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# Toward a Multi-Wavelength Geometric Distortion Solution for WFPC2

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**Abstract.** The inner calibration field of omega Cen has been used to examine the geometric distortions of WFPC2 as a function of wavelength. We used multiple observations of this field shifted in the range of 0.25” to 35” and exposed through F300W, F555W, and F814W filters. All observations have been reduced using the IRAF/PSF/ALLSTARS package which yields the standard error of a single position 0.08, 0.05 to 0.06 pix, depending on the filter. The master catalog of all positions was used to obtain new distortion coefficients by differential method. Although the chosen set of observations do not allow us to find the non-perpendicularity of coordinate axes (skew), they provide clues on the scale change from filter to filter and within uncertainties confirm the values of previously found distortion coefficients. Future improvements will include more observations with rotated fields of stars and at selected epochs.

## 1. Introduction

The geometric distortion of *HST* WFPC2 has received repeated attention in terms of astrometric calibrations (e.g., Holtzman et al. 1995, Anderson 2001, Casertano & Wiggs 2001, Anderson & King 2003). The goal of astrometric calibration of *HST* WFPC2 is not only to obtain a world coordinate system (WCS) free of distortion down to a precision level of 1 mas, but also to obtain a contiguous and seamless image over the field of view of the entire CCD mosaic. To achieve this goal, coordinates of individual CCD chips must be translated into the WCS and fluxes stacked up, employing point spread function fitting. If the knowledge of the PSF across the whole CCD mosaic frame, precise CCD mosaic metrology, and a distortion-free WCS are neglected, image resampling and stacking will produce an unwanted blurring of the objects of scientific interest.

In this study, the inner calibration field of $\omega$ Cen exposed through filters F300W, F555W and F814W has been used to examine the geometric distortion of WFPC2 as a function of wavelength. Although the chosen set of observations do not allow us to find the non-perpendicularity of the coordinate axes (skew), it provides clues on the scale change from filter to filter, and, within uncertainties, confirms the values of previously found distortion coefficients. Future improvements will include more observations with rotated fields of stars at different selected epochs.

## 2. Data Set and Reductions

The WFPC2's wavelength-dependent geometric distortions have been computed from a series of overlapping images of the globular cluster $\omega$ Cen, taken in three WFPC2 bandpasses—F300W, F555W and F814W—over a single five hour period in June 13, 1997. Each set of the F330W, and F814W images consists of two central pointings with a $0\farcs25$ shift and four outer pointing pairs with $35''$ shifts (with an offset of $0\farcs25$ in each pair). The set of F555W images has offsets at $35''$, $15''$, and $0\farcs25$. The IRAF/PSF/ALLSTARS tasks were used to

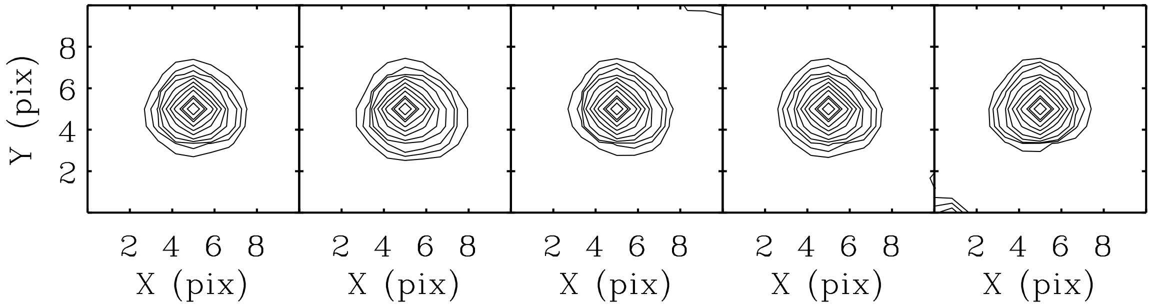


Figure 1. Contour plot of the composite PSF as a function of position on the WF2 chip (filter F555W). The panels, from left to right, represent the observed PSF in the center, lower left, lower right, upper right and upper left of the chip, respectively.

obtain the star positions on 136 CCD chips for all 34 images. The PSF fitting implements the empirical PSF fitting as a sum of an analytical function and look-up tables of residuals between the actual PSF and the fitting function (Stetson 1987, Stetson, Davis, & Crabtree 1990). An analytical Moffat function and six lookup tables were chosen to provide the best representation of the undersampled image cores and extended wings of the PSF in WFPC2's data in order to calculate the image centers. An IRAF script was written to automate the detection of objects, selection of PSF stars, fit the analytical PSF to detected images and provide an output with $X, Y$ and instrumental magnitudes for all four WFPC2 CCD chips. About 50–100 bright, unsaturated and isolated stars, well distributed over the chip, were selected to generate a template PSF. If the normalized standard scatter in the fit of an analytical PSF to the observed PSF stellar profile exceeded 0.020, the stars selected for the PSF template were examined interactively, poor images were deleted and the PSF fit was repeated until a normal scatter of 0.02 was achieved.

