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HST Temporal Optical Behavior: Models and Measurements with ACS

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Abstract. While HST provides a stable stellar image relative to ground-based observatories, it features its own characteristic changes in the PSF it delivers to the Science Instruments (Lallo et al. 2005). HST focus has been monitored and adjusted throughout the life of the observatory. More recently, the resolution and off-axis location of ACS/HRC has allowed us to accurately measure changes in coma and astigmatism as well. The aim of this current work is to relate the accurate and reliable phase retrieval measurements of wavefront error back to characterizations more common to science data analysis (e.g. encircled energy, FWHM, ellipticity). We encourage the further examination of these effects on HST science observations.

1. Introduction

It has been known since early in the Mission that the focal length of HST varies on both orbital and longer time scales (Bély 1993). These changes have generally been attributed to a physical motion of the secondary mirror (SM) resulting from variations in the metering truss structure that supports it. HST focus has always been monitored on at least a monthly basis (Fig.1). The primary purpose for this monitoring is to characterize the focus state of the observatory and accurately plan the time and amount of the occasional SM move for focus maintenance.

ACS/HRC has enhanced our ability to measure the additional image aberrations of coma and astigmatism. Like focus, these aberrations vary over the HST orbit, suggesting the possibility of a more complex motion of the SM, or other sources of misalignment. As part of our routine monitoring program in recent years, phase retrieval analysis (Krist & Burrows 1995) is performed on stellar targets in HRC and values of focus, 0 and 45 degree astigmatism, and x and y coma (Zernike coefficients 4 through 8) are obtained over an orbit at roughly monthly intervals.

The plots in Fig.2 show these data. Units are in microns rms wavefront error for coma and astigmatism, and microns of SM despace

2. PSF Morphology in ACS

It is well known that the morphology of the ACS PSF in both WFC and HRC exhibits appreciable field dependence (see Krist 2003). However, the understanding of how that PSF morphology varies over time and as a function of e.g. focus has not been well understood. Understanding the ACS PSF and the factors that affect it has become increasingly important as science observations in fields such as weak lensing and circumstellar environments continue to push the limits of what is observable.

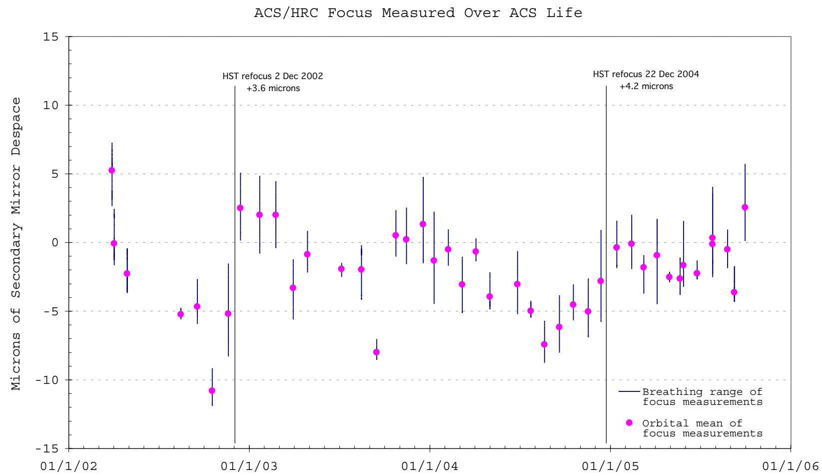

Figure 1.: Secondary mirror (SM) despace (in microns) determined from a monthly series of observations of isolated bright stars in the ACS/HRC. Phase Retrieval was used to first calculate the Zernike focus term (z4) for the star in each observation, which can then be related to microns of motion at the SM. The filled circle represents the orbital mean of the focus observations, while the bar represents the range of measurements obtained for that orbit.

