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FLATFIELDING AND PHOTOMETRIC ACCURACY OF THE FIRST *HUBBLE SPACE TELESCOPE* WIDE FIELD CAMERA[1]

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ABSTRACT

Long exposures with the original *HST Wide Field Camera* (WFC) through the *F555W* and *F785LP* filters show gradients in the background following standard pipeline calibration. We show that these gradients also appear in stellar photometry, and thus must be predominantly the result of inaccurate flatfielding at a level of 10%–20%. Color errors may be even larger. Applying corrections to the flatfield frames based on the background structure leads to an improved accuracy of ~4% for single-measurement photometry within a single CCD chip, compared to the ~10% accuracy suggested by previous studies. We have reanalyzed the *F555W* and *F785LP* calibration photometry to derive zero points appropriate for corrected data; these new zero points have internal consistency at a level of ~1.2%, based on comparison between the chip-to-chip offsets and the sky levels observed in corrected images. This indicates that relative photometry approaching 1%–2% is achievable with the WFC. The new zero point values for corrected data are 22.90, 23.04, 23.04, and 22.96 (*F555W*), and 21.56, 21.64, 21.44, and 21.47 (*F785LP*) for chips WF1–WF4, respectively. Comparison is made with other zero points, and the applicability of "delta flats" is briefly discussed.

1. INTRODUCTION

The *Hubble Space Telescope* (*HST*) was expected to provide unparalleled opportunities for accurate stellar photometry in crowded fields. For very crowded fields the instrument of choice is the PC mode of the Wide Field/Planetary Camera[3] (WFPC), but the WFC is often used for constructing color–magnitude diagrams over larger fields, such as fields in the LMC (Elson *et al.* 1993) or the bulge of M31 (Rich & Mighell 1993). Such color–magnitude diagrams are often constructed using two of the largest passband filters, *F555W* ("*V*") and *F785LP* ("*I*"). However, accurate detector calibrations and sky determinations are essential for the reliable photometry needed to construct such diagrams. These are also essential in the study of faint galaxies for the measurement of isophotal parameters, magnitudes, and color-inferred redshifts.

From earth orbit, the "sky" background seen by *HST* is due primarily to zodiacal light (rather than the OH lines which dominate the ground-based night sky at $\lambda \gtrsim 7000$ Å). At $\lambda \sim 9000$ Å the background is ~22.2 mag arcsec^{-2} at high ecliptic latitudes (Windhorst *et al.* 1992), and is expected to be about 1 mag brighter at low ecliptic latitude (see MacKenty *et al.* 1992). After proper flatfielding, we expect such a background to appear flat. Surprisingly, early long-exposure WFC images obtained as part of the Medium Deep Survey (MDS) key project (Griffiths *et al.* 1994) showed structure and gradients in this background at a level of ±10%. It was originally believed that this structure was an *additive* component arising from scattered earthlight (MacKenty 1992), but this seems unlikely for two reasons:

(1) 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

(2) 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) cautions that there are expected errors in the broadband flatfields at levels consistent with the structure we are seeing.

In this paper, we present photometric evidence that the pipeline calibration flatfield frames c191513jw.r6h (*F555W*) and c1915143w.r6h (*F785LP*) are in error by as much as 20% (peak-to-peak) across a single WFC chip. A first-order correction to these errors is described and new zero points are derived for use with corrected data.

2. DATA ANALYSIS

2.1 Modeling the Background Structure

In order to study the background structure, we examined MDS images acquired 1992 January 06–08 (UT). These images are of a high galactic latitude field near 3C 273, and they contain ~10–20 stars and ~80 field galaxies brighter

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[1] Based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA, Inc., under NASA contract NAS 5-26555.

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[3] This paper refers to the original, pre-servicing WFPC; it is not relevant to data acquired with WFPC-II.

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than $V=24$ (Griffiths *et al.* 1994). However, as the ecliptic latitude is quite low (5°), the sky brightness is significant ($\sim 0.1 e^{-1}$/sec/pix). Eight images in each of $F555W$ and $F785LP$ were combined to remove cosmic-ray events and improve the signal to noise; the total integration times are 15 770 and 18 224 s, respectively. The background in each filter/CCD combination was fit interactively with a bicubic spline surface fit, carefully avoiding all objects. We estimate the fits to be correct within 1%–2%, except in the very corners in a few cases where the fits are poorly constrained. We will refer to these simply as the "V and I surface fits."

The V surface fits for WF1, WF2, and WF3 were modified to remove the "doughnuts" or pupil images (Hester 1992), now believed to be caused by pinholes in the $F122M$ filter which was used as a neutral density filter in creating the $F555W$ flatfield. Figure 6.6(a) of Hester (1992) shows these features clearly. The worst of the features has an amplitude of about 3%. We modeled the doughnut structures semi-empirically, assuming circular inner and outer edges and constant amplitude (in the uncalibrated data), and with the approximate positions and amplitudes determined by comparison with the pipeline flatfield image and the MDS data. The three vanes in each pupil image were likewise modeled. The final V surface fits incorporate these models; generally, the residuals are quite small, although residuals near the edges of the doughnuts may be as high as 3%–5% due to the diffraction effects being poorly approximated.

