicate the existence of a problem at the time the data were taken. A pedigree of DUMMY indicates that the flatfield is identically 1, thus no real flatfield correction has been performed. A pedigree of GROUND indicates that the flatfield has been obtained purely from data taken during the pre-launch Thermal Vacuum test, and thus does not reflect properly the illumination function typical of the HST OTA; in this case, zonal errors of several percent can be encountered. Such cases are extremely rare after the summer of 1996, but are not uncommon for data taken in 1994 and early 1995, when the basic camera calibration was not yet completed.

A completely new generation of flatfields has been delivered between late 1995 (for the filters used in Hubble Deep Field observations) and 1996. These flatfields are more accurate than the previous ones, although few users will need to recalibrate as a result of this change. In the optical, the new flats differ from the old by 1% or less over the vast majority of the chip, with the differences growing in the outer 50 pixels of the chip to about 8% at all wavelengths. Longward of 850 nm, differences of up to 1.5% are seen across the main body of the chips, and shortward of 300 nm the differences between the old and new flatfields are less than 3% over most of the chip.

WFPC2 flatfields are defined so that a source of constant brightness produces the same count rate per pixel across the image. However, due to geometric distortion of the image by the optics, the area of WFPC2 pixels on the sky depends on location on the chip. The total variation across the chip is a few percent. Therefore, the photometry of point sources is slightly corrupted by the standard flattening procedure. This effect, and its correction, are discussed in "Geometric Distortion" on page 28-12.

27.3 Dark Current Subtraction Errors

27.3.1 Electronic Dark Current

At the operating temperature of -88 C, maintained after April 23, 1994, the WFPC2 CCDs have a low dark background, ranging between 0.002 and 0.01 e^{-}/s/pixel. A relatively small number of pixels have dark currents many times the value. These *warm pixels* are discussed in great detail in Chapter 26. To remove the dark current, the standard pipeline procedure takes a dark reference file (which contains the average dark background in DN/s), multiplies it by the dark time (determined by the header keyword DARKTIME), and subtracts this from the bias subtracted image. Prior to April 23, 1994, the CCDs were operated at –77 C. The correction procedure is the same for these early data, but the average dark current was about an order of magnitude higher due to the higher temperature. Hence, the dark current correction is both more important and less accurate than for later data.

The dark time is usually close to the exposure time, but it can exceed the latter substantially if the exposure was interrupted and the shutter closed temporarily, for example as a consequence of loss of lock. Such instances are rare and should be identified in ther header keyword EXPFLAG and in the data quality comments for each observation, but will also be indicated by a difference between the exposure start and end time which is greater than the total exposure time. The true dark time differs slightly from pixel to pixel because of the different time elapsed between reset and readout. To the extent that dark current is constant with time, this small differential is present both in the bias image and in the observation itself, and therefore is automatically corrected by the bias subtraction.

New dark reference files are delivered on a weekly basis, but because of the necessary processing, they are usually available a week or two later than the observation itself. As a result, the dark used in the pipeline is not the same as the dark reference file recommended by StarView. The primary difference between successive darks is in the location and value of hot pixels. This difference will be most notable if a decontamination occurred between the images used to create the dark and the observation itself. However, because direct treatment of the warm pixels themselves, rather than dark file subtraction, now appears the best way to remove warm pixels, many users will find that they do not need to reprocess with the most up-to-date dark file. For more details, see “Warm Pixels” on page 26-16.

Until August 1996, the weekly standard darks were based on a relatively small number (10) of exposures, taken over a time span of two weeks, in order to track the variable warm pixels. However, these darks can be a significant component of the total noise in deep images. Observers whose (pre-August 1996) images are formed from exposures totalling more than five orbits may therefore wish to recalibrate their data using the so-called *superdarks*, which have been generated by combining over 100 individual exposures (see the reference file memo on the WFPC2 Web page).