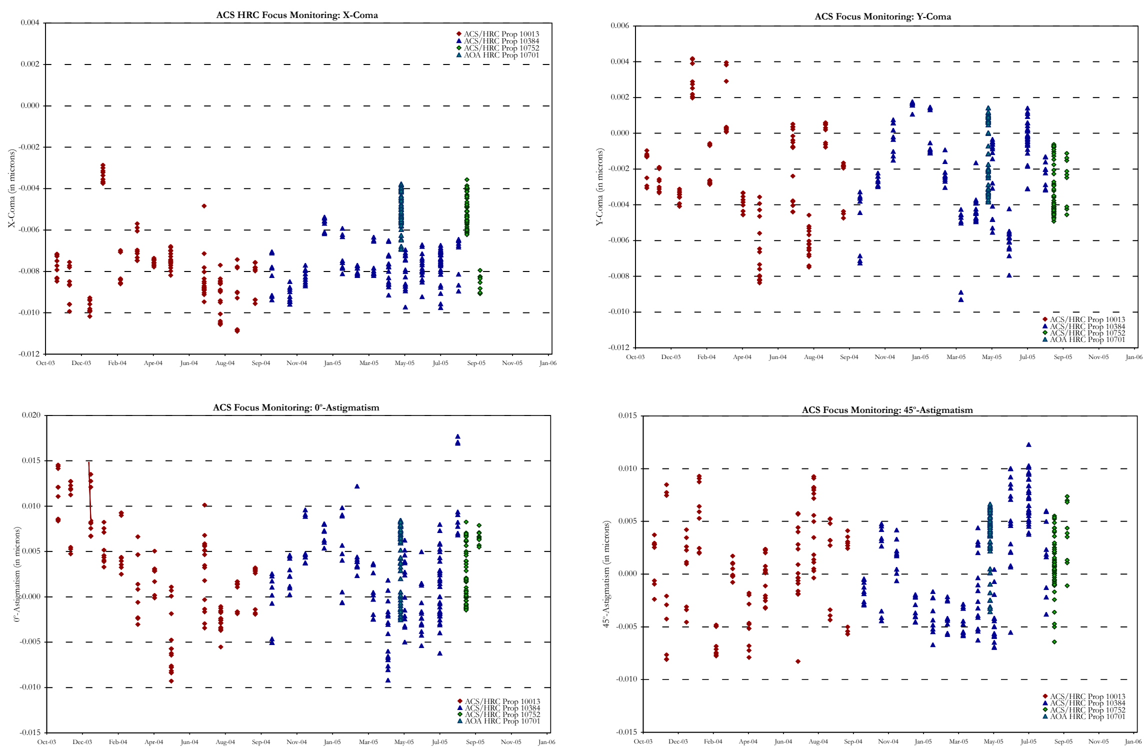

Figure 2.: Coma (top row) and astigmatism (bottom row) measured from the monthly set of observations used to monitor ACS and HST focus. Phase Retrieval was used to determine the Zernike terms z5 through z8 from these data. Each point corresponds to an observation within an orbit, and are plotted in units of microns *rms* of wavefront error as a function of time.

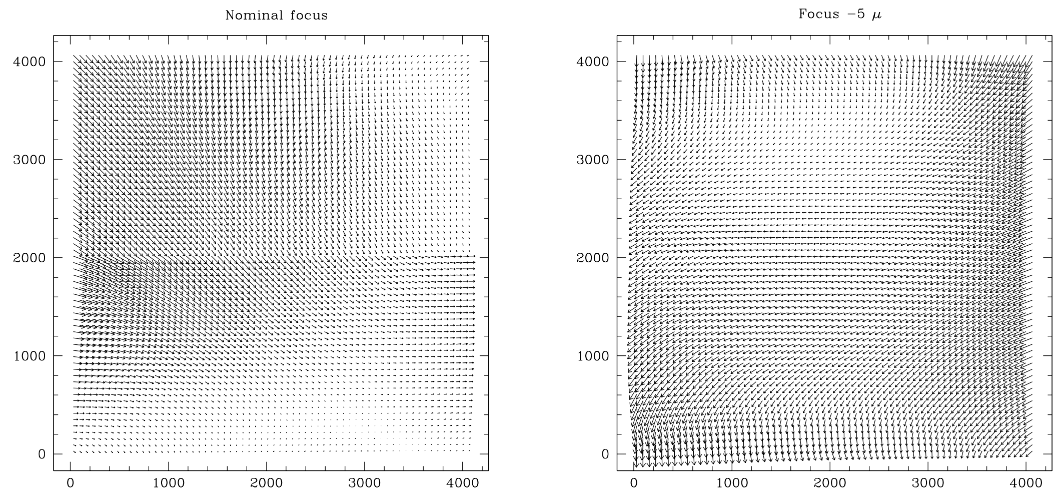

Figure 3.: PSF ellipticities in the ACS/WFC measured from Tiny Tim PSF models. At left: ellipticities measured from models at nominal focus. At right: ellipticities measured from models at $\sim -5\mu$m of SM despace.

