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Simulation of HST PSFs using Tiny Tim

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Abstract. **Tiny Tim** has been used for generating *Hubble Space Telescope* (*HST*) point-spread functions (PSFs) for deconvolution, algorithm testing, proposal planning, and optical studies. The most recent version, V4.0, includes new mirror zonal error maps and revised aberrations, significantly improving the PSF models.

1. Introduction

Tiny Tim is a stand-alone program for simulating *HST* PSFs as viewed with the on-board imaging cameras (WF/PC-1, WFPC2, FOC, COSTAR/FOC). PSFs generated with **Tiny Tim** have been used extensively for deconvolution, algorithm testing, proposal planning, and optical studies. The most recent version, V4.0, is significantly better than earlier releases, producing more accurate PSFs due to better maps of the *HST* mirror zonal errors and improved aberration values. The software package is available via anonymous ftp at *ftp.stsci.edu* in the *software/tinytim* directory.

2. What is Included in Tiny Tim

The *HST* focus changes slowly over time due to shrinkage of the telescope truss from desorption. The secondary mirror has occasionally been moved away from the primary to compensate. The desorption changes have been characterized by measuring observed PSFs. **Tiny Tim** computes the focus for an aberrated camera with adjustments for desorption and mirror moves, based on a user-specified date of observation. Since desorption has nearly stopped, it is no longer included in the focus values for the corrected cameras (WFPC2 and COSTAR/FOC).

Each camera has its own set of aberrations (astigmatism, coma, spherical, etc.) which have been determined using phase retrieval methods. The measured aberrations for FOC f/96, WF/PC-1 PC6, WFPC2, and COSTAR/FOC are used by **Tiny Tim**. The PC6 values are used for the other WF/PC-1 channels, which may result in some PSF mis-matches. The measured focus offsets among the WFPC2 cameras are also included.

Circular zones in the *HST* mirrors resulting from the polishing process have important effects on the PSFs. In the aberrated PSFs, they affected the diffraction ring structures, and in the corrected ones, they cause scattering which results in a low level halo extending out to about $3''$. Maps of these errors were initially obtained from pre-launch interferograms by Perkin-Elmer and were used by **Tiny Tim** (up to V3.0). Recent maps obtained from phase retrieval of on-orbit WFPC2 data are much better and significantly improve the PSF models. These improvements were introduced in V3.0: they are illustrated in Figures 1 and 2.

The WF/PC-1 and WFPC2 instruments contain Cassegrain repeater optics with their own secondary mirrors and spiders. Since these obscurations are in the same plane as those from the telescope, they appear to shift with respect to the telescope's depending on field position. This leads to position-dependent PSFs. These effects were significant in WF/PC-1, but are less so in WFPC2. The shifts are determined by **Tiny Tim** based on user-specified object positions. Multiple positions can be simulated in a single run by providing a list of coordinates.

The *HST* PSF varies significantly with wavelength. In narrow-band filters, where the PSF does not change much over the bandpass, the diffraction rings are sharp. However, in wide-band filters the changes in the PSF result in blurring of the diffraction structures. These effects are accounted for in the software by adding together PSFs from different wavelengths with weights appropriate for a given filter. By default, **Tiny Tim** will create a PSF integrated onto detector-sized pixels. It can, however, creates PSFs at finer samplings. Such PSFs are useful in deconvolution of undersampled data (like WF/PC-1 or WFPC2) and in peak-centering analysis. Note that in WFPC2 there is a sub-pixel variation which is not included (except as a general pixel-level scattering function applied only to normally sampled PSFs).

3. What is Not Included in Tiny Tim

Despite including all of the above parameters, **Tiny Tim** does not account for all important factors. This is typically because they are not well characterized, or vary on short timescales.

The focus of the telescope is known to change slightly over the period of an orbit due to thermal effects ("breathing"). Also, it is known to change sometimes depending on where the telescope is pointed. While a model for breathing has been developed, it relies on thermal data for a given observation which is not readily available. The pointing-dependent effect, which is about three times worse than breathing, has not been characterized. Note that these effects are not limited to changes in focus but also in coma and astigmatism.

