Systematic Errors in WFPC Photometry

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I. Introduction

The unusual character of the WFPC point spread function (PSF) leads to many peculiarities in the photometric behavior of reduced data. The most obvious effect on the PSF is that approximately 85 percent of the total light of a point source is spread into a halo that covers many hundreds of pixels. Only the central few pixels contain information at fairly high S/N levels. Beyond the problem of adding up all of the flux in a noisy picture, there are several sources of error, including a subtle by-product of spherical aberration, that can lead to systematic errors in the accuracy of photometry in WFPC frames.

II. Errors in Processed Data

One source of error in the production of photometry concerns how well the pipeline reduced the data. Currently, the dominant error introduced by WFPC data reductions are problems with the flat fields. No matter how well you measure the brightness of a source on a frame, if the flat field has variations of 10 – 30 percent, your photometry will be no better than that (see Biretta, this volume). Fortunately, with the accumulation of large numbers of deep exposures in uncrowded regions, a sky-flat can be produced for the WFC (see papers by Phillips et al.; Ratnatunga et al., this volume). Although the similar production of a PC sky flat is very unlikely, the errors in its flat fields are less horrific due to the smaller PC field of view.

The proper flat-fielding of a chip and the ability to combine photometry from different chips depends upon the accuracy of the cross-chip normalization. These normalizations, which should correct for the variation in the overall sensitivity of the chips, are affected by flat-field variations within and among the chips. Depending on how the normalizations are calculated, the effects may be as large as 5 – 10 percent; see the offsets in Figure 4. With the improved sky flats, this error should be reduced.

Other possible sources of photometric error, such as the A–to–D correction and flipped parity of the odd-even noise pattern in the bias (possibly in older data), are much smaller than those introduced by the flat fields. However, these may become significant, especially for extended field, low surface brightness applications, given the use of more accurate flats.

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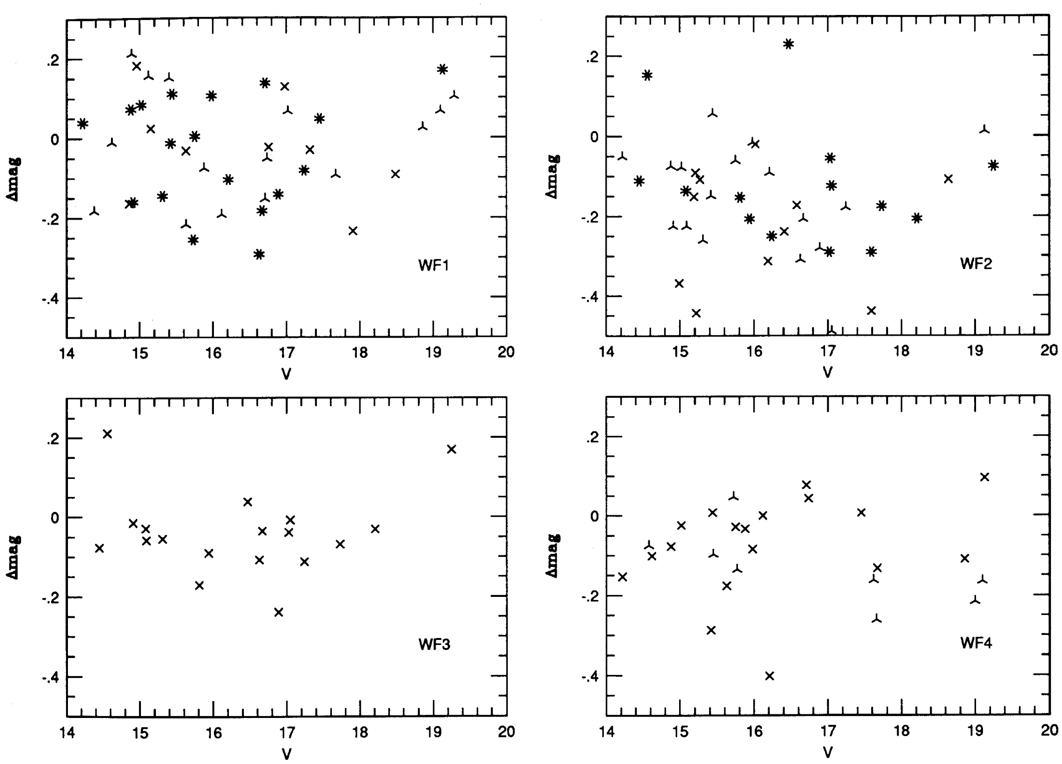
III. The PSF and Photometric Measurements

