

References

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F555W (by this time corrected from the SV system by -0.14 mag) and -0.03 mag in F785LP.

The *HST* magnitudes obtained independently at Basel and STScI for all stars measured in common are in agreement to within the measuring errors quoted above. The residuals calculated for individual images attest a very consistent determination of the photometric zero-points. Systematic differences amount to only a few hundredths of a magnitude. They become larger at the fainter magnitudes due to unavoidable matching errors that are caused by the different magnitude limits of the object lists generated at STScI and in Basel.

V. Summary and Conclusions

Confronted with the complicated image structure produced by the WFC of the spherical aberration impaired *HST*, crowded-field photometry becomes even more difficult. We relied on a well designed observing strategy and reduction procedures that evolved from those developed for ground-based data. Very reliable photometry down to limits imposed by photon statistics was obtained by fitting an analytic model to the dominating core of the PSF. Spatial variations of the PSF, combined with flat field errors, affect the relative stellar photometry by less than 0.07 mag rms. Images taken at the time of frequent decontamination events and focus adjustments show significant temporal changes of the PSF, that correspond to magnitude offsets of up to 0.15 mag for a given epoch. The determination of aperture corrections depends on the availability of an adequate number of well isolated stars that are bright but do not saturate the chip. Subsequent zero-point calibration of the instrumental total magnitudes was based on the SV Report (Hunter et al. 1992) and/or independent ground-based calibration. Several recent studies revealed discrepancies between the two techniques, caused by an unknown combination of various instrumental effects. However, the overall photometric errors of order of 0.1 mag are acceptable for our scientific program.

In order to overcome the shortcomings in the calibration of WFC images, the following consequences arise

- the flat fields used in the standard data processing pipeline should be replaced by appropriate sky flats,
- the stellar monitoring program should include all chips, and not only one region of a particular chip,
- photometric sequences like the one in ω Cen should be observed regularly and for different telescope position and orientation.

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data we discovered a significant pattern of systematic fluctuations larger than 0.02 mag rms (Figure 1). This is obviously due to the history of decontamination events and focus adjustments which occurred in the course of the first campaign (see MacKenty, this volume). Subsequent correction of all instrumental magnitudes for every epoch and chip/filter combination led to homogeneous instrumental photometry. For IC 4182, the statistical error of the magnitudes, averaged over all epochs, is typically well below 0.10 mag for F555W < 24.5 mag and F785LP < 23.0 mag. In the case of NGC 5253, the errors are larger due to the more extreme crowding.

IV. Zero-Points

The zero-point calibration of the WFC magnitudes depends on the camera, filter, flat field, contamination, and the digital aperture used for the photometry. This part of the calibration process is the most crucial of our program because it strongly affects the accuracy of our distance determination. Two different techniques can be used and checked against each other:

- rely on the work of the IDT (Hunter et al. 1992), and/or
- use independent ground-based observations.

Either direct aperture photometry of truly isolated stars or (partial) growth curves of relatively isolated stars lead to the determination of the actual fraction of detected light covered by the PSF. The full aperture referred to in the SV Report has 80 pixels diameter. The corresponding mean aperture corrections derived for the ROMAFOT magnitudes are given below, normalized to an exposure time of 1 sec.

Target	F555W	F785W
IC 4182	7.42 ± 0.01	7.17 ± 0.01
NGC 5253	7.36 ± 0.02	7.16 ± 0.01

The total magnitudes were calibrated by applying the zero-points given in Table 12.15 of Hunter et al. (1991).

Because more than 1 year has elapsed between the determination of the SV zero-points and the time of our recent observations (NGC 5253), and the last decontamination has taken place in August 1992, we were aware that the telescope photometric system might have changed. Therefore, archived images of two of the regularly monitored calibration stars, taken at a time closest to our data, were reduced. A zero-point correction of -0.14 mag was found for F555W relative to the SV Report. No correction was needed for the F785LP zero-point.