Since August 1996, the weekly standard darks have been produced by combining the relevant superdark with the warm pixel information in the dark frames taken that week. The combined file is obtained by using the superdark value for all pixels that appear normal in the weekly dark, namely, for which the dark current value in the weekly dark does not differ from the superdark value by more than 3 σ. For pixels that do deviate more than 3 σ, the weekly dark value is used. This compromise allows a timely tracking of warm pixels, while maintaining the low noise properties of the superdark for pixels that do not appear to change. Recalibration may still be appropriate, because the weekly standard dark is not yet available when the image is processed and archived at STScI.

27.3.2 Dark Glow

While the electronic dark current is relatively stable between observations, a component of the “dark current” has been seen to vary between observations. The intensity of this *dark glow* is correlated with the observed cosmic ray rate, and the glow is believed to be due to luminescence in the MgF_2 CCD windows under cosmic ray bombardment. As a result of the geometry of the windows, the dark glow is not constant across the chip, but rather shows a characteristic edge drop of about 50%. The dark glow is significantly stronger in the PC, where it dominates the total dark background, and weakest in the WF2. The average *total* signal at the center of each camera is 0.006 e^{-}/s in the PC, 0.004 e^{-}/s in WF3 and WF4, and 0.0025 e^{-}/s in WF2; of this, the true dark current is approximately 0.0015 e^{-}/s, and the rest is dark glow. For more details, see the *WFPC2 Instrument Handbook*, Version 4.0, pages 71-75.

Because of the variability in the dark glow contribution, the standard dark correction may leave a slight curvature in the background. For the vast majority of observations, this is not a significant problem, because of the very low level of the error (worst-case center-to-edge difference of 2 e^{-}/pixel) and its slow variation across the chips. However, if an observation requires careful determination of the absolute background level, observers are encouraged to contact their WFPC2 contact scientist or the Help Desk (`help@stsci.edu`).

27.4 Image Anomalies

In this section we present a number of unusual occurrences which occasionally affect WFPC2 data.

27.4.1 Bias Jumps

The average bias level for each image is obtained from the engineering data file (`.x0h`/`.x0f`) separately for even and odd columns. However, WFPC2 is subject to *bias jumps*, changes of the bias level during the readout. Large bias jumps (> 0.5 DN) are relatively rare, but small bias jumps, at the 0.1 DN level, affect about 10% of all images. Figure 27.1 shows a very unusual event where the bias has jumped in two chips during the same image.