Another modification was made to the I surface fit in order to remove a small degree of "odd–even" pattern that was detected in the flatfield. This pattern can be easily seen by convolving the flatfield frame, c1915143w.r6h, with an appropriate kernel (e.g., $-1/2$, 1, $-1/2$) and averaging over several lines, or by comparing an average of all odd columns with all even columns. However, the odd–even pattern has a peak-to-peak amplitude of only $\sim 1\%$ and thus is negligible from the standpoint of photometry, particularly in apertures of more than a few pixels area.

To summarize, the modified surface fits provide "correction flats" that account for large-scale flatfield errors in both filters, the pupil images in the $F555W$ pipeline flat, and odd–even pattern in the $F785LP$ pipeline flat. Contour plots of the surface fits for WF2 are shown in Fig. 1.

Both surface fits were then normalized by the mean value over columns 41–780 and rows 51–780, a reasonable characterization of the useable area of each chip and avoiding any poorly-constrained portions of the fits. We normalize each chip independently so that noise characteristics in the data will be preserved as much as possible.

It should be noted that the ideal way to determine the background is to median or otherwise filter and combine a large set of unregistered or independent frames, creating a so-called "super sky flat". This takes considerable effort and access to a very large data set; such a project is currently underway (Ratnatunga *et al.* 1994; also see Griffiths *et al.* 1994). We made a preliminary effort of this nature: a combined set of the ten frames from the second MDS observation (1992 May 11) was divided into deep $F785LP$ images from the GTO 3685 project (courtesy of I. R. King), and successfully removed gradients to the level of $\lesssim 3\%$. This test provided some of the first evidence that these gradients are multiplicative.

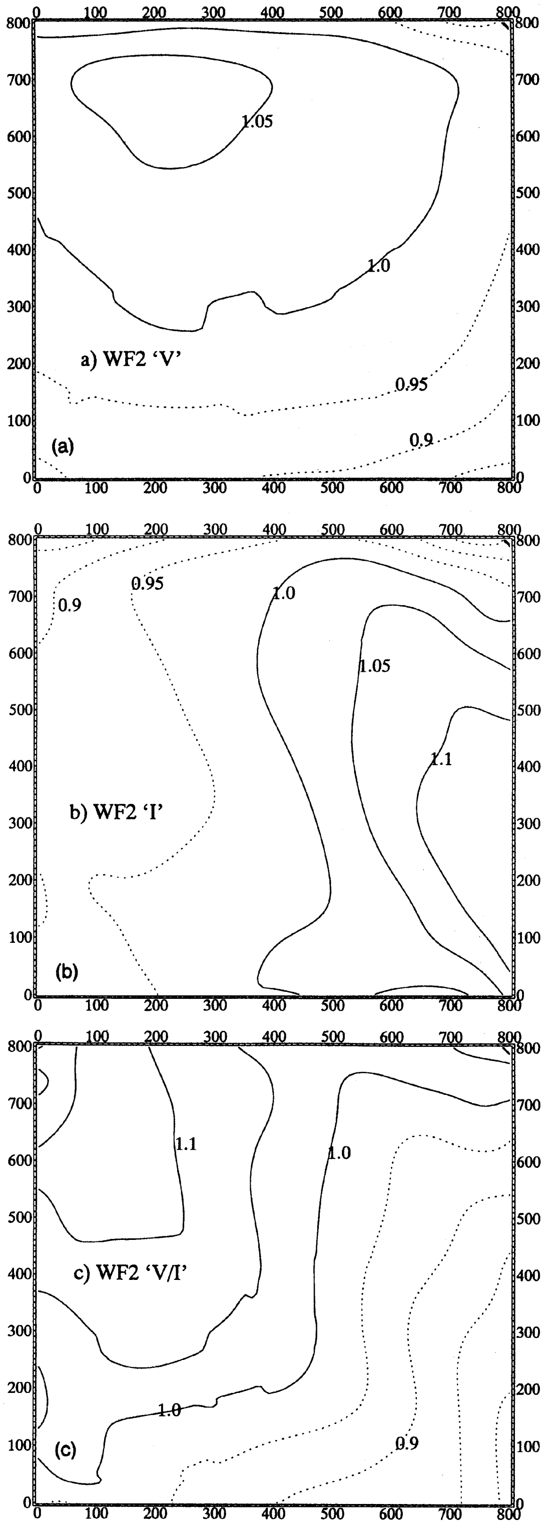

FIG. 1. The V and I surface fits for WF2 (a and b), and their ratio (c). The latter gives an idea of the magnitude of color errors introduced by the current pipeline flatfielding. The zero point has been arbitrarily selected.

