Tiny Tim vs ePSF: A Study of PSF Models for Hubble's Advanced Camera for Surveys

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Abstract
This study compares the Tiny Tim PSF against an empirically-derived or effective PSF (ePSF; Anderson & King 2006) for the HST Advanced Camera for Surveys/Wide Field Channel imaging. We manipulate the Tiny Tim PSF FITS files into a format that can be utilized by the ePSF FORTRAN photometry code. Then we perform PSF photometry on globular cluster NGC 6397 and analyze the photometry and astrometry results. We find that the ePSF models outperform the Tiny Tim PSFs in every measurement of stellar sources in this field.

See the full text of ACS ISR 17-08 at www.stsci.edu/hst/lacs/documents/isrs/isr1708.pdf.

Introduction
Tiny Tim is a program that creates point spread functions (PSFs) for the various instruments of the Hubble Space Telescope (HST). Released in 1992, it has served as the primary PSF generation tool for the lifetime of HST (Krist et al., 2011). The history and wide usage of the Tiny Tim PSF model make it a useful benchmark for comparisons with other HST PSF models.

Anderson & King (2006, hereafter: AK06) detail the creation of an effective PSF model for ACS/WFC. The effective PSF is constructed by analyzing empirical data, or in this case, observations of stellar sources with ACS/WFC, instead of using instrumental models of the telescope. While AK06 explain their ePSFs in depth, they do not make a comparison to Tiny Tim. The Tiny Tim output was not compatible with this code, and neither was the specific format of the AK06 ePSFs compatible with other photometry codes. Therefore, the main challenge of this study was to generate Tiny Tim PSFs that the AK06 FORTRAN code (img2xym WFC.09x10.F) can access in order to complete this comparison.

Creating Tiny Tim PSFs
In order to compare the AK06 ePSFs and the Tiny Tim PSFs, we required the two types of PSF models to use the same point source photometry code, otherwise our results may have been sensitive to different measurement methods. To this end, we generated Tiny Tim PSFs in a format compatible with the AK06 FORTRAN photometry code.

We produced Tiny Tim PSFs at 9.5 focal fiducial positions across each detector. We conducted this comparison in F606W because it is one of the most common filters and has the most data available, but this procedure will work for different filters. We ran the three Tiny Tim modules (tiny1, tiny2 and tiny3) associated with ACS/WFC. In order to match the resolution of the AK06 ePSF, we commanded tiny3 to subsample the models by a factor of 4. We list a full account of the input parameters in ACS ISR 17-08.

Tiny Tim does not convolve the PSF with the charge diffusion kernel when producing subsampled models. The charge diffusion is a physical effect of the detector in which charge migrates into adjacent pixels and causes blurring. However, the charge diffusion has an appreciable effect on the PSF (Krist, 2003) and ignoring it would result in an inaccurate comparison because the charge diffusion exists in the empirical data used to build the effective PSF of AK06. We resolved this by applying the charge diffusion kernel to subsets of the PSF image from Tiny Tim with the same pixel phase. The pixel phase refers to the location within a pixel where the star is centered. We select all the pixels that match a particular pixel phase, convolved the charge diffusion kernel, and then repeated this 15 times to correct all pixel phases corresponding to the the 4x4 subsampled PSFs. Figure 1 shows examples of the AK06 ePSFs, the Tiny Tim PSFs output directly from the program, and the Tiny Tim PSFs corrected for the charge diffusion.

We then took all the Tiny Tim PSF models and created a single FITS image in a format compatible with the AK06 FORTRAN code img2xym.

Photometry and Astrometry Comparison
We performed photometry on ten F606W calibrated images (observation sets j7112020.nn.fits and j7113020.nn.fits) where each contains five images of a field of globular cluster NGC 6397 located 5.5° SE from the core (GO-10424, PI: Richer) observed in 2005. We identified reference stars and solved for their positions across each detector. We conducted this comparison in F606W because it is one of the most common filters and has the most data available, but this procedure will work for different filters. We ran the three Tiny Tim modules (tiny1, tiny2 and tiny3) associated with ACS/WFC. In order to match the resolution of the AK06 ePSF, we commanded tiny3 to subsample the models by a factor of 4. We list a full account of the input parameters in ACS ISR 17-08.

We examined the pixel phase to determine if the location on the pixel where the peak of the source falls changes the reported position in a systematic way. The photometry measures subpixel precision, and we calculated the pixel phase by subtracting the integer value of the position and then shifting the values by 0.5 as seen in this example formula for the X position: phase(x) = x-int(x)+0.5. The function int() in python truncates the number after the decimal and returns the integer value. The 0.5 shift is a matter of convention to plot the phase from –0.5 to 0.5 in order to have (0, 0) representing the center of the pixel.

We plot the pixel phase against the residuals in X and Y for each PSF model in Figure 3 for sources with an instrumental magnitude of –12 to –11. We restrict the magnitude range in order to see the effect of the pixel phase without additional trends due to differences in S/N of the sources. The residuals show no trend as a function of pixel phase for the AK06 ePSF in the left column. However, in the Tiny Tim PSF in the right column, we see structure in the residuals that indicate systematic shifts in the reported position based on the pixel phase. This type of bias in the pixel phase is often the result of the PSF model being sharper or duller than the true PSF in the image (Anderson & King, 2000).

Results
We note that this experimental setup does have limitations. We chose the NGC6397 field because it contains a large stellar population with a wide range of magnitudes, but we did not examine sources beyond the saturation limit of the detectors. Tiny Tim allows users to change the size of the PSF during construction, and therefore it is reasonable to assume that an extended PSF from Tiny Tim would be better at fitting the diffraction spikes associated with these luminous objects. Finally, we did not test the photometry on any stellar populations with crowding as that is beyond the scope of this work.

With these caveats, we conclude that the empirically derived effective PSF models from AK06 provide better fits to stars for both the photometry and astrometry measurements than the corresponding Tiny Tim PSFs.

Find the complete details of the analysis in the full text of ACS ISR 17-08 at www.stsci.edu/hst/lacs/documents/isrs/isr1708.pdf.

References
Anderson & King 2006 • Anderson & King 2006 • Astropy Collaboration 2013 • Hoffmann & Anderson 2011 • Krist 2003 • Krist et al. 2011