2002 HST Calibration Workshop
Space Telescope Science Institute, 2002
S. Arribas, A. Koekemoer, and B. Whitmore, eds.

WFPC2 Status and Overview

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Abstract. The current status of the Wide Field and Planetary Camera 2 is reviewed, with special emphasis on the five years since the previous *HST* Calibration Workshop. The WFPC2 continues to work nearly flawlessly, with the only major problem being a shutter anomaly in October, 2000, which put the camera offline for approximately a month. The two servicing missions (SM3a and SM3b) did not affect the long-term characteristics of the WFPC2. We also report on the status of basic WFPC2 characteristics (photometry, focus, and astrometry) and briefly mention some of the recent WFPC2 projects.

1. Highlights From the Past Five Years

It has been five years since the previous calibration workshop, and the report by Whitmore (1997) on the status of the WFPC2. An earlier status report was provided by MacKenty (1995). The current report will therefore concentrate on the past five years. WFPC2 has been operating for almost nine years now (launch was December, 1993), and over 125,000 external science exposures have been taken. The instrument has worked almost flawlessly during this period, with the only mechanical problem being a shutter anomaly in October, 2000, which put the WFPC2 offline for approximately one month. This problem was due to the degradation of the LED-sensor assembly in the shutter mechanism combined with slight mechanical misalignments. The problem was solved by increasing the length of time the LED is on before reading the sensor. A detailed report is available in Casertano (2000a).

Two servicing missions have occurred during the past five years, Servicing Mission 3a in December, 1999, and Servicing Mission 3b in March, 2002. In both cases, extensive post servicing mission tests have shown that the WFPC2 characteristics (e.g., quantum efficiency, point-spread-function, flatfields, ...) have not been affected. The only minor exception is a temporary (approximately one month) increase in the UV contamination rate, presumably due to additional contaminants originating from the shuttle and/or other newly installed instruments during the servicing mission. Detailed reports covering these post servicing mission tests are available in Casertano et al. (2000b) and Koekemoer et al. (2002a).

Table 1 shows how the filter usage has changed over the past five years. There are two trends responsible for most of the changes. The first is the increased usage of the very wide filters F300W, F450W, F606W, and F814W. This evolution was inspired by the Hubble Deep Field, which employed these four filters. The second trend is for the increased usage of the narrow-band filters, especially F656N (Hα), F658N (redshifted Hα), and F502N (OIII).

Some of the scientific highlights originating from WFPC2 during the past five years have been the Hubble Deep Field South; untangling the nature of gamma gay bursts; and observations of supernovae at $z > 1$ that support the existence of dark energy, to name just a few. On the calibration front, the development of the DRIZZLE software (Fruchter & Hook 1997), and formulae for the correction of Charge Transfer Efficiency loss (Whitmore, Heyer, & Casertano 1999, Dolphin 2000) were important contributions.

When one reflects on the fact that the WFPC2 has received the lion's share of observing time during the past nine years, on arguably the most important telescope ever developed, it would appear to be a fair statement to say that the WFPC2 camera may be the most successful astronomical instrument ever built. The astronomical community owes a great debt of gratitude to John Trauger and the Instrument Development Team that designed and built the WFPC2.

Table 1. Historical Usage of Filters since Launch

Filter	Dec/93–Sep/02[a] (# of exposures)	rank	Dec/93–Aug/97[a] (# of exposures)	rank	Comments
F814W	18867	1	7689	1	
F606W	16560	2	3033	3	NOTE CHANGE
F555W	11700	3	5506	2	
F300W	6300	4	1381	6	NOTE CHANGE
F450W	3729	5	680	14	NOTE CHANGE
F675W	3316	6	1516	5	
F702W	2756	7	1755	4	NOTE CHANGE
F439W	2304	8	1254	7	
F656N	2283	9	684	13	NOTE CHANGE
F336W	2219	10	1225	8	
F170W	1991	11	1129	9	
F547M	1903	12	806	10	
F850LP	1542	13	698	12	
F502N	1165	14	451	21	NOTE CHANGE
F1042M	1043	15	500	18	
F673N	1042	16	518	17	
F160BW	966	17	755	11	NOTE CHANGE
F658N	934	18	300	24	NOTE CHANGE
F410M	926	19	382	22	
F953N	921	20	549	15	
F255W	919	21	487	19	
F218W	755	22	469	20	
F791W	588	23			
F785LP	503	24			
F631N	355	25			
F467M	336	26			
F622W	237	27			
F588N	200	28			
F380W	198	29			
F487N	191	30			
F122M	181	31			

