Flat-Fielding and Photometric Accuracy of the WFC with F555W and F785LP

Andrew C. Phillips[1], Duncan A. Forbes[1] and Matthew A. Bershady[1]

Abstract

Deep F555W and F785LP exposures with the Wide Field Camera (WFC) show gradients in the sky background at a level of 10–20 percent following pipeline calibration. These gradients also appear in stellar photometry and thus must be the result of inaccurate flat-fielding. Applying corrections to the flat-field frames based on the background structure leads to an improved internal accuracy of ~4 percent for single-measurement photometry, compared to the ~10 percent accuracy suggested by previous studies. Re-analysis of calibration photometry leads to new zero-points for F555W and F785LP which have internal consistency at a level of ~1.2 percent, based on comparison between the chip-to-chip offsets and the sky levels observed in corrected images.

I. Introduction

Early long-exposure WFC images obtained as part of the *Medium Deep Survey* (MDS) key project showed structure and gradients in the sky background at a level of ±10 percent following pipeline calibration. It was originally believed that this structure was an additive component arising from scattered earthlight, but this is unlikely because:

- the structure appears similar in images of different exposures, epochs and pointings (i.e., different orientations of the telescope with respect to the sun and earth); and
- the structure is quite different in the two passbands we used; while changes in amplitude might be expected from scattered light, large changes in *spatial* structure are unlikely.

Furthermore, Hester (1992) [IDT Report] strongly cautions that there are problems with the accuracy of the broad-band flat-fields.

We have found photometric evidence that the pipeline calibration frames, C191513JW.R6H (F555W) and C1915143W.R6H (F785LP), are in error by as much as 20 percent (peak-to-peak) across a single WFC chip. We have derived a first-order correction to these errors and have re-analyzed the IDT Report photometry (Hunter et al. 1992, in the Final Orbital/Science Verification Report) to derive new zero-points. A more detailed description of this investigation is given in Phillips et al. (1993).

1. Lick Observatory, University of California at Santa Cruz, Santa Cruz, CA 95064

II. Scattered Light or Flat-Fielding Errors?

We examined multi-orbit F555W and F785LP images of a high galactic, low ecliptic latitude field acquired in January 1992, as part of the MDS. The sky background in each filter/CCD combination was fit interactively with a bi-cubic spline surface fit, carefully rejecting all objects. We estimate these fits are correct within 1–2 percent. The F555W surface fits for WF1–WF3 were modified to crudely remove the doughnuts or pupil images (Hester 1992); the F785LP surface fit had a correction applied to remove the odd-even pattern in the pipeline flat.

Is the background structure multiplicative or additive? To address this question, we selected an MDS field in the SMC which contained numerous well-exposed stars, and which was observed on two occasions, 19 and 21 November 1992. The two sets of observations were offset by about 17 arcsec (~170 pixels), allowing us to perform differential photometry between different areas of the chips. We examined the worst case – the WF2/F785LP combination – and selected 17 relatively isolated stars which appeared in both sets of observations. Aperture photometry was performed with the IRAF APPHOT package.

Ratios of the photometric measures for each star from November 19 and from its offset position on November 21, are compared to the ratio of the surface fits values in the two corresponding positions. Figure 1a shows the ratio of the sky values in the overlapping fields compared to the ratio of the F785LP surface fit. There is a clear linear correlation present, confirming what we have qualitatively noted above: the structure in the background is fairly constant over time, in this case the 10 months from January to November 1992. Figure 1b shows the ratio of the count rate for each star in a 1.0 arcsec radius aperture vs. the surface fit ratio. These ratios have been corrected for PSF variations using model PSFs created with Tiny Tim (Krist 1992). *The correspondence between object photometry and background structure proves the structure is multiplicative and is due to incorrect flat-fielding.*