Another potential source of errors is the shape and variability of the PSF. Of course, how you produce your photometry determines how seriously you are affected by such problems. The two popular photometry methods are aperture and PSF-fit photometry. The latter is preferred for most fields observed with the *HST* because of their crowded or complex nature. However the numbers from PSF-fit techniques, which measure the flux within a small radius around the center of the source, must somehow be tied to calibrations of some standard system, which are measurements of the total count rate. The connection between them, the so-called aperture corrections, are a major source of systematic error in the calibration of WFPC PSF fluxes.

Figure 1. NGC 188 Standards

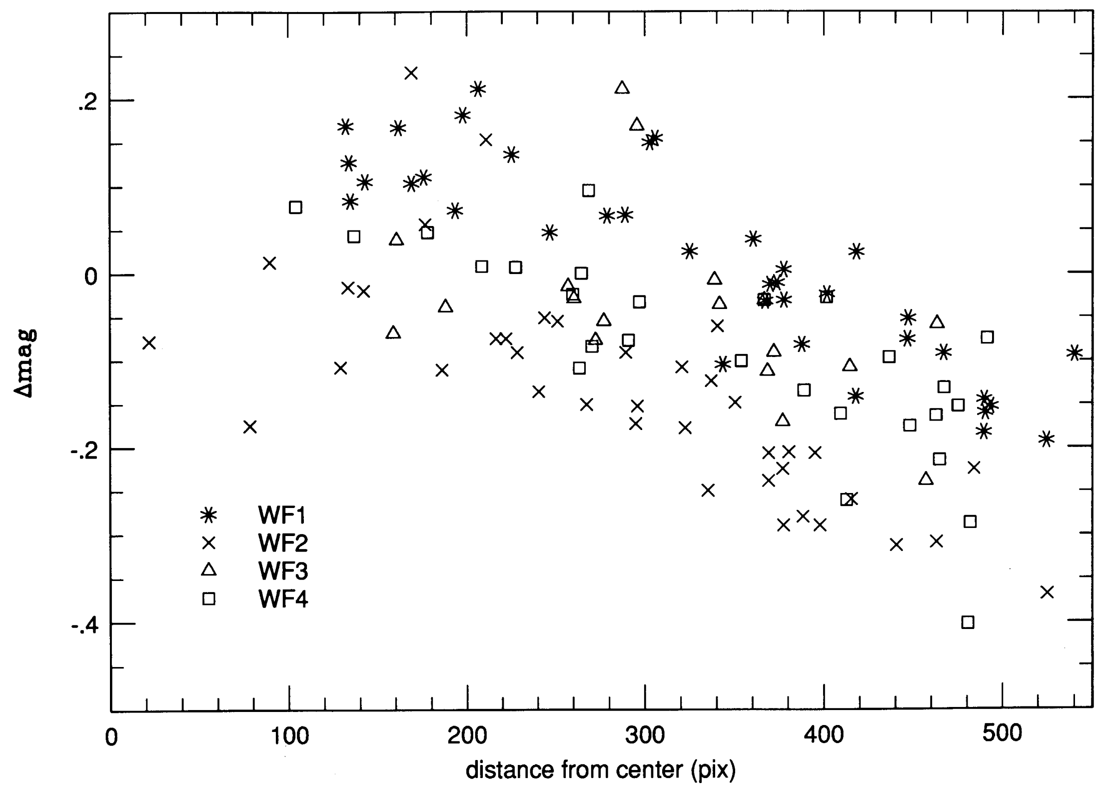


The following analysis of the WFC photometry was made using three fields in the open cluster NGC 188, taken in August 1992 and processed with the current STScI pipeline (i.e. no sky-flat correction). There are a large number of fairly isolated stars, with known magnitudes from the ground (Caputo et. al, 1990) populating most of the chips. The comparison to ground truth is vital, considering the complex nature of the aperture corrections and the flat fields.