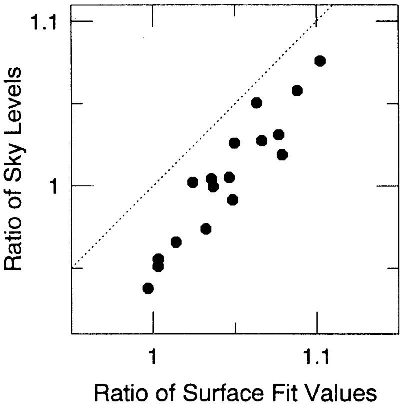

FIG. 2. Ratio of sky values vs ratio of surface fit values. These data are with the *F785LP* filter and WF2. The sky values are from annular sky apertures around each star and may be somewhat contaminated by other objects, but this should be removed in the ratio to first order. The ratio is formed from the 1992 November 19 vs 1992 November 21 observations. The ratio in the surface fit is formed from the corresponding (offset) positions of each star on the two dates.

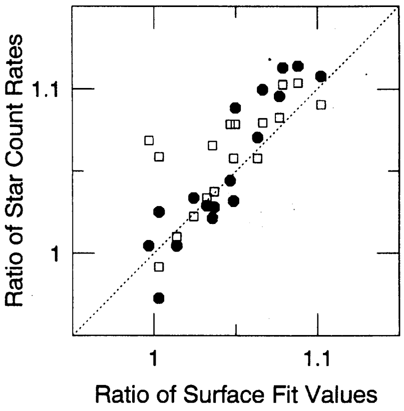

FIG. 3. Ratio of the stellar fluxes vs ratio of surface fits, as in fig. 2. Filled and open symbols are with and without PSF correction, as discussed in the text.

2.2 *Background Structure: Multiplicative or Additive?*

In order to test more thoroughly whether the background structure is multiplicative or additive, we selected an MDS field in the SMC (near the cluster NGC 346) which contained numerous well-exposed stars. This field was observed twice, on 1992 November 19 and again on November 21. The two sets of observations were offset by about 17″ (∼170 pixels), allowing us to perform *differential* photometry between different areas of the chips. We examined the filter and chip with the strongest background gradients, the WF2/*F785LP* combination, and selected 17 relatively isolated stars which were bright but unsaturated, and appeared in both sets of observations. Aperture photometry was performed with the IRAF APPHOT package, using a 1.″0 (10 pixel) radius aperture and the median sky value from an annulus of 3.″0–4.″0 radius. The sky annulus may not be free of other stars, but any contamination should have the same effect in both positions and thus be of no consequence.

Figure 2 shows the ratio of the sky values in the overlapping fields compared to the ratio of the *I* surface fit at the two positions for each star. 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. The offset between the two sets of observations indicates that the "sky" was darker by about 3% during the second set of exposures 2 days later. Changes in sky brightness on this order and time scale have been noted by others, and appear to be correlated with the Sun angle of the telescope (Ratnatunga *et al.* 1994).

We then calculated the difference in count rate for each star between the two positions, and compared this to the ratio of the surface fit at the two positions. These are shown by the open symbols in Fig. 3. There are two outliers, which are the two stars farthest from the symmetry axis of the camera. Since a fairly small aperture was used, we might expect changes in the PSF to have some effect. Using Tiny Tim (Version 2.1; Krist 1992), we calculated and corrected for PSF-induced differences in the ratios, and these corrected values are shown in Fig. 3 as solid symbols (while Tiny Tim may not reproduce the actual PSFs well, it should reflect the *change* in PSF with respect to position, at least to first order). After the correction, all the outliers fit, and a linear relationship is apparent. *This correspondence between object photometry and background structure proves the structure is multiplicative, i.e., it is due to incorrect flatfielding.*

As a further test, and to verify that the *F555W* structure is likewise multiplicative, we obtained archived images taken as part of the WFPC PSF Calibration Program (see Baggett & MacKenty 1993a). In these images, the bright star HD151406 ($V\simeq 9$) was imaged in a 5×5 grid of positions across WF2. We performed aperture photometry using a large (7.″0 diameter) aperture, and compared the resulting stellar magnitudes to the surface fits at the appropriate position on the chip. The results are shown in Fig. 4. Again, in *F785LP* there is a very clear correlation between the photometry and the surface fit to the sky. In *F555W* the data span a smaller range of values and although the correlation is less obvious, it is still present. The dispersions in these plots is 0.036 mag for *F555W* and 0.039 mag for *F785LP*, in-