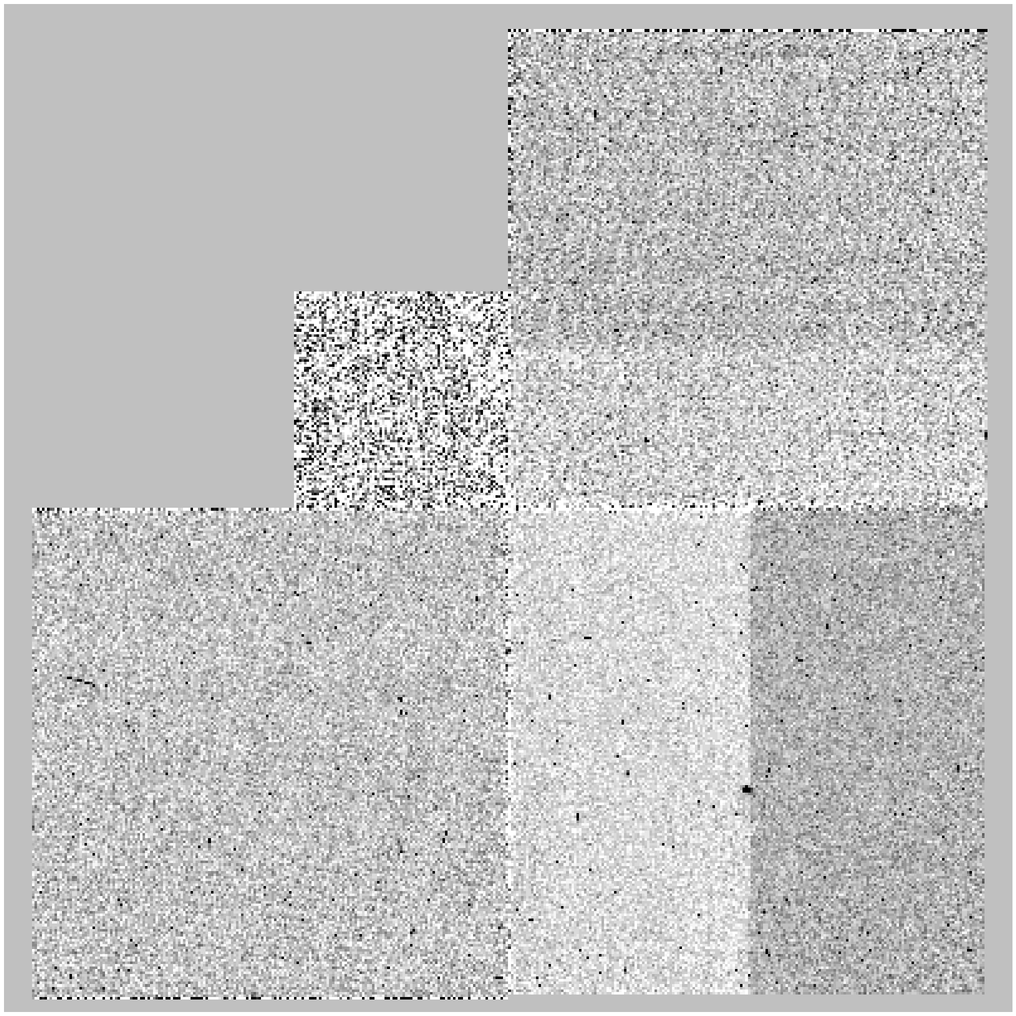
Bias jumps are fairly obvious from a cursory inspection of the image, but users are alerted to their possible presence by a comment in the data quality file (suffix `.pdq`). Bias jumps are currently identified by an automatic procedure that searches the overscan data for possible anomalies; for details see *WFPC2 ISR* 97-04. Only jumps larger than 0.09 DN are reported. Prior to August 1996, the identification of bias jumps was done manually. Some of the bias jumps indicated in the data quality file are false positives, caused by image features, such as strongly saturated stars, which affect the overscan data.

There is no standard procedure to remove this defect, but it can be corrected by measuring the jump in the `.x0h` (bias) file or directly in the image if the image is clean enough. Standard IRAF procedures such as **imexamine** or **imstat** are sufficient to obtain a good estimate of the offset. The offset can then be removed, for instance, by subtracting the bias jump and then copying out the affected chip to another image, using the command:

```
im> imcalc image_in image_out "if (y.lt.YJUMP) then im1 \
>>> else (im1 - BJUMP)"
```

where YJUMP is the line at which the jump occurs, and BJUMP is its amplitude. The image `image_out` can then be copied back into the appropriate WFPC image group using the **imcopy** task.