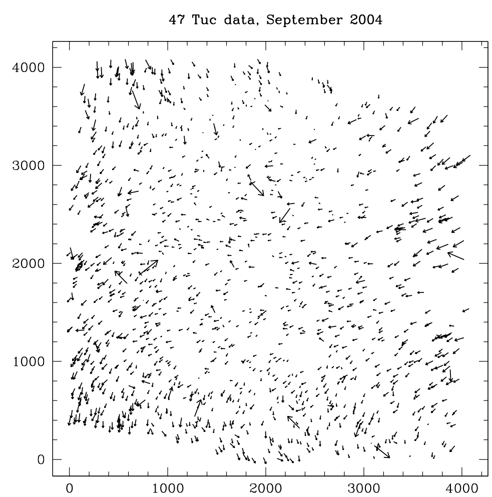

Figure 4.: PSF ellipticities of stellar sources in 47 *Tuc* observed in the ACS/WFC with $F814W$ while HST was known to be in a negative focus state of $\sim -5\mu$m

2.1. Observed and Modeled PSF Ellipticities in WFC

Using Tiny Tim, we generated model PSFs on a finely-sampled grid of field positions on the WFC (Fig.3). Here, measured PSF ellipticities across the WFC field are shown for nominal focus (left) and a Secondary Mirror despace of -5μm or 30nm wavefront error (middle). In Fig.4 we show PSF ellipticity measurements using stellar data from observations of 47 *Tuc* observed with $F814W$ while HST was known to be in a negative focus state of $\sim -5\mu$m (Sept 2004). The ellipticities measured in the 47 *Tuc* data are in good agreement with those in the -5μm model. It is clear that even such a modest despace (typical of orbital focus variation) results in an observable change in ellipticity over the WFC field.

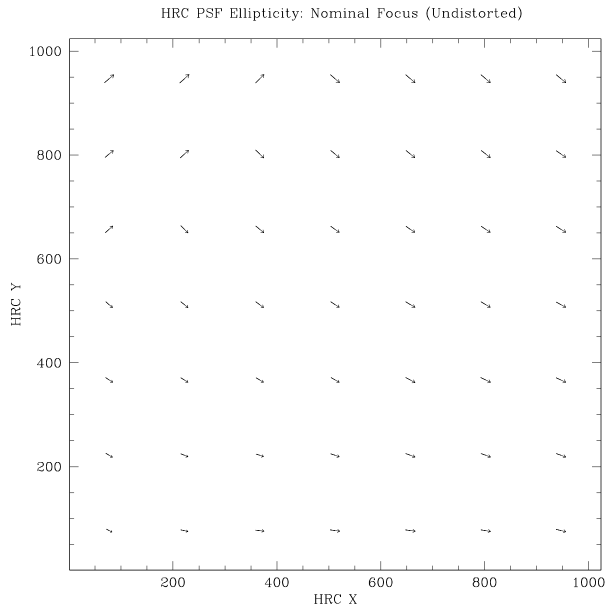

Figure 5.: PSF ellipticities in the ACS/HRC measured from Tiny Tim models at nominal focus. The length of the vector represents $10e$, where e is the ellipticity of the PSF.

2.2. Modeled Ellipticities in HRC

Using Tiny Tim, we generated model PSFs with the F555W filter on a 7×7 grid of positions across the HRC field. We examined the variation of the PSF ellipticity as a function of focus (holding coma and astigmatism constant), and as a function of coma and of astigmatism at nominal focus. We show the measured ellipticities (calculated from image moments) for the nominal focus case (Fig.5), and the difference in ellipticities at 5μm on either side of nominal focus (Fig.6).

Fig.7 illustrates the change in ellipticities over typical ranges of coma (left pane) and astigmatism (right) at nominal focus. It is clear that as with WFC, changes in focus induce a measurable effect on ellipticity, presumably due to astigmatic changes in the PSF due to the combined effects of the HST OTA and the ACS optics. However, neither coma nor astigmatism variations alone at a constant focus (as might be due to slight motions of optics within the HRC instrument itself) have shown a comparably significant effect on the observed PSF morphology.

3. Conclusion

Changes in the field-dependent morphology of the PSF in both HRC and WFC appears more strongly sensitive to focus variations due to HST SM despace than to the observed range of coma and astigmatism. While these aberrations have been shown to exhibit behavior on orbital and longer timescales, the causes of these variations are not yet well-understood. Though the use of phase retrieval can precisely quantify these variations, more familiar—though less sensitive—"real world" characterizations of the observed PSF (e.g. encircled energy, FWHM, and ellipticity) are far less sensitive to the range of coma and astigmatism observed than to focus. Understanding the state of the HST focus at the time of one's observations is necessary to achieve the photometric and astrometric precisions required of many current HST programs (see Gilliland et al. 2002; Casertano & Suchkov 1997), and to accurately describe the morphologies of barely resolved objects.