The differences between ground photometry, converted to the WFPC F555W standard system, and raw instrumental magnitudes returned by a PSF-fit algorithm are shown in Figure 1. Each panel is a different chip, plotting the difference in magnitude versus the Caputo V measurement for the stars. The different symbols denote from which of the three pointings the data was derived; there do not seem to be any significant trends with such timing. The most striking feature of the plots is the large dispersion in magnitude differences, much greater than the errors quoted by Caputo, and equally large in bright stars as well as faint. Some of the scatter must come from variations in the flat fields, but there are other sources of error.

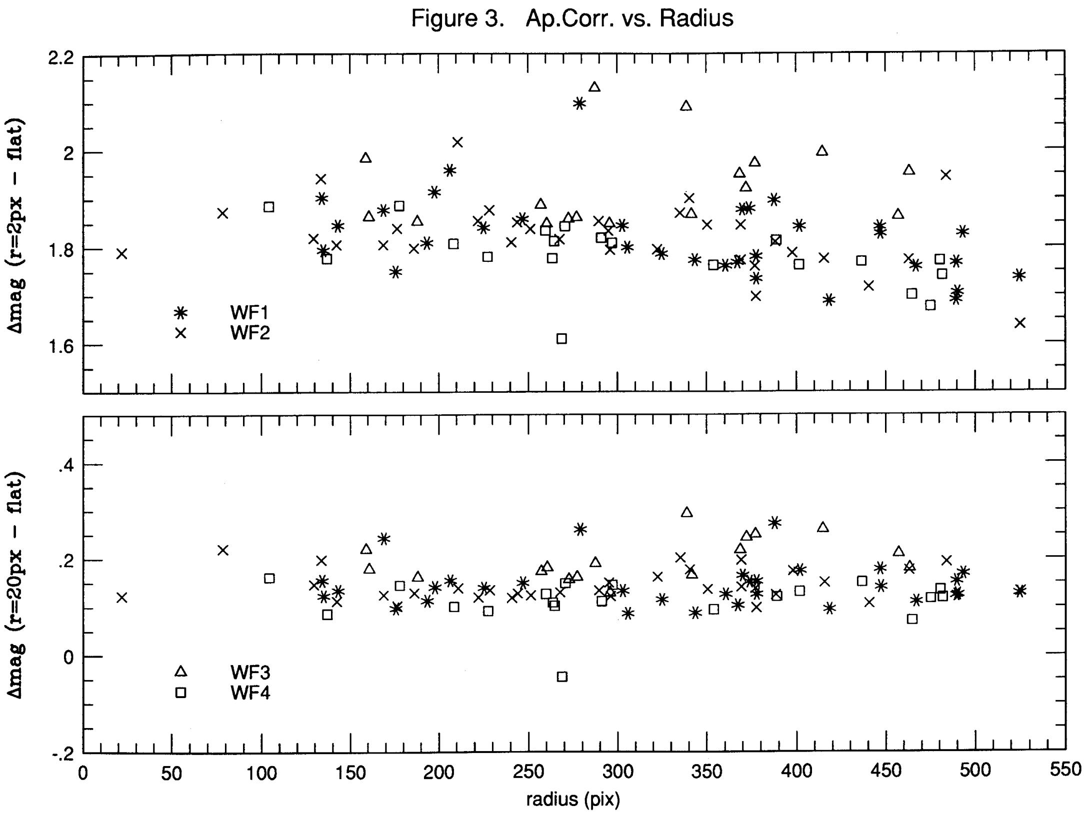
If errors arise from PSF structure and variation, they should correlate well with the distance from the center of symmetry of each chip. Figure 2 shows the same differences in magnitude plotted versus distance from the center of symmetry. Each chip is plotted as a different symbol. There is a clear correlation between delta magnitude and the distance from the centers of symmetry, in the sense that stars further from chip center are measurably brighter. The slopes of the relations, and their similarity among the chips, is highly suggestive of a PSF artifact. (The offsets in the zero points of the relations may indicate errors in the flat-field normalizations.)