Figure 27.1: Bias Jump in Two Chips



27.4.2 Residual Images

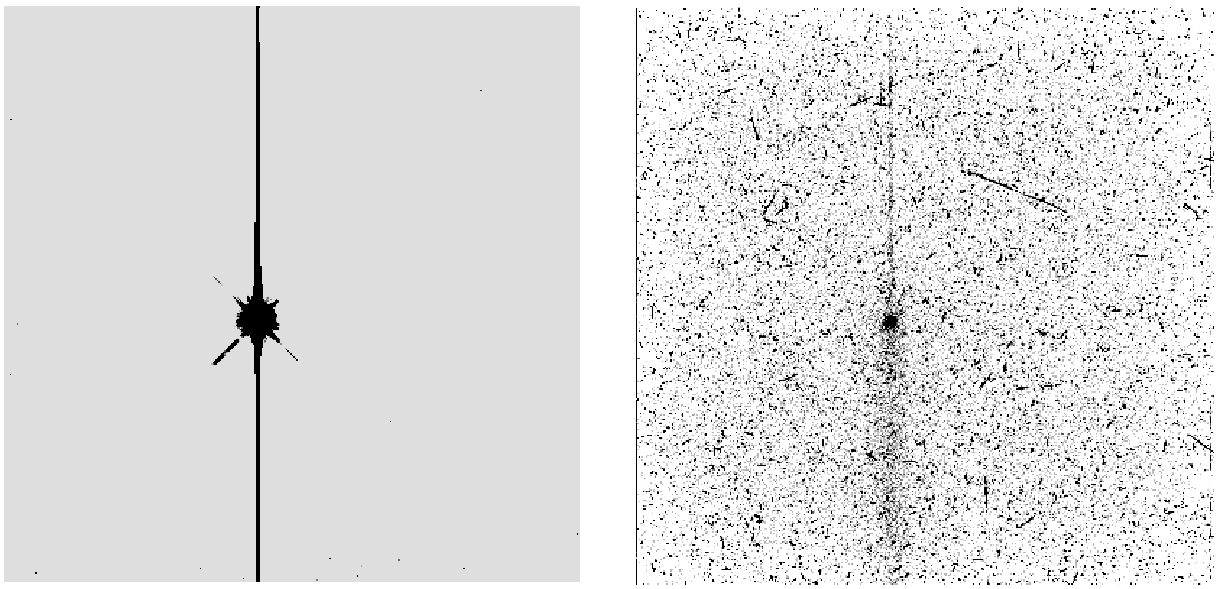
Observations of very bright sources can leave behind a residual image. This residual is caused by two distinct effects. In the first effect, charge in heavily saturated pixels is forced into deeper layers of the CCD which are not normally cleared by readout. Over time, the charge slowly leaks back into the imaging layers and appears in subsequent images. The time scale for leakage back into the imaging region depends on the amount of over-exposure. Strongly saturated images can require several hours to clear completely. The second effect is caused by charge transfer inefficiencies. At all exposure levels some charge becomes temporarily bound to impurities in the silicon of the CCD. The effect is most noticeable in images with high exposure levels, probably because electrons become exposed to more impurities as the wells are filled. This effect leaves behind charge both in bright regions of the image and in the part of the chip through which the bright objects were read out.

Figure 27.2 shows a saturated star on PC1 and the residual image seen in an 1800 second dark calibration frame which was started six minutes later. Note that the residual image is bright not only where the PC image was overexposed (effect 1), but also in a wide swath below the star due to the second effect and a narrower swath above the star due to bleeding during the exposure.

Figure 27.2: Saturated Star and Residual Image

a) Saturated Star on PC1

b) Residual Image on Dark Frame 6 Minutes Later



Ghosts

Ghost images may occur on images of bright objects due to internal reflections in the WFPC2 camera. The most common ghosts are caused by internal reflections in the MgF_2 field flatteners. In these ghosts, the line connecting the ghost and the primary image passes through the optical center of the chip. The ghost always lies further away from the center than the primary image. Figure 27.3 gives an example of one of these ghosts.

Ghosts may also occur due to reflections on the internal surfaces of a filter. The position of these ghosts will vary from filter to filter and chip to chip. For any given filter and chip combination, the direction of the offset of the ghost from the primary image will be constant, although the size of the offset may vary as a function of the position of the primary image. Filter ghosts can be easily recognized by their comatic (fan-shaped) structure. Particularly bright objects may produce multiple ghosts due to repeated internal reflections. Figure 27.4 shows an example of filter ghosts.