Figure 1 presents the contour plots of the composite PSF as a function of position on the WF2 chip. It is well known that the observed PSF varies as a function of position on WFPC2 chips, with the off-center PSFs being noticeably more asymmetric due to coma and astigmatism. The quality of the PSF fit for each CCD chip was monitored by examining $\chi^2$ as a function of $X, Y$ and magnitude. The stars with poor images (high $\chi^2$, large magnitude errors) were rejected from the subsequent astrometric reductions, and only stars with good measurements (Figure 2) were used to calculate the geometric distortions. On average, there are over 30,000 such stars per filter.

## 3. The Model of Geometric Distortion

The geometric distortion model for WFPC2 has been described by Holtzman et al. (1995), which, is essence, is a polynomial transformation between observed and distortion-free coordinates. Recently, Casertano & Wiggs (2001) attempted to improve the geometric solution for WFPC2 using data which were specifically designed to provide good sampling in all regions of the field of view. Here we use the Holtzman formalism with Casertano's modification to calculate the geometric distortions of WFPC2 at three different wavelengths.

The geometric correction is based on a bicubic polynomial which transforms the pixel coordinates $(x, y)$ of each WFPC2 chip to geometrically corrected coordinates ($X_g$,$Y_g$), matching the scale and orientation of the PC1 chip. The transformation operates on a single 800×800 CCD image in a coordinate system with its origin at the center of a CCD, i.e., $X = x - 400$ and $Y = y - 400$:

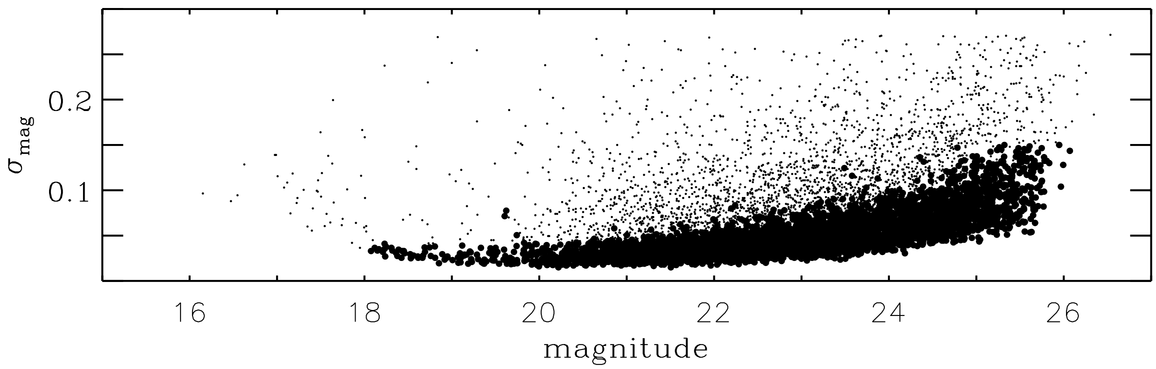


Figure 2. The distribution of errors in magnitude as a function of magnitude for the WF2 chip. Only stars denoted by the bold dots are kept in the astrometric reductions.