Figure 2. NGC 188 radial correlation



If this is a real feature of the PSF, it should also show up in the aperture corrections. Photometry of NGC 188 stars was performed through several apertures; these numbers were compared to total magnitudes measured via curves of growth. The results for two apertures, narrow (2 pixel) and wide (20 pixel) radii, are shown in Figure 3. The correlation seen in the small aperture photometry decreases with increasing aperture width. In the widest case (20 pixels, containing over 80 percent of the total flux), there is no significant correlation. Thus the core of the star may become overly bright but the total brightness of the point source is conserved no matter where it may lie on a single chip.

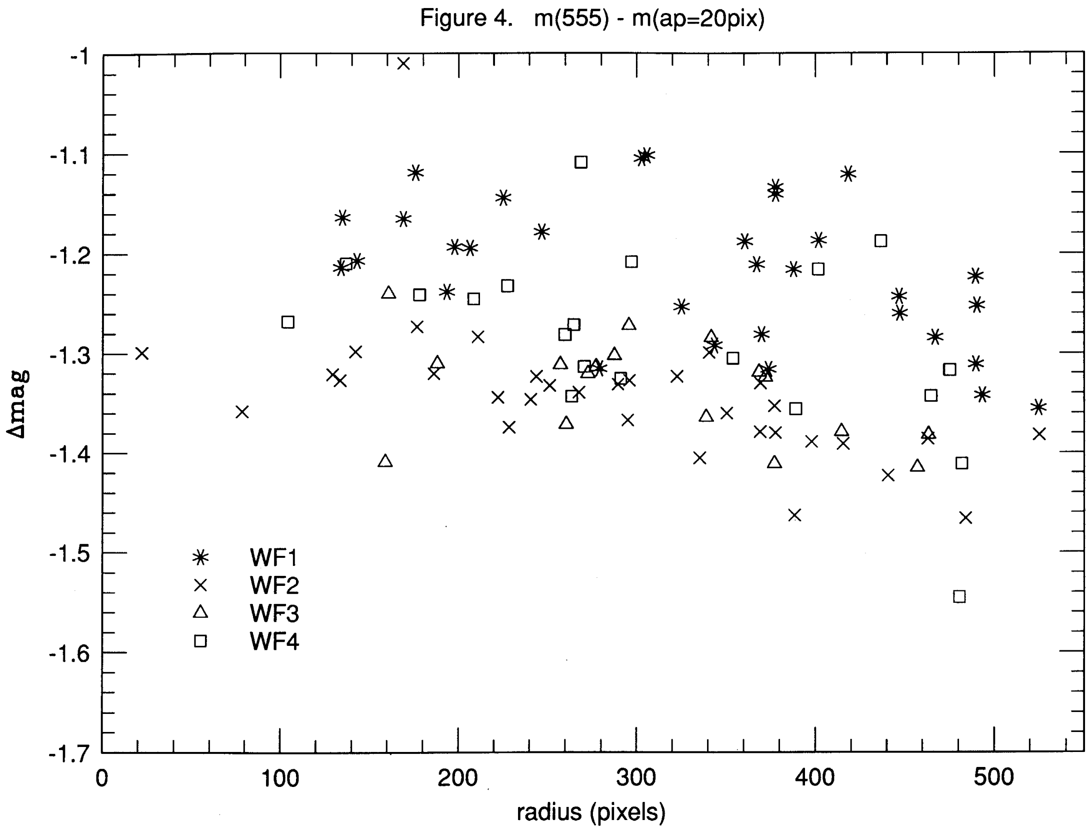
This effect has been mentioned before as the core-halo effect (see Holtzman et al., 1991, and the WFPC OV/SV Final Report). The PSF becomes vignetted towards the