Figure 27.3: Field-Flattener Ghost in WF2—Image Shows Entire CCD

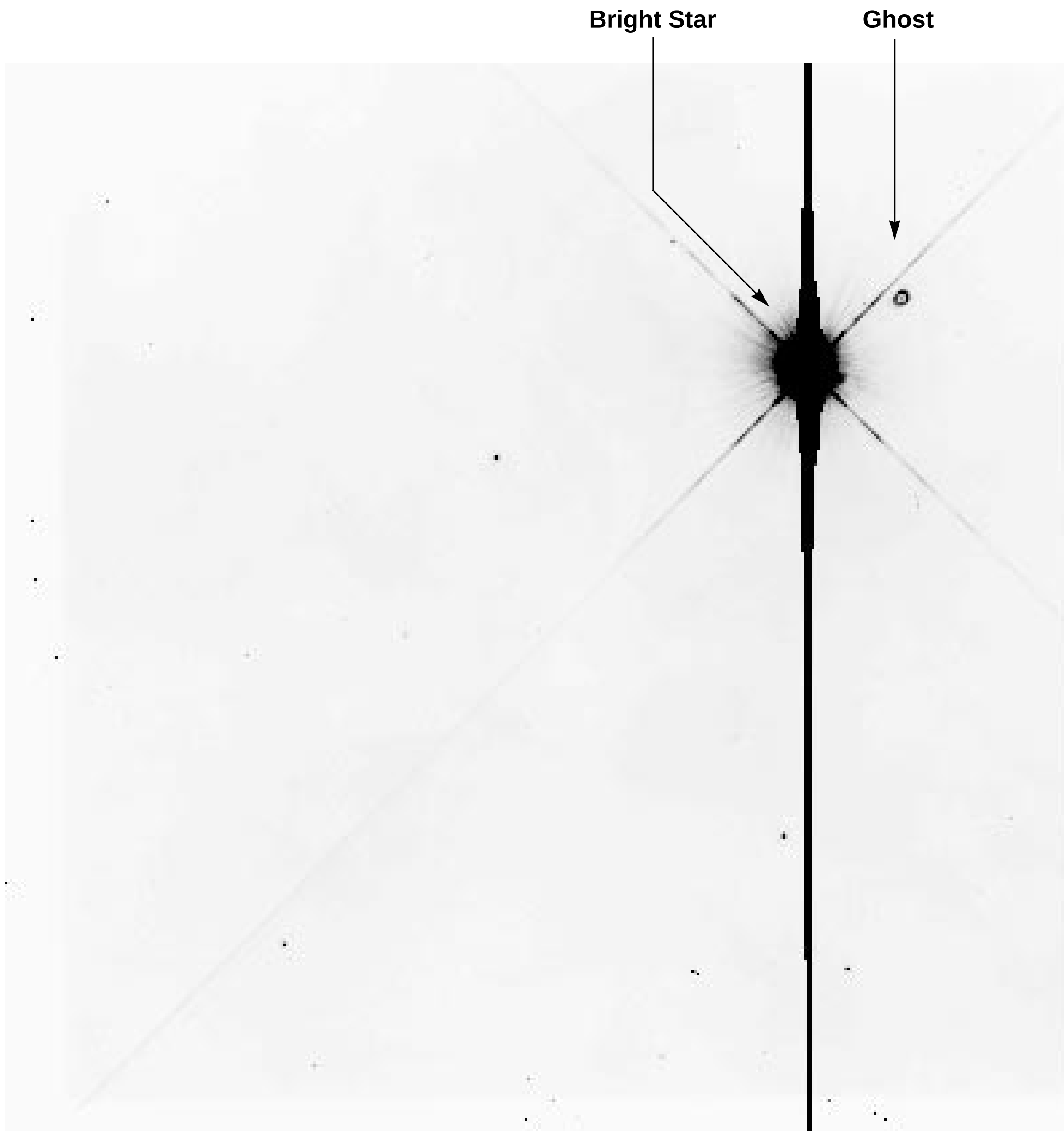
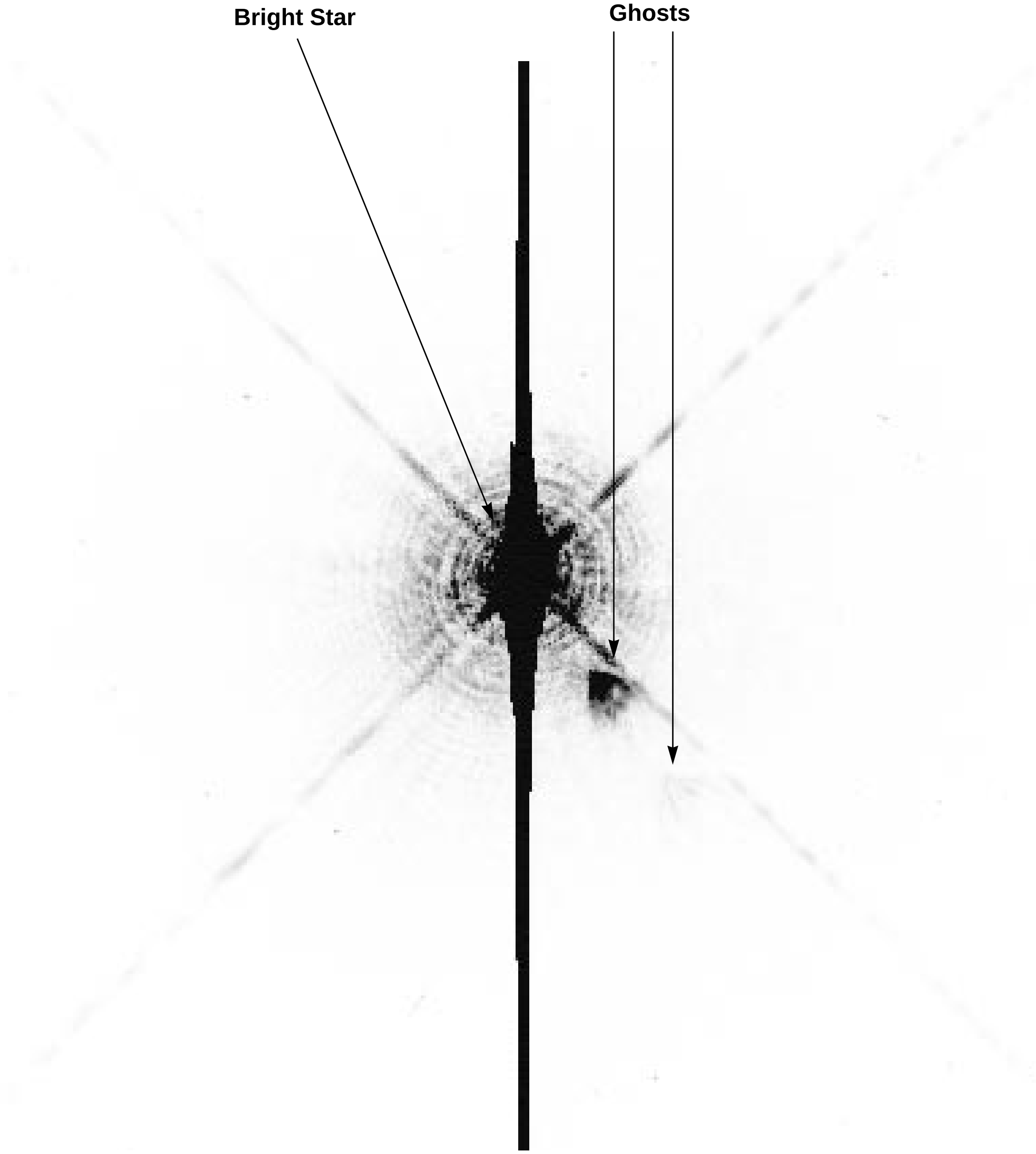