[a]External exposures only

2. The Basics

2.1. Photometry

The photometric stability over a short period of time for the major broadband filters continues to be very good, with rms scatter $<1\%$ (Figure 1). However, a slow (few percent during the 9 years in orbit), linear decrease is present in the throughput for most filters. This appears to be due to the degradation of Charge Transfer Efficiency (CTE) with time (See Figure 4.6 of Koekemoer et al. 2002a).

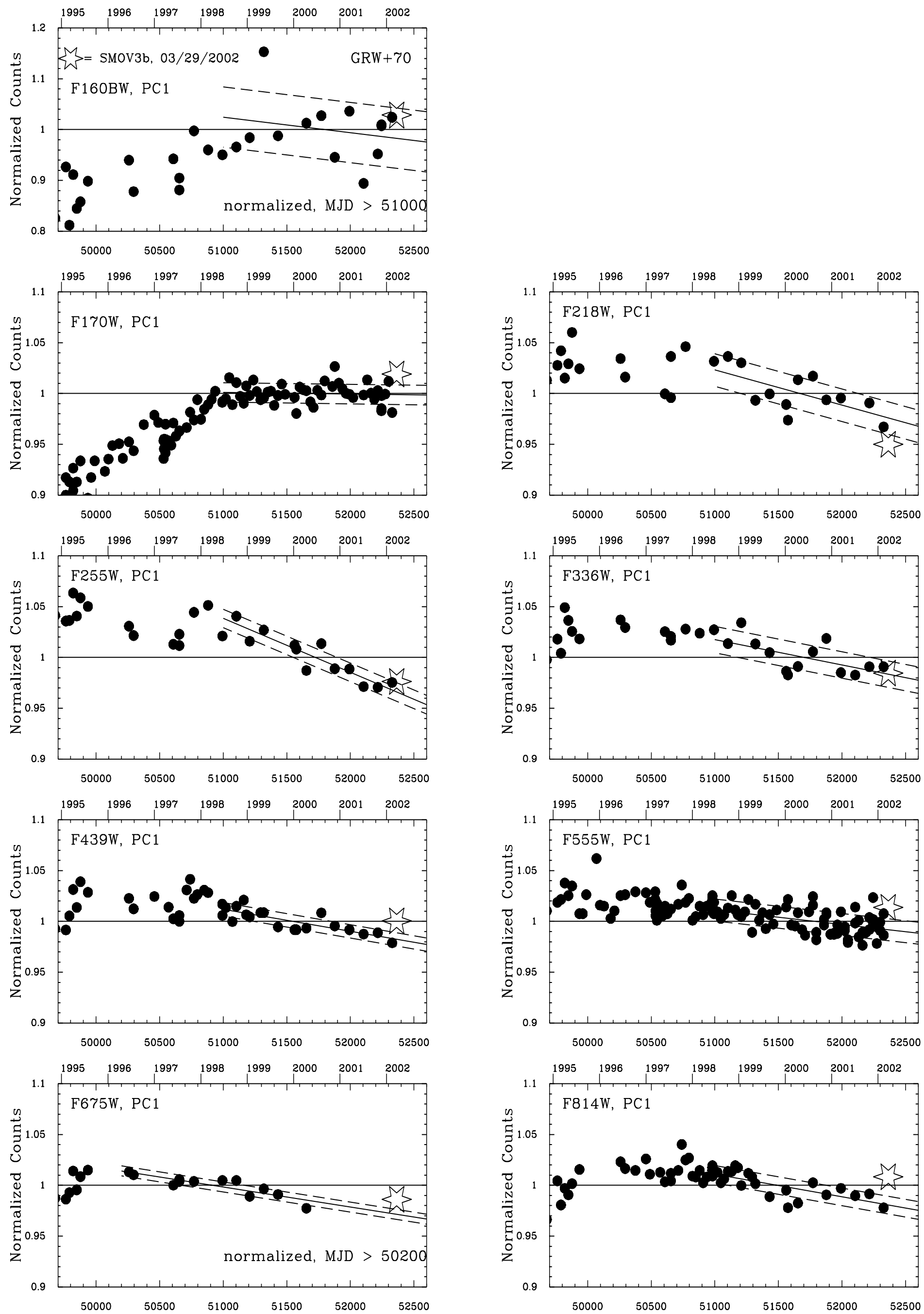

Figure 1. Comparison of post-SM3b photometric monitoring observations (the large stars) with historical trends. (Whitmore & Heyer 2002a, Koekemoer et al. 2002a).

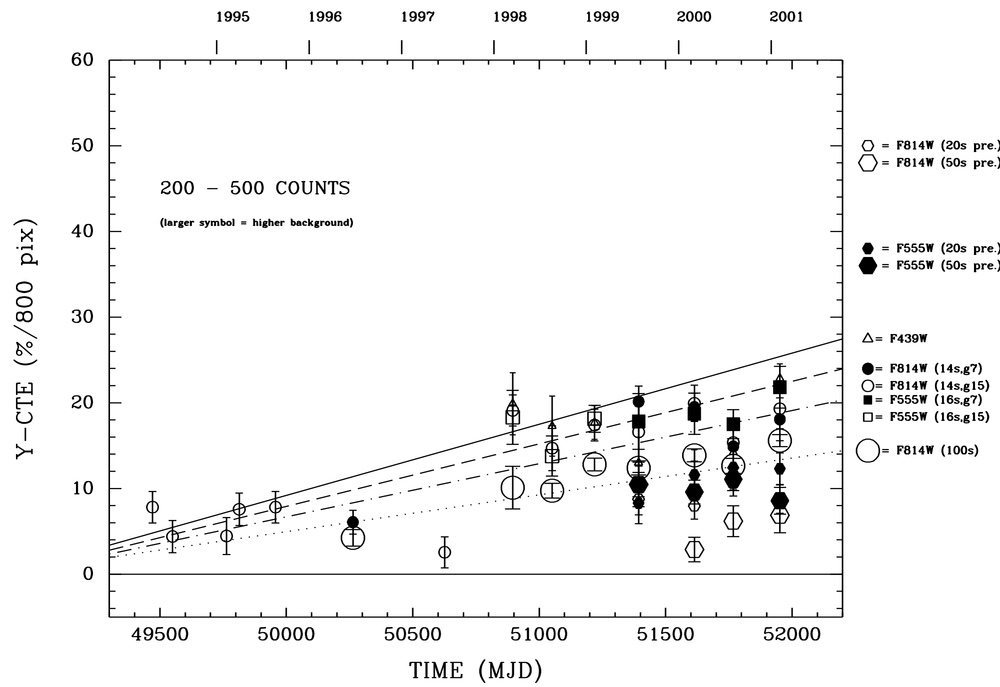

Figure 2. Growth of Y-CTE with time for faint stars (Heyer, 2001).

This degradation of CTE with time continues to be perhaps the most significant problem for the WFPC2. The existence of CTE loss was first discussed by Holtzman et al. (1995b). They advocated using a 4% ramp to correct for the problem at the time. Whitmore et al. (1999) more fully characterized CTE loss, and showed that it is a function of 1) Y position on chip (parallel CTE), 2) X position on the chip (serial CTE), 3) target brightness, and 4) background level. They also found that the problem was growing linearly with time (see Figure 2). Since then, several other studies have confirmed the effect, and have added important contributions to the characterization of the CTE. In particular, the recommended formula for correcting for CTE loss is currently that of Dolphin (2000 = original paper, 2002 = WWW site with latest update). Other contributions of interest include studies of CTE residuals (Biretta & Mutchler 1997, Baggett et al. 2000), using cosmic rays to measure CTE loss (Riess 1999), extended source CTE (Riess 2000), CTE monitoring (Heyer 2001) and CTE at very low levels and a reexamination of the long-vs.-short anomaly (Whitmore & Heyer 2002b). There is also a nice summary of CTE loss for various *HST* instruments (Stiavelli et al. 2001).