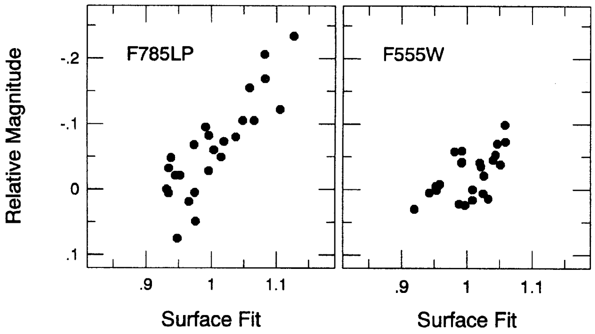

FIG. 4. Photometry of HD151406 vs normalized surface fit at different positions across WF2. Shown are *F785LP* (left) and *F555W* (right).

dicating that the limiting accuracy of single-measurement photometry is ≲4%, rather than ~10% as found by Holtzman *et al.* (1991) and Hunter *et al.* (1992). Random errors of ~3% are observed by others (e.g., Stetson 1993; Neuschaefer 1993), so a dispersion of ≲4% is consistent with our estimate 1%–2% accuracy for the correction flats.

3. DISCUSSION

The fact that significant large-scale errors are present in the pipeline flatfields has several implications. For example, it means that calibrating photometry cannot be performed in only one region of a chip (e.g., the center of WF2, as in the case of the Stellar Monitoring Program). Furthermore, while many investigations are not seriously affected by photometric errors of order 0.1 mag, the effects of the flatfielding errors on colors can be significant. In Fig. 1(c) we show the ratio of the V and I surface fits for WF2. Deviations from unity are of order ±10% across much of the chip, i.e., measured $V-I$ colors may change systematically by 0.2 mag over only half the width of the chip. Errors of this magnitude are a significant fraction of the range in intrinsic galaxy colors (e.g., Yoshii & Takahara 1988), and could have substantial consequences for e.g., galaxy redshift estimations based on color. They are especially severe for interpretation of cluster color–magnitude diagrams, since such errors will manifest themselves as an offset in color *and/or* a broadening of, for example, the main sequence—even when measured within a single chip. In cases where color gradients on angular scales of order $0\farcm5$–$1'$ are of interest, these systematic errors are particularly dangerous.

Evidence of flatfielding errors and their effects on photometry have been apparent for some time. Indeed, Hunter *et al.* (1992) state: "In the WFC images it is apparent that there are variations in the zero points across the chips." They conclude that "stellar photometry is easy to do with the WFPC at 0.1 mag accuracies but rapidly becomes more difficult and precarious below this." This conclusion supported the preliminary conclusion of Holtzman *et al.* (1991), who found a limiting accuracy of 0.09 mag in *F555W*. However, the errors from the flatfielding must be a significant component of the photometric limitations.

The flatfield errors in *F555W* are presumably caused by spatial variations in the red leak of *F122M*, which was used as a neutral density filter to avoid saturation by the bright earth. Other flatfields which were created using the *F122M* filter will likely suffer similar errors. The *F785LP* structure is apparently due to residual streaks from combining only a small number of usable "streak flats." For a more detailed discussion of these and other flatfield errors, see Hester (1992) and other chapters in the Final Orbital/Science Verification Report (Faber 1992).

Since we have normalized the surface fits to the mean value over most of each chip, the old zero points should be applicable to corrected data. However, now that we understand more about the large-scale systematic errors involved, we can reexamine the calibrating photometry in the hopes of improving the zero points for use with corrected data. Indeed, the dispersions in Fig. 4 are smaller (~4%) than the dispersions in the zero point measurements in Hunter *et al.* (~6% rms), implying that the quoted zero point errors include a significant contribution from flatfielding errors and that correcting for these could improve the precision of WFC photometry. In the next section we reanalyze the calibrating photometry to derive new zero points.

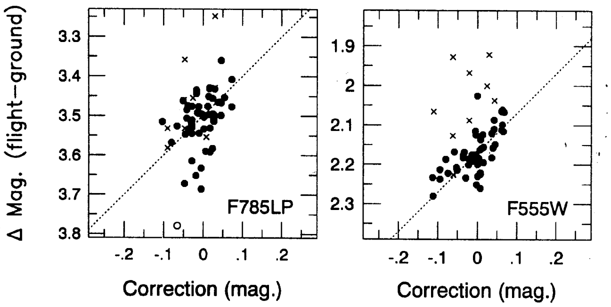

FIG. 5. The ω Cen photometry of Hunter *et al.* (1992) plotted against the appropriate correction from the surface fits. The data for each chip has been offset by the difference in the sky levels seen in our January 1992 images, in order to compensate for chip-to-chip zero point differences. Excluded points are stars within 50 pixels of the pyramid shadow (×) and one of the measurements for star 1655 (open symbol; see text).