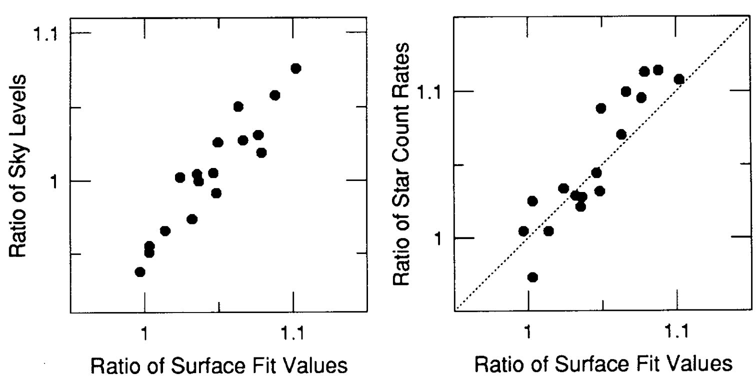

Figure 1a: Ratio of sky values *vs.* ratio of surface fit values for WF2/*F785LP*. The sky values are from annular sky apertures around each star and may be somewhat contaminated by other objects, but this should be removed in the ratio to first order. The ratio is formed from the 19 November *vs.* 21 November observations. The ratio in the surface fit is formed from the corresponding (offset) positions of each star on the two dates. **Figure 1b:** Ratio of the stellar fluxes *vs.* ratio of surface fits, as in Figure 1a.

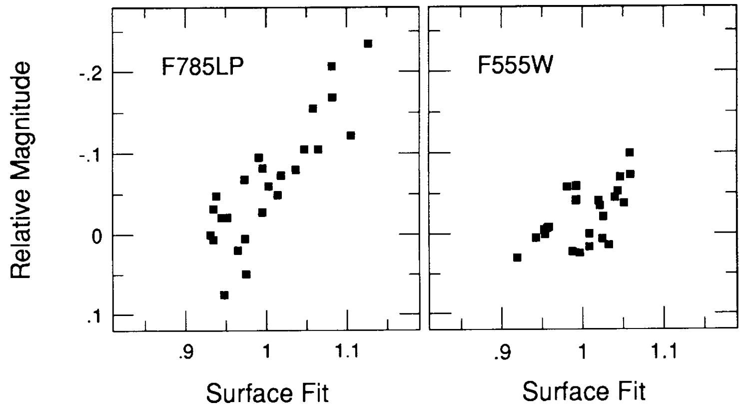

Figure 2: Photometry of HD151406 *vs.* normalized surface fit at different positions across WF2. Shown are $F785LP$ (left) and $F555W$ (right).

As another test, we obtained archived images taken as part of the WFPC PSF Calibration Program (see Baggett & MacKenty 1993). In these images, the bright star HD151406 ($V \approx 9$) was imaged in a 5×5 grid of positions across WF2. We performed aperture photometry using a large aperture, and compared the resulting stellar magnitudes to the surface fits at the appropriate position on the chip, shown in Figure 2. There is a very clear correlation between the photometry and the surface fit in F785LP; in F555W the correlation is also present. The dispersion in Figure 2 is 0.036 (F555W) and 0.040 (F785LP) magnitudes, implying that single-measurement photometry to ≤4 percent is more representative than the ~10 percent limit on accuracy found by Hunter et al. (1992) and Holtzman et al. (1991).

III. New WFC Zero-Points

The surface fits provide a first-order correction to the pipeline flat fields. Knowing something about the systematic errors involved, we can re-analyze the calibrating photometry in the hopes of improving the zero-points. We selected the ω Cen photometry of January 1992 (Hunter et al. 1992); because it was acquired within a few days of our surface fit data, we are assured that contamination effects will be the same in both. The Hunter et al. photometry is given in their Table 12.12. We find that most of the data follow the expected linear relationship between photometry and corrections derived from the surface fits. However, we find all stars less than 50 pixels from the edge of the pyramid shadow tend to be discrepant, so we have excluded these stars in our analysis. In the F785LP data, we have also excluded the short exposure measurement of star 1655 because it differs from its long exposure counterpart by over 0.25 magnitudes. There is still evidence of smaller anomalies in the remaining data set.