The determination of the photometric zeropoints is also an important topic for many projects. A comparison of zeropoint determinations from five different studies for the primary broad band filters is shown in Figure 3. The rms scatters for the five studies are 0.043 mag for F336W, 0.034 mag for F439W, 0.016 mag for F555W, and 0.018 mag for F814W. We note that the most widely used filters, F555W and F814W, are particularly good, with rms scatter less than 0.02 mag.

In the past, the zeropoints determined at STScI have been based on observations of our monitoring star, GRW+70D5824, and the SYNPHOT (synthetic photometry) package in STSDAS. We are now engaged in a project to determine zeropoints (and check Holtzman's transformation equations) based on comparisons with: Stetson (2002) standards, Saha et al. (2002) standards, and a few Landolt (1992) standards. See Heyer et al. (2002) for details.

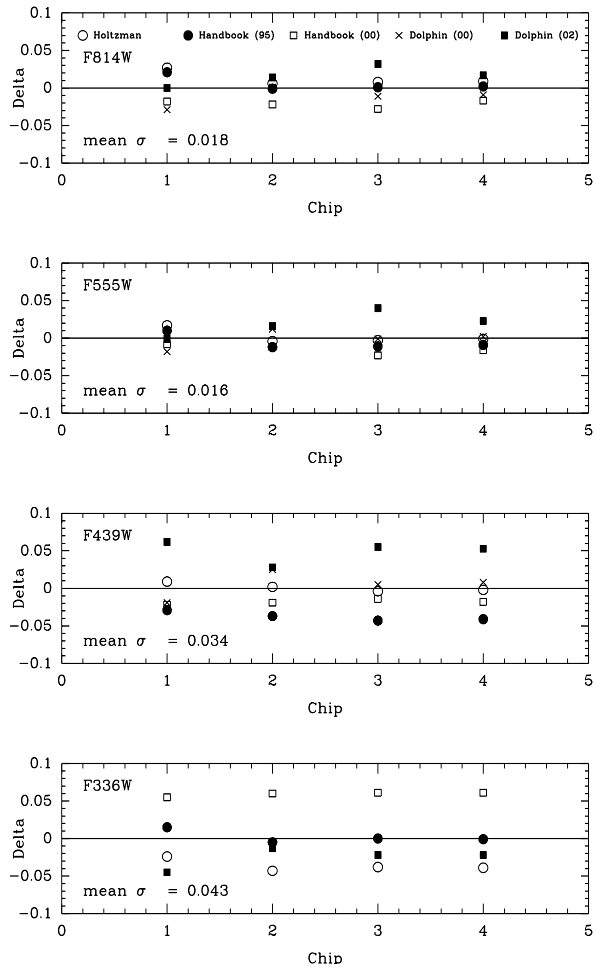

Figure 3. Comparison between five different zeropoint determinations (Heyer, Richardson, Whitmore & Lubin 2003).

We conclude this section by noting that although CTE loss has compromised photometric accuracy to some extent, for typical observations it is still possible to obtain absolute photometric accuracies of a few percent with WFPC2.

2.2. Focus

The frequency of focus moves required to stay within 2.5 microns of best focus (which roughly equals the orbital variations induced by "breathing") has decreased, due to the slowing rate of OTA shrinkage caused by water desorption. Figure 4 shows the WFPC2 focus position since launch. Note that the recent trend is slightly negative. A focus adjustment was therefore made in November, 2002. The focus measurements are made on the PC, due to its better spatial sampling. The other chips are slightly out of focus, since there is no mechanism to adjust separately the focus for each chip. In particular, the worst focus is on the WF3 chip, which is about 5 microns out of focus relative to the PC. For further discussion and information on how focus affects photometry see Suchkov and Casertano (1997).

2.3. Astrometry

The ability to transform accurately from x, y instrument coordinates to RA, DEC coordinates on the sky is fundamental for a large fraction of WFPC2 observations. In addition, the advent of dithering increases the need for very accurate relative astrometry, so that blurring of the image due to a poor geometric solution is not introduced when recombining the image.