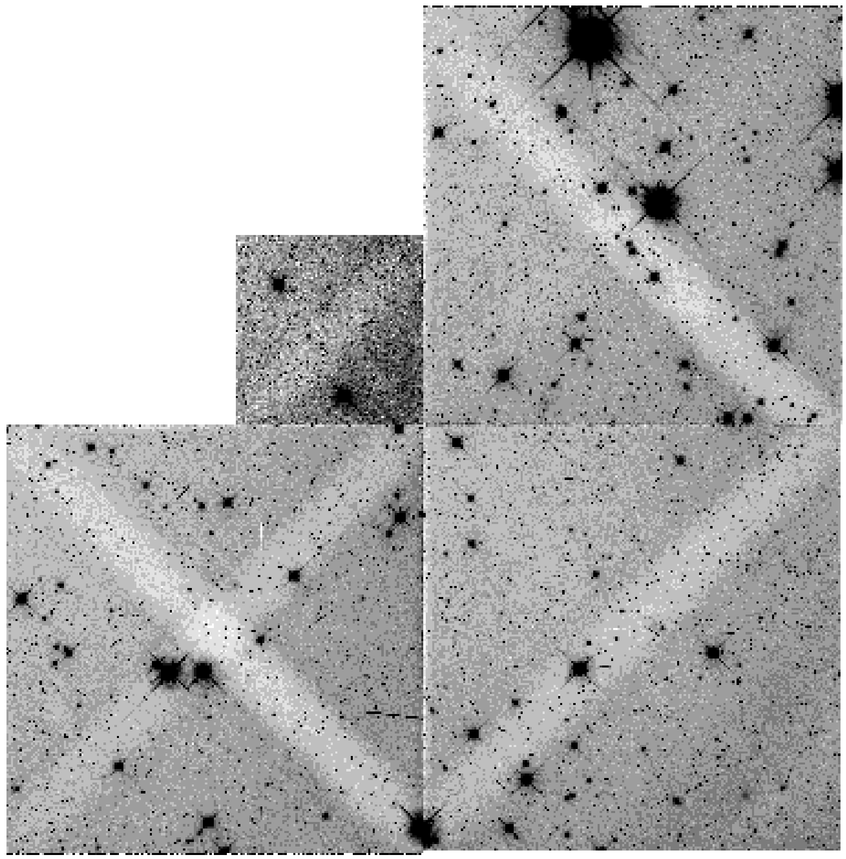
Figure 27.4: Detail of Filter Ghosts on WF4