An independent check with ground-based data (J. Tonry, private communication to A. Saha) for 15 uncrowded stars on three of the four WFC chips shows agreement in zero-point between the transformed values and *HST* magnitudes to 0.01 mag in

At STScI a variant of DoPHOT (Schechter et al. 1993) for iterative object location and analytic model fitting (elliptical Gaussian profile) was applied. This program also performs object classification. The model parameters were derived for every chip and epoch separately, accounting for the time dependence of the PSF. By correcting for an additive term, the relative instrumental photometry obtained for every star on all the individual images was tied to the photometry of a template image constructed of stacked frames.

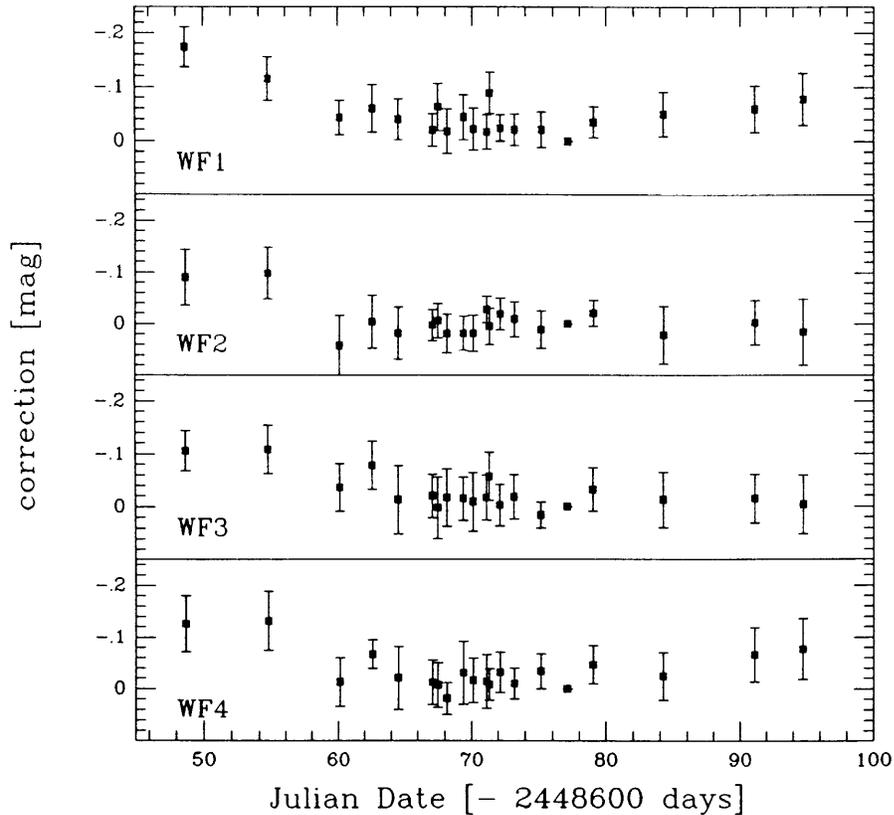


Figure 1: ROMAFOT magnitude corrections for all four chips relative to epoch 16. The values are based on 13 to 25 bright stars from F555W images of IC 4182.

In Basel the ROMAFOT (Bounanno et al. 1979, 1983) package as implemented in the MIDAS environment was used. It performs non-linear best fits of a Moffat function, offers interactive inspection of both the profiles and the residual image, and accepts the subsequent definition of additional stellar components and/or holes for optionally improving the local fit. Object lists generated from coadded images included unwanted spikes due to the aberration problem of the telescope and many spurious events (low-level cosmic rays). The majority of them could be excluded by fitting the PSF with floating parameters and using the resulting profile width as a powerful discriminator to distinguish between stars, extended objects, point like CR hits, and the like. In order to define an average core PSF for each filter and campaign, we examined the few isolated stars available in the least crowded part of the field. The FWHM of the core PSF is typically 1.9 pixels for F555W and 2.1 pixels for F785LP. The adopted PSF was kept fixed for all images. Temporal changes of the PSF were examined by plotting the magnitudes of individual stars versus epoch. In the IC 4182

- zero-point corrections put the instrumental magnitudes on the *HST* photometric system. The nominal zero-point corrections given by Hunter et al. 1992 in the SV Report differ from more recent determinations (Freedman et al. 1993; Phillips et al. 1993).
- the actual distance determination makes use of empirical period-luminosity relations, defined in a ground-based photometric system. This necessitates the transformation of *HST* magnitudes to a standard system like the Johnson-Kron-Cousins system. The transformations given by Harris et al. (1991) are only valid for solar abundances and cover a limited color range.
- the determination of the apparent magnitude at maximum of a SN may include transformation of original photometry to modern systems and fitting of the available data with a standard template light curve.