A number of geometric distortion solutions were determined shortly after launch, including those by Holtzman et al. (1995a), Trauger et al. (1995), and Gilmozzi et al. (1995). These had $\approx$5 mas residuals near the center and 10–15 mas residuals in the corners. Casertano & Wiggs (2001) developed a much better solution with uncertainties $\approx$1.2 mas on the WF and 4 mas on the PC. Most recently, Anderson & King (2003) produced what is currently the best solution with $\approx$1 mas rms per star. Kozhurina-Platais et al. (2003) are extending this work done in the F555W filter to encompass other wavelengths.

3. Recent WFPC2 Projects

3.1. UV Contamination Rate Update

The UV throughput for WFPC2 degrades with time due to contaminants within the cameras that freeze out on the faceplate. For example, the throughput in the F160W filter on the PC declines by about a percent per day. The throughput can be recovered by heating the WFPC2 and sublimating the contamination off the faceplate. Until recently, these decontaminations were done roughly once per month.

A recent reexamination of the UV throughput as a function of time by McMaster & Whitmore (2002) shows that the contamination rates have decreased by roughly 50% since WFPC2 was launched. Hence, we now have a long enough baseline to determine temporal trends, rather than simply measuring the rate for a given year. This allows us to average the data, and provides a simpler, more accurate correction. The lower rate has also allowed us to save telescope time by extending the time between decontaminations from 30 to 50 days.

3.2. Pointing Accuracy

Pointing accuracy is less important for the WFPC2 than for most of the other instruments, due to its wide field of view. However, there are instances where larger than normal excursions between the true and intended positions can cause problems. Hence, we try to keep the observed offsets to $\approx 1''$, so that the uncertainty due to guide star positions is the dominant error. However, as the FGS-to-FGS alignments change with time (e.g., do to desorption in the new FGS's after they are launched), the observed offsets also change, and depend on which of the three FGSs is "dominant."

A recent examination of the pointing accuracy by Brammer, Whitmore & Koekemoer (2003) showed an offset of $\approx 1.5''$ between the commanded and actual pointing positions for WFPC2. While not particularly important for most WFPC2 users, this does increase the uncertainty in determining absolute astrometric positions from the 1–2$''$ values imposed by uncertainties in guide star positions to a value of 2–3$''$. A realignment of the FGS-to-FGS positions in October, 2002, is expected to solve this problem. We note that for cases where accurate astrometric accuracy is important, the users can remove this offset by determining the positions of astrometric standards that are in the WFPC2 field of view, if they exist.

3.3. Flatfield Update

High quality flatfields are critical for a variety of astronomical projects, especially those where very accurate photometry is required. Improved flatfields were developed by Koekemoer, Biretta, and Mack (2002) and installed in the calibration pipeline in March, 2002. Improvements included: 1) the first major revision since previous flats were produced (based