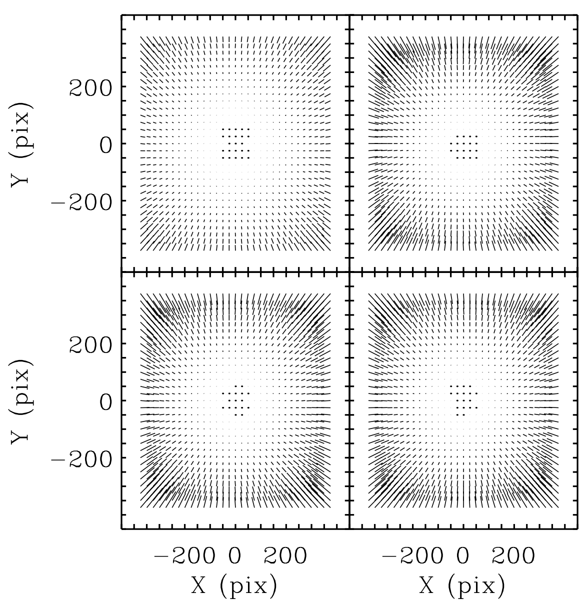


Figure 3. The distortion correction maps for the F300W filter and all four chips. The grid is depicted using raw pixel coordinates with the zeropoint at 400,400. The size of the longest arrow corresponds to $\sim 6$ pixels for PC1 (upper left panel), and twice as much for the remaining panels (WF2, WF3, WF4). The distortion maps for the other two filters are nearly identical.

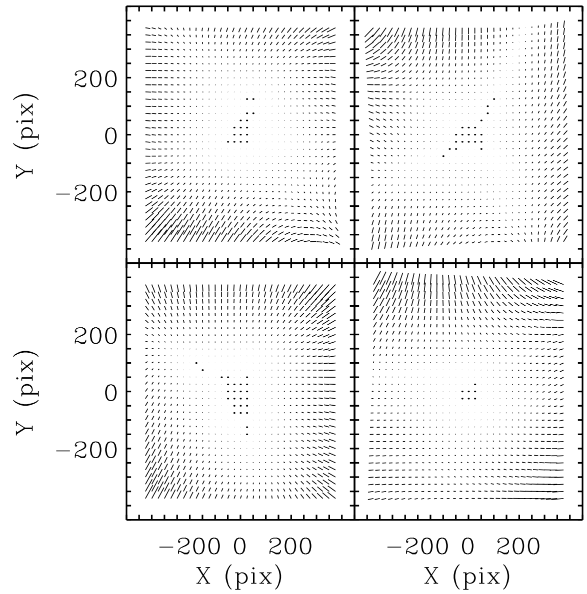


Figure 4. Differences in the distortion correction in the sense "F555W–F814W." The small amount of these differences along with a fairly random pattern change from chip to chip indicate that the differences are negligible.

$$X_g = C_1 + C_2X + C_3Y + C_4X^2 + C_5XY + C_6Y^2 + C_7X^3 + C_8X^2Y + C_9XY^2 + C_{10}Y^3$$
$$Y_g = D_1 + D_2X + D_3Y + D_4X^2 + D_5XY + D_6Y^2 + D_7X^3 + D_8X^2Y + D_9XY^2 + D_{10}Y^3$$

where the different sets of coefficients $C$ and $D$ are defined for each CCD/detector. Details on actual calculations can be found in the papers listed above.

## 4. WFPC2 Geometric Distortion

Holtzman et al. (1995) point out that there should be a small but perceptible difference in the amount of expected distortion as a function of wavelength. The required corrections to account for cubic distortion (see coefficients $C_4$–$C_{10}$ and $D_4$–$D_{10}$) are displayed in Figure 3. Nominally they all look the same, however, the differences can be quantified by examining the maximum distortion at the location $X = \pm 375$ and $Y = \pm 375$ pixels. Cubic distortion in the F300W filter is definitely larger than in the F555W filter. The average increase in distortion for the F300W filter is 3%, or 0.37 PC1 pixels. The cubic distortion is essentially identical in the F555W and F814W filters. This is illustrated by Figure 4 which shows the differences in cubic distortion in the sense "F555W–F814W" for the WFPC2 chips. The longest vector is 0.12 PC1 pixels or 5.4 mas, which is comparable with the image centroid precision. It appears that the existing sets of geometric distortion coefficients cannot fully account for the cubic distortion in the F300W filter. More CCD frames with dense stellar fields like $\omega$ Cen are required to obtain more accurate distortion coefficients for this filter.

## 5. Conclusions

The traditional PSF fitting techniques have been applied to obtain working sets of $x, y$ coordinates for an assorted set of *HST* WFPC2 frames with the globular cluster $\omega$ Cen in three bandpasses. We used a bicubic polynomial model to derive geometric distortions in F300W, F555W, and F814W filters. The main conclusion of this study is that existing sets of geometric distortions do not fully represent distortions in the F300W filter. The differences in such distortions between the F555W and F814W filters are only at the level of a few mas, which is comparable with the attained precision of image centering. Since the chosen set of observations have not been rotated with respect to each other we could not find the non-perpendicularity of coordinate axes—a skew parameter.

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