The Cepheid program aims at obtaining the mean magnitudes of the discovered Cepheids with an overall accuracy of ± 0.10 mag and to determine their periods to 10 percent accuracy. In the following we concentrate on the stellar photometry.

III. Core PSF Photometry

In pursuit of a time-critical observing schedule, repeated images of a field in one of the two target galaxies were taken with the Wide Field Camera in the F555W and F785LP passbands. A summary of the two observing campaigns is given below. The back-to-back exposures were combined to remove cosmic ray events.

Target	Observing Dates	F555W	F785LP
IC 4182	27 Jan – 12 Mar 1992	19 epochs (2 x 4200s) 1 epoch (1 x 4200s)	2 epochs (2 x 4200s)
NGC 5253	31 May – 19 Jul 1993	18 epochs (2 x 3600s) 2 epochs (2 x 2100s)	5 epochs (2 x 3600s)

Two independent teams utilizing different software for crowded-field photometry reduced the aberrated *HST* images and searched for variables. Both groups used an analytical model PSF to fit the dominating core of the severely undersampled WFC PSF. This part of the stellar image contains most of the S/N and is least affected by the variation of the WFC PSF across the field. No effort was undertaken to follow the field dependence of the PSF. Tests performed on images of the LMC cluster NGC 1850 taken during Science Verification with different field positioning and orientation showed that the combined effect of flat field uncertainties and PSF variations is less than 0.07 mag rms. In our experiments, all images were taken in the same telescope position and orientation, so the photometry of any particular star is unaffected by spatial variations of the PSF.

Core PSF Photometry from Wide Field Camera Images

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I. Introduction

This contribution reports on the reduction and photometric calibration of WFC images taken during *HST* observing Cycles 2 and 3. The program (PI: A. Sandage) consists of a series of experiments designed to determine the Cepheid distances to galaxies that have produced prototypical supernovae of type Ia. The goal is the calibration of the absolute B and V magnitudes of normal SNe Ia at maximum light and freed of absorption effects. The current Cepheid program is an empirical test of the reliability of SNe Ia as distance indicators for an accurate and unambiguous determination of H_0 (see also Sandage & Tammann 1993). Before turning to calibration issues and a presentation of our analysis techniques, we summarize the scientific results obtained so far.

The first SN to be calibrated in this program was SN 1937C in the parent galaxy IC 4182. Twenty-eight Cepheids were discovered and used for the determination of a reddening-free distance modulus of $(m - M) = 28.36 \pm 0.09$ (Sandage et al. 1992; Saha et al. 1994). Our second target NGC 5253 produced the two SNe 1895B and 1972E. Its distance modulus is $(m - M) = 28.06 \pm 0.06$ (Sandage et al. 1994) based on eleven Cepheids with unambiguous periods. Combining the individual values for the absolute magnitudes of the three type Ia SNe covered by our program so far gives mean values of $\langle M_B(max) \rangle = -19.55 \pm 0.08$ and $\langle M_V(max) \rangle = -19.58 \pm 0.09$.

II. Relevant Calibration Issues

The practical realization of this program consists of several reduction steps (see Labhardt et al. 1993; Saha et al. 1994), some of which involve crucial calibration issues

- preliminary processing in the standard STScI data processing pipeline depends on the reliability of the images used for bias subtraction and flat field correction. The standard flat fields generated from short exposures of the sunlit Earth differ from sky flats recently constructed from long Medium Deep Survey exposures (Phillips et al. 1993 and this volume; Ratnatunga, this volume).
- temporal and spatial variations of the PSF both affect the instrumental photometric zero-point. A meaningful search for variable stars measured at different epochs requires the same photometric scale to be maintained throughout the whole experiment (see next section).

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