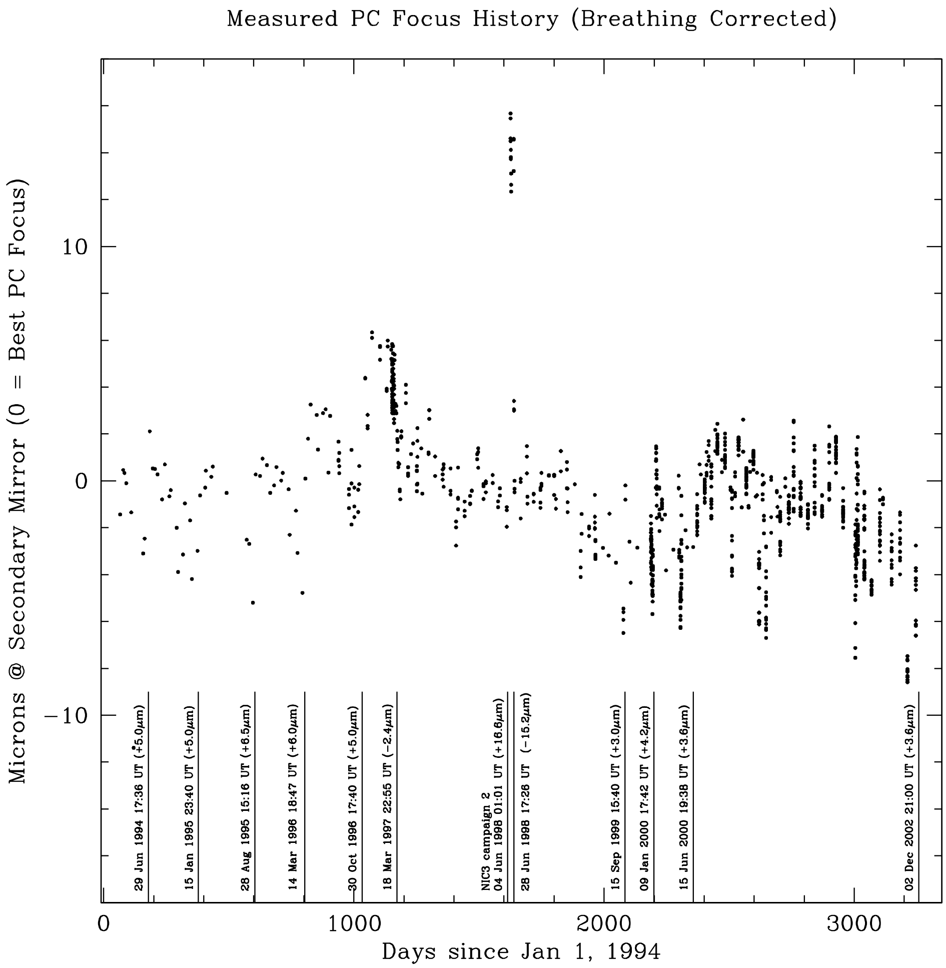

Figure 4. Measured focus position for WFPC2 since launch. A value of 0 microns is the optimal focus position.

on 1994–1995 data), 2) inclusion of new dust spots as a function of time, 3) measurement of the time dependence of large-scale features caused by long-term changes in the camera geometry, 4) measurement of pixel-to-pixel structure to levels below ≈0.3% for the PC and ≈0.2% for the WF chips. Improved UV flatfields were also produced by Karkoschka & Biretta (2001; installed in 2001), and Karkoschka (2003).

3.4. CADC "Association" Images

The Canadian Astronomical Data Center (CADC), in conjunction with the European Coordinating Facility (ECF), have combined WFPC2 images from the archives to produce "association" images. These are currently being used as preview images for the *HST* archives. The images will be available through the HST archive in the near future. For more information see the CADC WWW site at: http://cadcwww.hia.nrc.ca/wfpc2/