Earth Reflections

Light from the bright sun-lit Earth is on rare occasion reflected off the Optical Telescope Assembly (OTA) baffles and secondary support and into the WFPC2. These reflections can occur when the bright Earth is less than ~40 degrees from the OTA axis. (The default bright Earth limb avoidance is 20 degrees. Science observations are not scheduled at smaller limb angles to the sunlit Earth). The light raises the overall background level of the field; however, the WFPC2 camera mirror supports can vignette the scattered light, producing either X-shaped or diagonal depressions in the level of the background. Figure 27.5 shows a typical example of the pattern formed by the scattered light. The scattered light in this image has a level of about 100 electrons. The darkest portion of the X is about 40 electrons below the average background level.

Figure 27.5: Scattered Light Pattern



27.4.3 PC1 Stray Light

The WFPC2 was originally intended to contain two separate pyramids—one for four PC cameras and the other for four WF cameras. Budget reductions caused the PC pyramid to be abandoned and the first WF camera to be replaced by a PC camera. However, the pyramid mirror corresponding to the PC camera was not reduced in size. As a result, baffling for the PC chip is not optimal, and a bright star falling on the pyramid outside of the PC field of view can produce an obvious artifact typically shaped like a broad, segmented arc. A star bright enough to produce a total count rate of 1 DN/s on the chip, will produce a ghost with a count rate of about 1×10^{-7} DN/pixel/s over the affected region. When scheduling observations, users should avoid placing stars brighter than $V \sim 14$ in the L-shaped region surrounding the PC.

27.4.4 Other Anomalies

Other image anomalies, such as bright streaks from other spacecraft, scattered light from bright stars near the field of view, and missing image sections due to dropped data occur on rare occasion. For more information, consult *WPFC2 ISR* 95-06, which can be obtained through the WFPC2 Web page or through the STScI Help Desk (`help@stsci.edu`).