Tiny Tim does not include large angle scattering. The scattering at angles larger than about $3''$ from the core was below expected levels in WF/PC-1 (the limited FOC dynamic range does not allow such scatter to be measured in that camera). In WFPC2, however, it is about an order of magnitude greater and includes streaks which radiate from the star. This is due to scattering by the electrode structure of the front illuminated CCDs (WF/PC-1 was back illuminated). It is not possible to model this effect (which is typically seen only in highly saturated star images). This will lead to possibly significant errors at large angles from the core in the models.

The WF/PC-1, WFPC2, and COSTAR/FOC instruments have as-designed field dependent astigmatism. However, the changes over the field of view are practically unmeasurable, and thus are not included in the models. Geometric distortions in WF/PC-1 and WFPC2 have been measured but are not included.

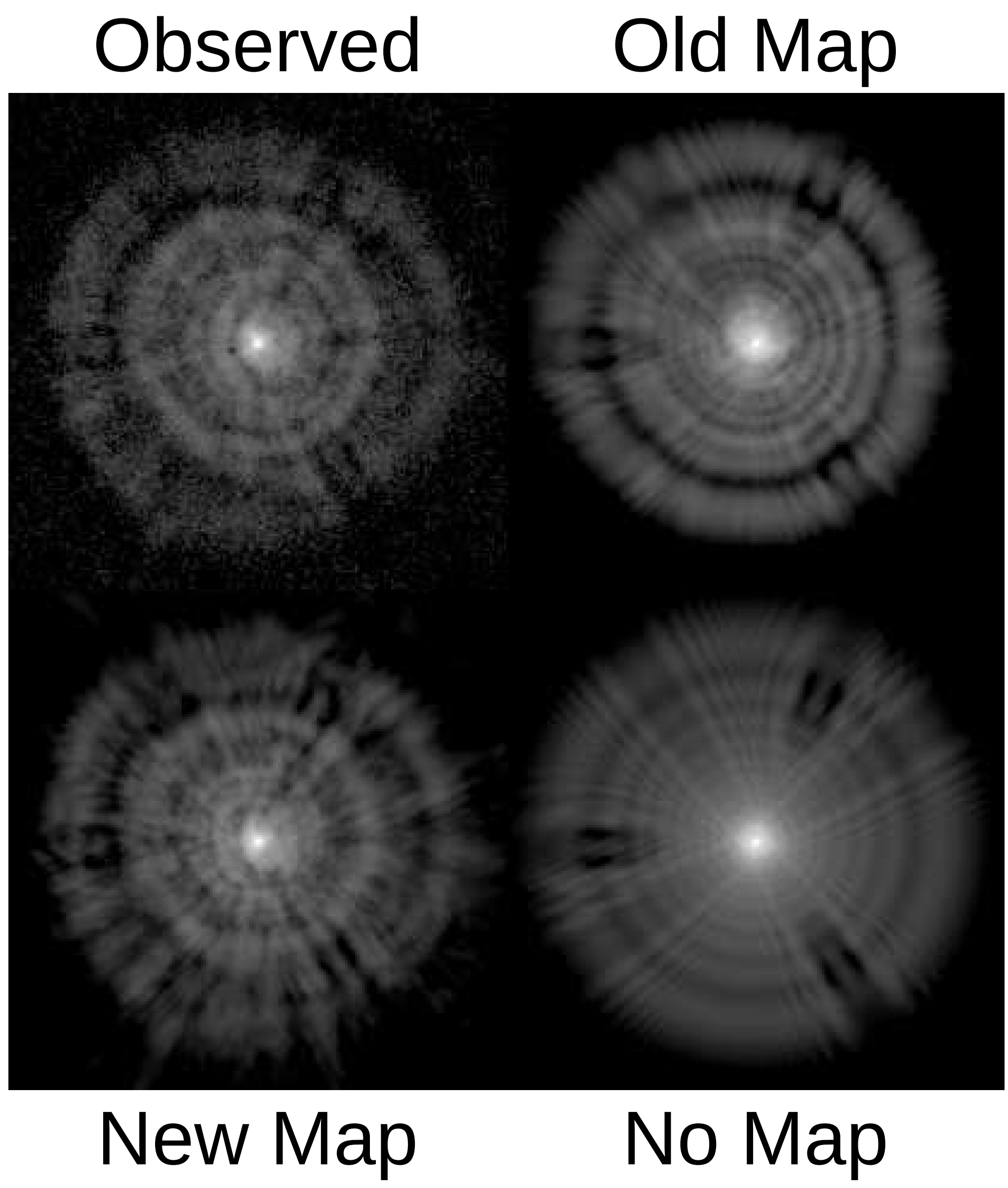

Figure 1. FOC f/96 observed and **Tiny Tim** model PSFs (pre-COSTAR) at 253 nm. The PSF generated using the old mirror map is typical of those produced by Tiny Tim previous to V3.0. The PSF using the new mirror map was created using V4.0b.