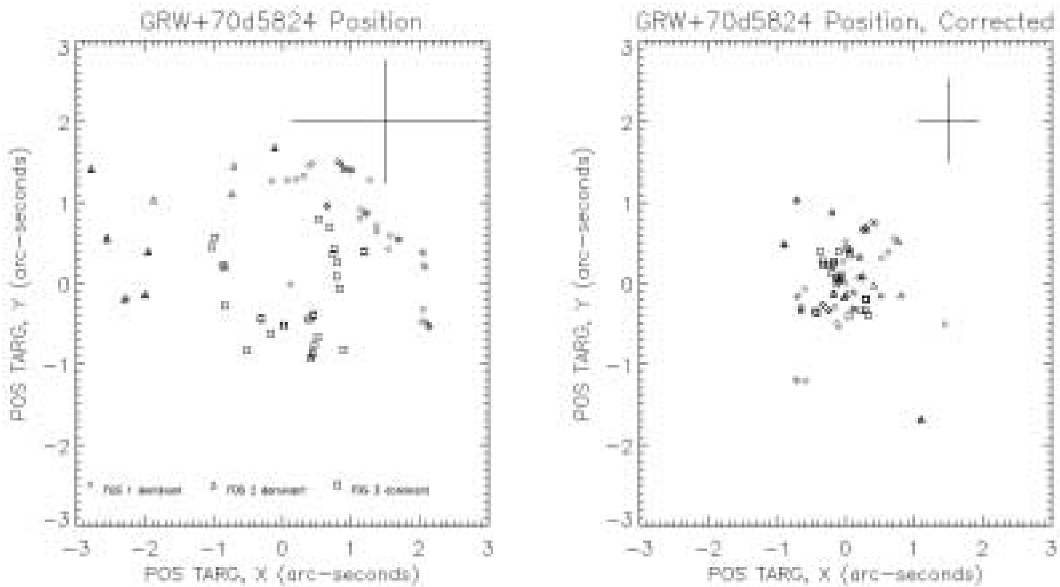

Figure 5. On the left are the raw positions of our standard star (GRW+70d5824) using different guide stars. On the right are the "corrected" positions. See Brammer, Whitmore & Koekemoer (2003) for details.

4. References and Resources

The WFPC2 has now been in orbit for almost nine years, and an extensive set of documentation has been developed. This includes both STScI developed documents, such as the *WFPC2 Instrument Handbook*, and papers in the astronomical journals, such as the two classic Holtzman papers (Holtzman et al. 1995a,b). The Data Analysis Library (formerly know as the WFPC2 Clearinghouse) provides easy access to both sets of documents, although it has not been extensively updated as far as the external astronomical literature since 1997, when the high volume of WFPC2 related articles became overwhelming. A history file is also maintained that provides a chronological record of various WFPC2 information (e.g., focus moves, decontamination dates, software changes, etc.).

The primary sources of WFPC2 documents are available via the WFPC2 WWW site at: http://www.stsci.edu/instruments/wfpc2/wfpc2_top.html. These include:

- *The WFPC2 Instrument Handbook–Version 7.0*, October 2002 (Biretta, Lubin, et al. 2002)
- *The HST Data Handbook for WFPC2–Version 4.0,* January, 2002 (Baggett, McMaster, et al. 2002)
- *The HST Dither Handbook–Version 2.0*, January, 2002 (Koekemoer et al. 2002b)
- *The WFPC2 Tutorial–Version 3.0*, July 2002 (Gonzaga et al. 2002)

Detailed reports on specific topics are available at the WFPC2 WWW site in the form of *Instrument Science Reports* (*ISR*s) and *Technical Instrument Reports* (*TIR*s, generally for internal use but available on request). The following software tools are also available:

- Exposure Time Calculator

- Linear Ramp Filter Calculator
- CTE Estimation Tool
- Polarization Calibration Tool
- Data Analysis Library (formerly WFPC2 Clearinghouse)

Other WWW sites of interest are:

- Andrew Dolphin's WWW page (e.g., CTE correction formula): http://www.noao.edu/staff/dolphin/wfpc2_calib/
- The WFPC2 "Metrics" page: http://www.stsci.edu/hst/metrics/SiUsage/WFPC2/

5. Summary

The WFPC2 continues to work almost flawlessly, with no major mechanical, electrical, or systems problems. The most serious problem that has occurred in its nine years of operation is a shutter malfunction in October, 2000, that resulted in one month of downtime before it was fixed. During most of this time the telescope has received the lion's share of the observing time (≈40%). The images from the camera have inspired both scientists and the public with incredible pictures that include the Hubble Deep Field, the collision of Comet Shoemaker-Levy with Jupiter, and the Eagle Nebula, to name just a few. The degradation of Charge Transfer Efficiency (CTE) with time has been perhaps the most important calibration issue, but for typical science exposures this still only amounts to a loss of about 10% of the throughput. A correction formula (Dolphin 2002) is available for point sources, and work continues on a tool to correct images on a pixel-by-pixel basis. An extensive set of documentation is available, both via the WFPC2 WWW site and in the astronomical community at large. WFPC2 will be replaced by Wide-Field Camera 3 (WFC3) during Servicing Mission 4, which is currently scheduled for February, 2005.

Acknowledgments. We wish to thank the entire STScI WFPC2 team, both past and present, for their support of the WFPC2. It has truly been a pleasure working with this dedicated group of people. Special thanks to Sylvia Baggett, who determined the statistics shown in Table 1, and Matt Lallo and Russ Makidon, who produced the focus plot shown in Figure 4. Finally, thanks to John Trauger, Jon Holtzman, and the IDT for building the WFPC2 and producing the original characterization of the camera.

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