3.1 *Zero Points*

We selected the ω Cen photometry of January 1992 (Hunter *et al.* 1992), because it includes measurements in both *F555W* and *F785LP* and because it was acquired within a few days of our surface fit data (thus assuring that contamination effects will be the same in both). The data consist of one long (~500 s) and one short (~40 s) exposure in each filter. Hunter *et al.* performed photometry using DAOPHOT (Stetson 1987) with aperture corrections applied for total magnitudes; the uncalibrated values are listed in their Table 12.12 relative to calibrated ground-based magnitudes.

In Fig. 5 we plot the measurements from Table 12.12 against the correction determined from the surface fits. For convenience, we show all four chips together. Knowing that the sky level in our data should reflect the chip-to-chip zero point offsets (see below), we have added these offsets to the data before plotting. In the figure, we immediately see that most points follow the expected linear relationship between photometry and corrections derived from the surface fits. However, there are several strongly discrepant points. In particular, we find all stars less than 50 pixels from the edge of the pyramid shadow tend to strongly deviate (up to ~0.3 mag) in the short exposure data. While it is not clear whether they deviate in the long exposure data, we can see no reason why they should not also be suspect, so we have excluded all these data from further consideration. The excluded stars are 1565, 1657 (WF2), 793, 1035, 1200 (WF3), 1056, and 4626 (WF4). Two of these stars, 1565 and 1657, were also excluded by Hunter *et al.* as being systematically deviant. In the *F785LP* data, we have also excluded the short exposure measurement of star 1655; this measurement differs from its long exposure counterpart (which appears consistent with the other data) by over 0.25 mag, so it is almost certainly flawed.

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TABLE 1. Zero points.

Chip (1)	Filter (2)	C^{IDT}_{orig} (3)	C^{IDT}_{unwt} (4)	C^{IDT}_{corr} (5)	C^{F93} (6)	$-\Delta\Sigma$(Sky) (7)	$\Delta C^{\mathrm{IDT}}_{corr}$ (8)	ΔC^{F93} (9)
WF1	F555W	22.862	22.881(.062)	**22.902(.024)**	22.80(.04)	–0.098	–0.083(.007)	–0.11(.01)
WF2	F555W	23.032	23.033(.033)	**23.036(.039)**	22.97(.05)	0.059	0.052(.010)	0.06(.01)
WF3	F555W	23.013	23.059(.089)	**23.040(.061)**	22.98(.03)	0.072	0.056(.017)	0.07(.01)
WF4	F555W	22.919	23.002(.089)	**22.959(.042)**	22.89(.04)	–0.034	–0.025(.015)	–0.02(.01)
all	F555W	22.984	—	—	—	—	—	—
WF1	F785LP	21.573	21.562(.032)	**21.564(.041)**	21.46(.13)	0.023	0.039(.011)	–0.14(.03)
WF2	F785LP	21.610	21.599(.079)	**21.635(.035)**	21.62(.10)	0.107	0.110(.010)	0.02(.03)
WF3	F785LP	21.466	21.457(.101)	**21.436(.086)**	21.61(.05)	–0.077	–0.089(.020)	0.01(.01)
WF4	F785LP	21.491	21.473(.077)	**21.465(.072)**	21.70(.04)	–0.053	–0.060(.026)	0.10(.01)
all	F785LP	21.556	—	—	—	—	—	—

Notes to Table 1.

1: CCD Chip
2: Filter
3: Original IDT zeropoints from Tables 12.13 and 12.15 of Hunter *et al.* (1992)
4: Zeropoints (and dispersions), recalculated from the data listed in Table 12.12 of Hunter *et al.* (1992) using *unweighted* averages
5: New zeropoints derived from corrected photometry, as described in text
6: Zeropoints from Freedman *et al.* (1993); the "F555W" values are actually for a Johnson *V*-band conversion
7: Sky offsets relative to mean value, in negative magnitudes
8: Column (5), relative to mean value (errors are standard deviation of the mean for the zeropoint value)
9: Column (6), relative to mean value (errors are standard deviation of the mean for the zeropoint value)

From the figure, it is clear that the remaining data set probably contains other anomalies, for example, the group of eight points in the *F785LP* data lying well below the linear relation. About half of the remaining discrepant points come from a very small region near column 220 (±40 pixels) and line 440 (±70 pixels) on chips WF2, WF3, and WF4. However, we know of no justification for rejecting these points, so they are included in the final sample.

We note that the dispersion in the *F785LP* data points is considerably larger than the formal measurement errors from DAOPHOT listed by Hunter *et al.* (typically ≲0.01 mag). In *F555W*, the formal errors are generally larger, but there are a few that are unrealistically small with respect to the flatfielding accuracy. Under these circumstances, it is inappropriate to use weighted averages based on the formal error estimates (as did Hunter *et al.*) since the dominant error source is not included. 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. These zero points have been calculated using the original (uncorrected) Hunter *et al.* photometry (column 4) and with the surface-fit corrections applied (column 5). Between these two *equivalent* sets, we see a significant improvement in the dispersion when the corrections are applied.