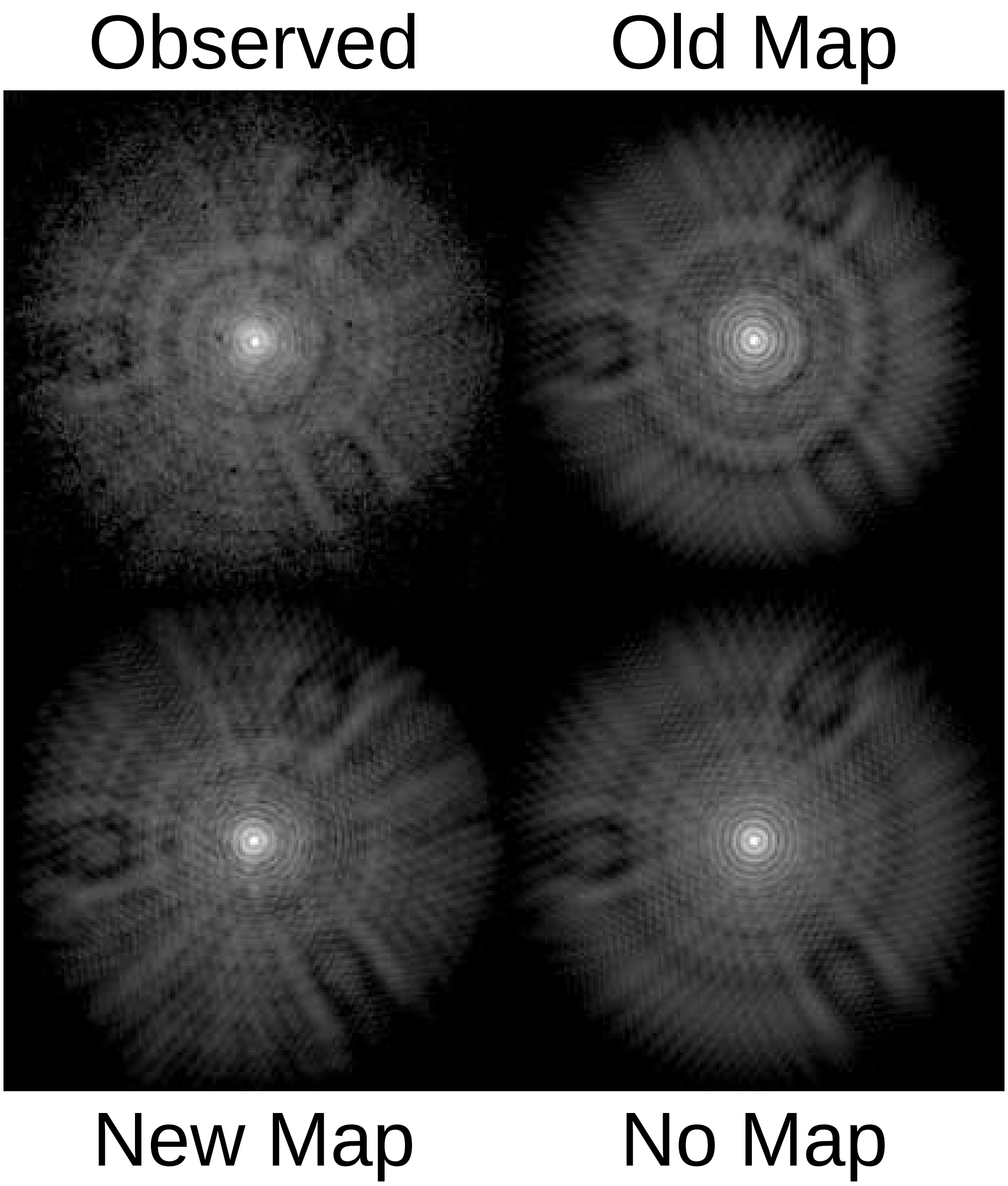

Figure 2. FOC f/96 observed and **Tiny Tim** model PSFs (pre-COSTAR) at 486 nm.