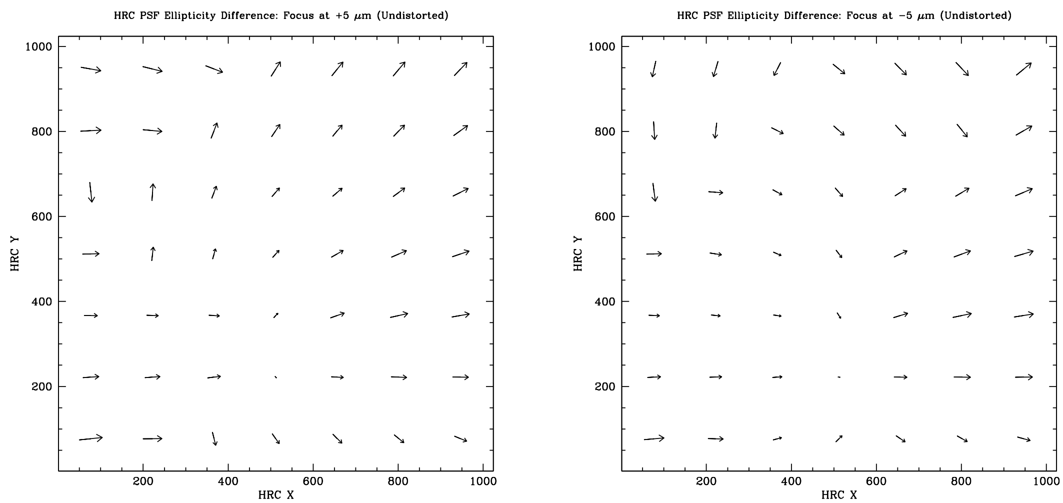

Figure 6.: Measured changes in PSF ellipticity in the ACS/HRC from Tiny Tim models at focus positions $\pm 5\mu$m on either side of nominal focus. Changes are shown relative to ellipticities measured from Tiny Tim models at nominal focus, with the length of each vector given by $10(\Delta e)$, where Δe is the difference in measured ellipticity relative to nominal focus at that field position.

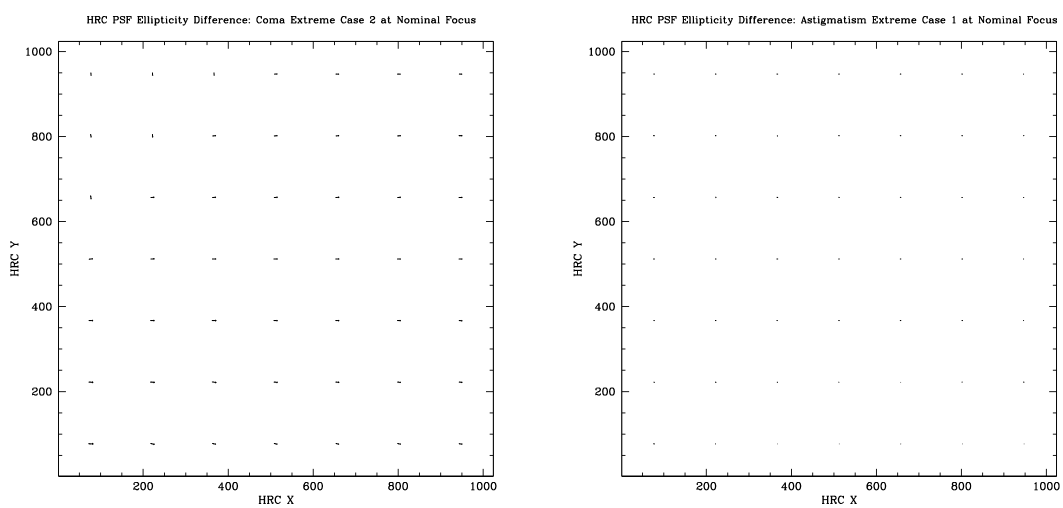

Figure 7.: Measured changes in PSF ellipticity in the ACS/HRC from Tiny Tim models at nominal focus over typical ranges of coma (left) and astigmatism (right). Changes are shown relative to ellipticities measured from Tiny Tim models at nominal focus for default coma and astigmatism values. Here, the length of each vector is given by $10(\Delta e)$, where Δe is the difference in measured ellipticity relative to default coma and astigmatism values at zero focus.

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