Freedman *et al.* (1993) have independently determined zero points for the *F555W* and *F785LP* filters; these are also included in Table 1 (column 6). (The *F555W* zero point actually refers to a calibration of *F555W* data to Johnson *V* magnitudes, but Freedman *et al.* note that the differences between *F555W* and *V* magnitudes are only of order 0.02 mag for stars of typical color.) While these determinations have not been corrected for the flatfield errors, Freedman *et al.* state that application of our surface-fit corrections change their individual chip zero points by only 0.02 mag rms, and the mean zero point for each filter by less than 0.01 mag. The small size of these differences validate our surface-fit normalizations. However, the Freedman *et al.* values differ from the new zero points we present here by -0.07 ± 0.02 mag in *F555W*; in *F785LP* there is considerable scatter, with the mean differing by $+0.07\pm0.16$. We will consider these differences below.

While the sky brightness itself cannot be used to determine *absolute* zero points, it can be used to independently measure the zero point *offsets* between the four chips, since the properly-flattened and calibrated background should have the same value everywhere. These differences are shown in column 6 of the table (relative to the average of the four chips), along with the offsets from the reanalyzed 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 mag 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 for corrected data has an *internal* accuracy of better than 2% across all four CCDs.

The Freedman *et al.* offsets are also in excellent agreement with the sky levels seen in *F555W*, and so the only disagreement between the two calibrations is the absolute offset of 0.07 mag. It seems likely that this discrepancy could arise in the large aperture correction—1.60 mag—in the Freedman *et al.* photometry, although a small portion may be due to the difference between *F555W* and Johnson *V*. The situation for *F785LP* is not as good, with the Freedman *et al.* zero points showing large discrepancies (0.13 mag rms) with the sky offsets.

3.2 Delta-Flats

We noted above that much of the structure in the background is relatively stable over time, appearing qualitatively similar at least over the time scale of ~1 yr. However, small residual gradients of order 3% can be seen in many frames acquired ~5 months or more after January 1992. It is important to recall that the buildup of contaminants on the field flatteners of the WFPC is expected to lead to changes in the camera transmission over time, particularly in the blue. For this reason, a program for obtaining "delta-flats" has been undertaken (Baggett & MacKenty 1993b). Unfortunately, *F785LP* has only recently been added to the delta-flat program, so our tests of the delta-flats have been limited to *F555W*. We find that most of the residual structure is removed by applying the appropriate delta-flat, to within an accuracy of ~1%, i.e., the accuracy of the surface fit. This is also further evidence that there is little (if any) significant scattered light in the frames we have examined.

4. CONCLUSIONS

Our conclusions can be summarized in the following points:

(1) The accuracy of the flatfield calibration of WFC is considered by examining the sky in long MDS exposures. Large-scale gradients of order 10%–20% are found. These gradients are quite different in *F555W* and *F785LP*.

(2) Stellar photometry shows a correlation with the background variations, demonstrating that the variations are due predominately to incorrect flatfielding.

(3) Correcting the photometry in the IDT report (Hunter *et al.* 1992) for the flatfield errors leads to an improvement in the dispersion in zero point measurements within each CCD.

(4) Reanalysis of the Hunter *et al.* data, corrected for flatfield errors, gives *F555W* and *F785LP* zero points whose chip-to-chip offsets are consistent with the observed sky levels to within 1.2% rms. The new zero point values applicable to our correction flats are 22.90, 23.04, 23.04, and 22.96 (*F555W*), and 21.56, 21.64, 21.44, and 21.47 (*F785LP*) for chips WF1–WF4, respectively.