Hunter et al. weight their averages by the formal DAOPHOT measurement errors, which in F785LP are typically ≤0.01 mag. Some of the F555W error estimates are equally small. However, the dispersion we find is considerably larger than these errors. Under these circumstances, it is inappropriate to use weighted averages based on the formal error estimates. We have therefore combined the data with equal weighting, and applying the same contamination values as Hunter et al. we derive new zero-points, shown in Table 1. Zero-points have been calculated using the original (uncorrected) Hunter et al. photometry (column 3) and with the surface-fit corrections applied (column 4). Between these two equivalent sets, we see a significant improvement in the dispersion when the corrections are applied.

Table 1

Chip (1)	Filter (2)	$C^{\rm IDT}$ (3)	$C^{\rm IDT}(corr)$ (4)	C^{F93} (5)	$-\Delta\Sigma$(Sky) (6)	$\Delta C^{\rm IDT}(corr)$ (7)	ΔC^{F93} (8)
WF1	F555W	22.881(.062)	**22.902**(.024)	22.80(.04)	–0.098	–0.083(.007)	–0.11(.01)
WF2	F555W	23.033(.033)	**23.036**(.039)	22.97(.05)	0.059	0.052(.010)	0.06(.01)
WF3	F555W	23.059(.089)	**23.040**(.061)	22.98(.03)	0.072	0.056(.017)	0.07(.01)
WF4	F555W	23.002(.089)	**22.959**(.042)	22.89(.04)	–0.034	–0.025(.015)	–0.02(.01)
WF1	F785LP	21.562(.032)	**21.564**(.041)	21.46(.13)	0.023	0.039(.011)	–0.14(.03)
WF2	F785LP	21.599(.079)	**21.635**(.035)	21.62(.10)	0.107	0.110(.010)	0.02(.03)
WF3	F785LP	21.457(.101)	**21.436**(.086)	21.61(.05)	–0.077	–0.089(.020)	0.01(.01)
WF4	F785LP	21.473(.077)	**21.465**(.072)	21.70(.04)	–0.053	–0.060(.026)	0.10(.01)

1. CCD Chip
2. Filter
3. Recalculated zeropoints (and dispersions) from the uncorrected data in Table 12.12 of Hunter et al. (1992)
4. New zeropoints derived from corrected photometry, as described in text
5. Zeropoints from Freedman et al. (1993); the F555W values are actually for a *V*-band conversion
6. Sky offsets relative to mean value, in negative magnitudes
7. Column (4), relative to mean value (errors are standard deviation of the mean for the zeropoint value)
8. Column (5), relative to mean value (errors are standard deviation of the mean for the zeropoint value)

V. Sky Offsets – A Validity Check

While the sky brightness itself cannot be used to determine *absolute* zero-points, it can be used to independently measure the zeropoint *offsets* between the four chips, since the sky background should have the same value everywhere. The sky offsets are shown in Column 6 of the table (relative to the average of the four chips), along with the offsets from the re-analyzed IDT photometry and the Freedman et al. zero-points (Columns 7 and 8). The new (corrected) zero-points are now in excellent agreement with the observed sky offsets, with an average difference of 0.012 and 0.011 magnitudes rms in F555W and F785LP; the differences are at the level expected from the standard deviation of the mean for the zero-points. This gives us confidence that we are analyzing the data correctly, and that the calibration has an *internal* accuracy of better than 2 percent.

Conclusions

- The accuracy of the flat-field calibration of WFC is considered by examining the sky in long MDS exposures. Large-scale gradients of order 10–20 percent are found in F555W and F785LP following pipeline calibration.

- Stellar photometry shows a correlation with the background variations, demonstrating that the variations are due predominately to errors in the flat-fielding.
- Correcting the photometry in the IDT report (Hunter et al. 1992) for the flat-field errors leads to an improvement in the dispersion in zeropoint measurements within each CCD. New zero-points have chip-to-chip offsets which are consistent with the observed sky levels to within 1.2 percent rms.

Researchers wishing to do relative photometry to better than 0.1 magnitude with the WFC will need to make appropriate corrections for the flat-fielding errors. With such corrections, it appears that photometry as good as 1–2 percent should be achievable.

The ideal way to determine the flat-field calibration is to median or otherwise filter and combine a large set of unregistered or independent frames, creating a so-called super sky flat. This effort, using a 100 image data set, is currently underway by the MDS group (Ratnatunga et al., this volume).

References

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