edge of a chip, greatly affecting the halo of the light distribution. The core of the PSF tends to be unaffected by this removal of light, so its brightness is more constant over the field of view. However, when the flat field (an aggregate of many overlapping PSFs) is applied, the total light of the star is restored, in effect removing the effects of the vignetting. Thus the cores of stars near the edge will be over-corrected and appear too bright relative to the total magnitude of the star.

The size of the effect in small apertures is on the order of 0.1 magnitudes, perhaps greater when measurements are more strongly biased to the central pixels of a PSF, for example PSF-fitting with DAOPHOT. Obviously the assumption of a simple aperture correction applied to all photometry in a single chip will lead to large systematic errors. A simple radial fit to the aperture correction curve may help cut the error in half. However, to truly minimize this effect, an empirical mapping of aperture corrections should be applied. Given that an appropriate dataset may not exist, it may be possible to compute a suite of PSF models, for example, by using Tiny Tim, plot aperture correction curves and normalize them to some real measurements, say, the aperture corrections at the centers of symmetry in the chips.

Even with appropriate aperture corrections, there may be other problems. Figure 4 shows the difference between ground truth and the large aperture measurements in NGC 188. As mentioned in the previous section, the offsets in zero-points between chips most likely indicate problems with the cross-chip normalization. There still seems to be a slight trend with distance from the centers of symmetry. This may be due to structure in the flat fields, which is somewhat (but not strongly) radially dependent, or perhaps to the flat fields imperfectly correcting for vignetting because of their different illumination pattern. If so, a sky flat would also help this problem.



IV. Contamination and Overall Calibration

A major concern to calibration, especially in the blue bandpasses, is the presence of contamination. The presence of a volatile substance on the front window of the CCD has two significant effects: 1) the diffraction of light about small enhancements (pockets) of contaminants (measles), and 2) the attenuation of incident flux, especially to the blue. The pockmarks known as measles are especially problematic if they land near the center of an object with a point-source-like light distribution. The scale of a measle is not much different from the core of a PSF, and thus will significantly perturb any attempt to fit a PSF. Such a problem may affect photometry by 5 – 10 percent or more.

The effect of the attenuation of flux is well-studied and discussed in detail in several STScI WFPC reports and in this volume. An important implication of the loss of flux is how rapidly it may affect photometry. The following table gives estimates of the time it will take for contamination buildup to result in a 10 percent loss of flux.

Filter	F194W	F230W	F336W	F439W	F555W	F785LP
Time	(hours)	(1-3 days)	30d	80d	140d	400d

These numbers are indicative of the general trends seen in the WF2 and PC6 chips; they may not be representative of the initial falloff after a decontamination or of variations between chips. There may be slight variations in the contaminants left of different chips, after different decontaminations. However, given the limited information in the monitor (centers of WF2 and PC6), a significant effect is not seen.

The successful calibration of WFPC photometry depends on the proper application of several corrections. Many of the problems in understanding the state of the WFPC instrument response and the PSF have become better understood after the accumulation of data (deep exposures for flat fields, contamination monitor, etc.) and intensive modeling. However our understanding of all effects on photometry is almost certainly incomplete, and residuals of a few hundredths of a magnitude in this or that correction may conspire to limit the overall photometric accuracy to worse than 0.05 magnitudes.

References

Caputo, F., Chieffi, A., Castellani, V., Collados, M., Martinez Roger, C., and Paez, E., 1990, A.J., 99, 261.

Holtzman, J. A., et al, 1991, ApJ Letters, 369, L35.