(5) The chip-to-chip offsets of the independent Freedman

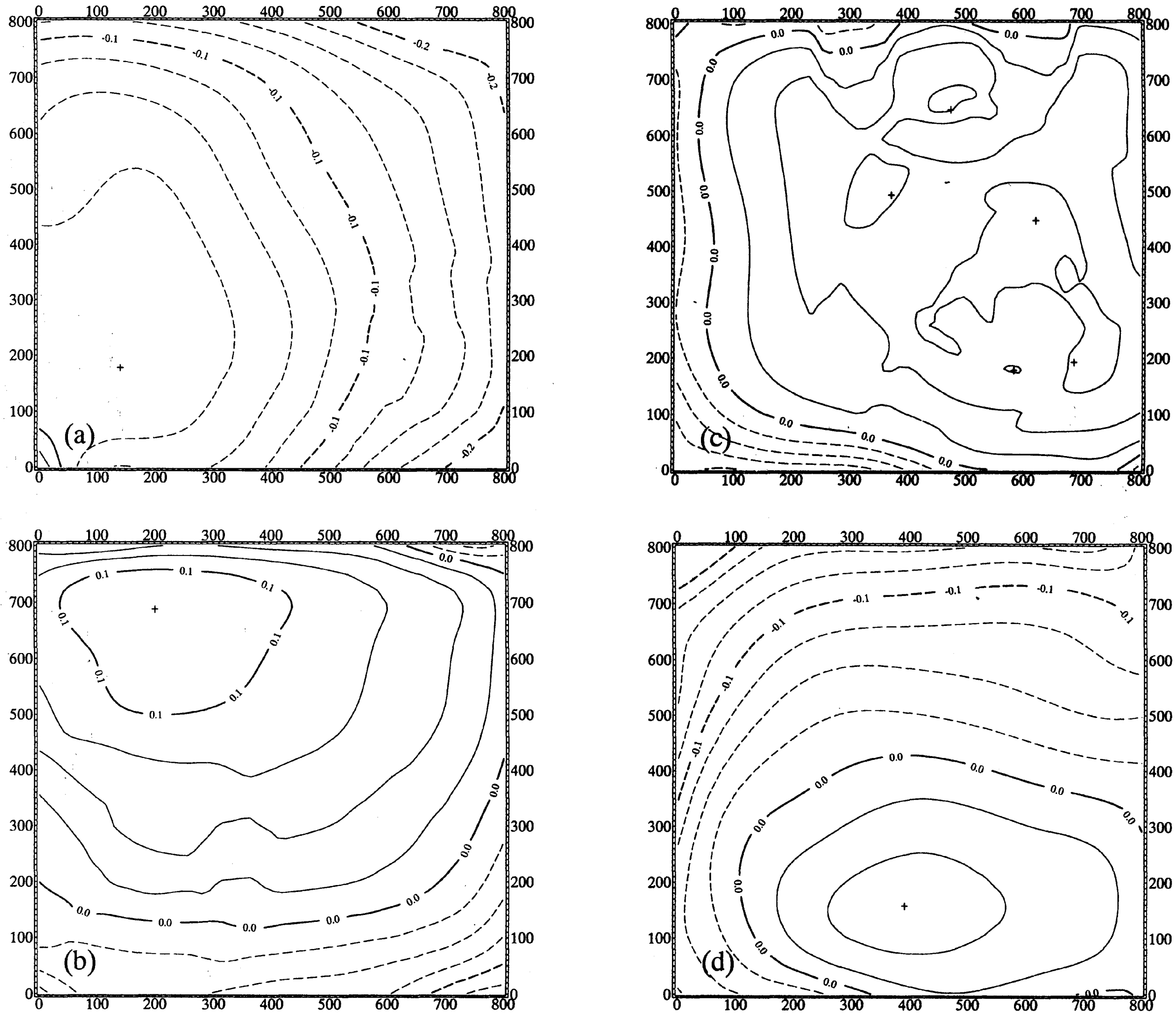

FIG. 6. Map of corrections to *F555W* photometry from pipeline processed data calibrated with the IDT zero point, 22.984. These values (in magnitudes) should be added to the photometry. The maps are created from the correction flats block-averaged by 25; the contour interval is 0.025 mag. It should be noted that the fit is poorly constrained near the edges of the CCD or pyramid shadow (the pyramid shadow occupies the region $x \lesssim 20$ and $y \lesssim 30$). Shown are maps for WF1 (a), WF2 (b), WF3 (c), and WF4 (d). The approximate location of local maxima are marked (+). Note that the correction frame for WF3 is very complicated; (c) will probably not give good results near the edges of the pupil images.

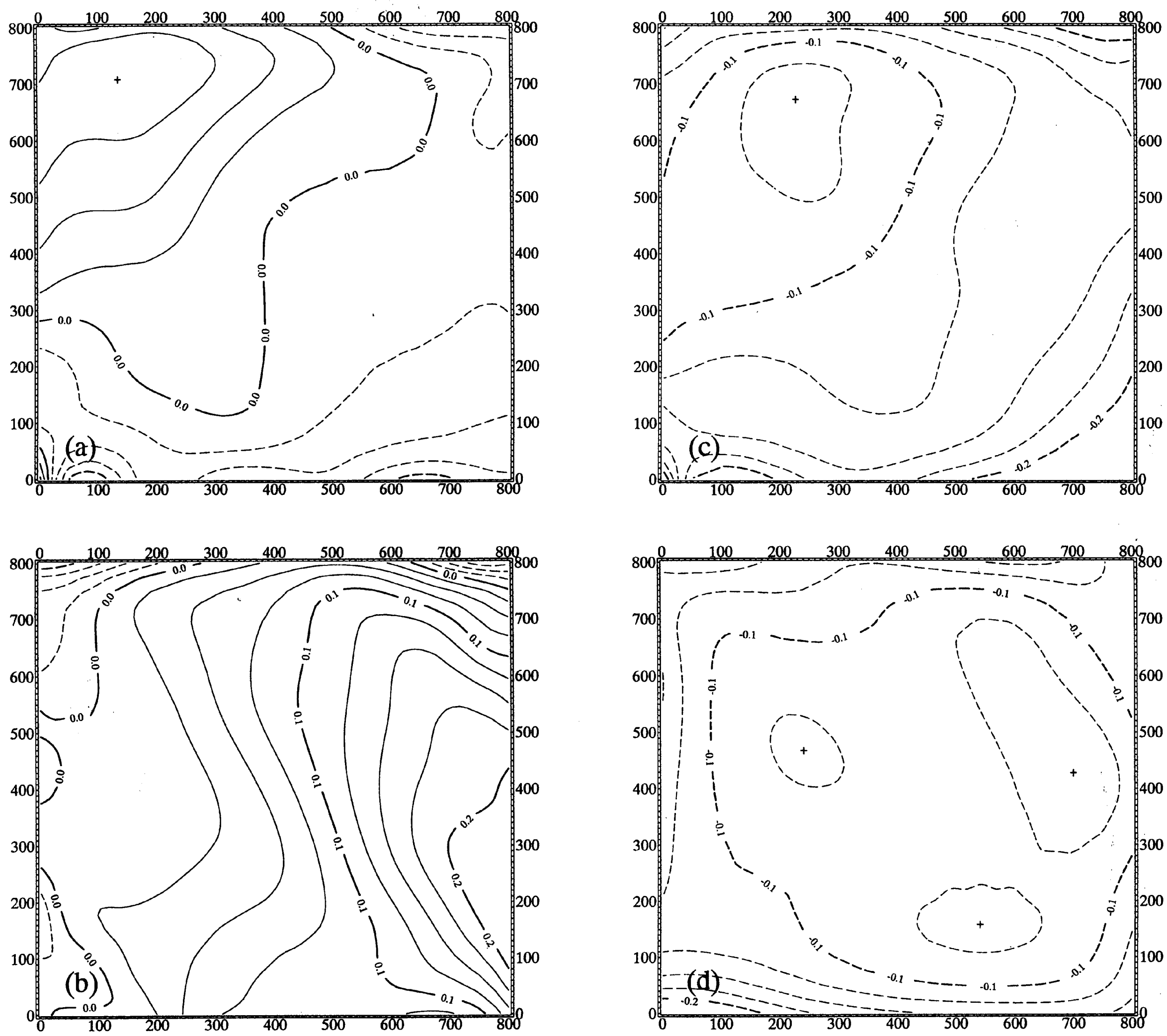

FIG. 7. Same as fig. 6 but for *F785LP* data calibrated with the zero point 21.556.

et al. (1993) calibration are also in excellent agreement with the sky levels in *F555W*, but show substantial disagreement in *F785LP*.

It is clear that researchers wishing to do relative photometry to better than 0.1 mag will need to be aware of the WFC flatfielding problems and will need to make appropriate corrections. This is particularly true when accurate colors are required, since the flatfield errors may be very dissimilar in different passbands. However, with such corrections it appears that relative photometry as good as 1%–2% should be achievable with multiple observations. The correction flats described in this paper are available upon request from the authors. Researchers wishing to obtain our correction frames over the Internet may contact the authors.

Note added in proof: The correction frames are now available on the Data Management Facility of the ST ScI on-line archive. They have been assigned the names e2a1258lw.r8h (*F555W*) and e2a1258lw.r8h (*F785LP*).

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APPENDIX

For the convenience of researchers who may wish to correct only a few measurements, we include contour maps of estimated flatfield errors in magnitudes, Figs. 6 and 7. *F555W* photometry calibrated with the single *F555W* IDT zero point value, $C^{\mathrm{IDT}}=22.984$ [from Table 12.15 of Hunter *et al.* (1992)], may be corrected to our zero point system by *adding* the appropriate values from Fig. 6(a)–6(d). Similarly, $F785LP$ photometry (calibrated with $C^{\mathrm{IDT}}=21.556$) may be corrected by values from Fig. 7.

Researchers wishing to apply a version of our correction frames, which has been cross-normalized by the sky level, should *multiply* our correction frames by the constant $10^{\Delta\Sigma(\mathrm{Sky})/2.5}$ in each filter. A single zero point is then appropriate for all four chips. These constants, from Table 1, are: 1.094, 0.947, 0.936, and 1.032 ($F555W$); and 0.979, 0.906, 1.073, and 1.050 ($F785LP$), for chips WF1–WF4, respectively. The appropriate zero points are then 22.983±0.006 ($F555W$) and 21.524±0.009 ($F785LP$). These have been calculated using unweighted averages of the corrected IDT data from Table 12.12 of Hunter *et al.*; the quoted errors are standard deviations of the mean for 50 and 53 stars, respectively. While we have quoted values to 0.001 mag, it should be kept in mind that the expected errors in the flatfield and calibrations are of order 1%–2%.

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