Focus-Diverse, Empirical PSF models for the *Hubble Space Telescope*'s ACS/WFC

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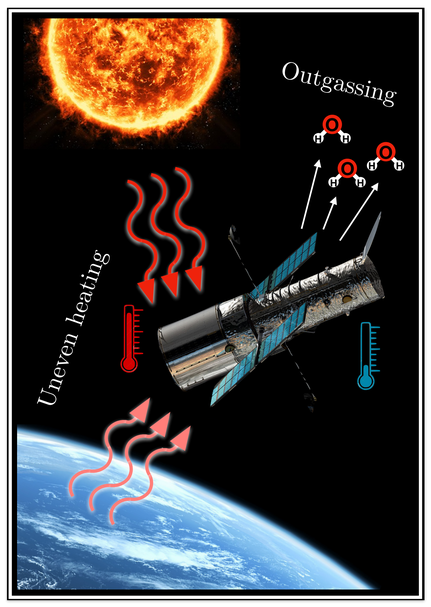
Abstract. Accurate Point-Spread Function (PSF) models are critical in a large variety of science investigations, from stellar photometry and astrometry to galaxy deconvolution. Focus variations, primarily due to uneven Sun and Earth heating of the *Hubble Space Telescope* but also to outgassing of the metering truss, have a significant impact on the shape of the ACS/WFC PSFs. These variations have been largely overlooked since the installment of the ACS in 2002. Now that thousands of images have been collected by the ACS/WFC over the past 17 years in many filters, we can analyze them in a self-consistent way and derive focus-diverse, empirical PSF models that we show to be superior to any prior library PSF models. These new PSF models will be soon made publicly available to the astronomical community through easy-to-use Python tools within the STScI astropy/photutils package.



✓ ***HST*: Best Telescope Ever!**

... but ...

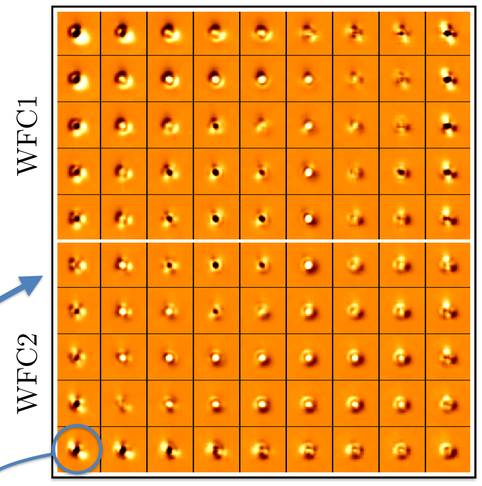
⊗ Uneven heating by Earth and Sun during each orbit, and still outgassing from the metering thruss

⊗ Continuous focus changes (periodically adjusted)

⊗ Spatial variations across the instruments' FoV

⊗ Sizable PSF variations between pre- and post- Service Mission 4

! **Many science cases struggle with precise PSF modeling**

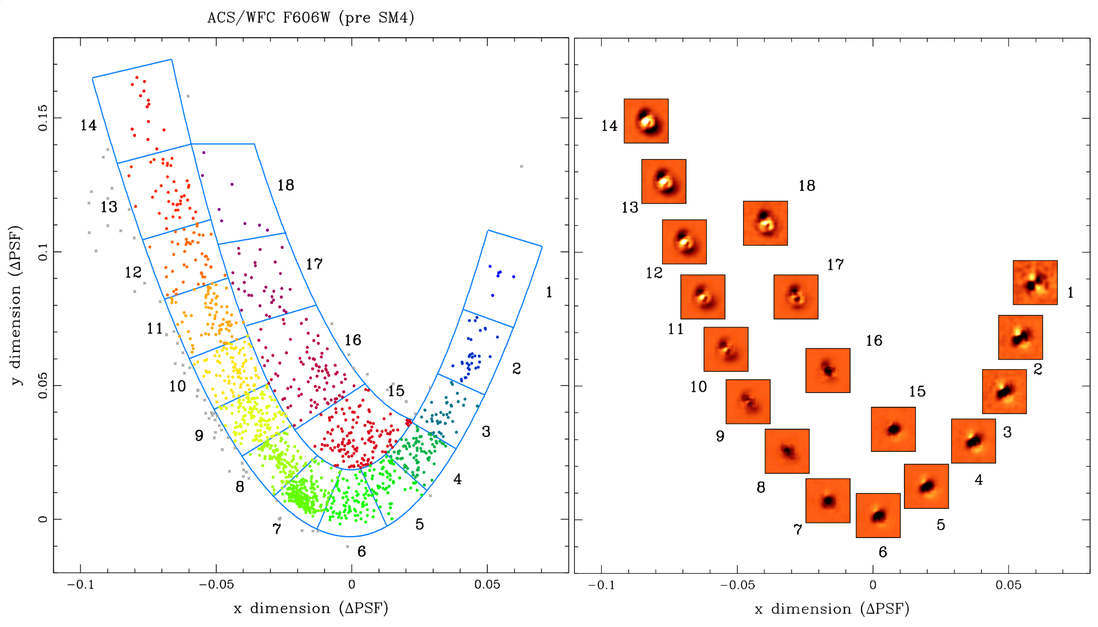


Spatial residuals of the local ACS/WFC F606W empirical PSF models (in an array of 9x5 across the two chips) with respect to the instrument-averaged PSF. Lighter (darker) colors mean more (less) flux with respect to the average PSF. Peak to peak variations can be as high as 10% of the total PSF flux.

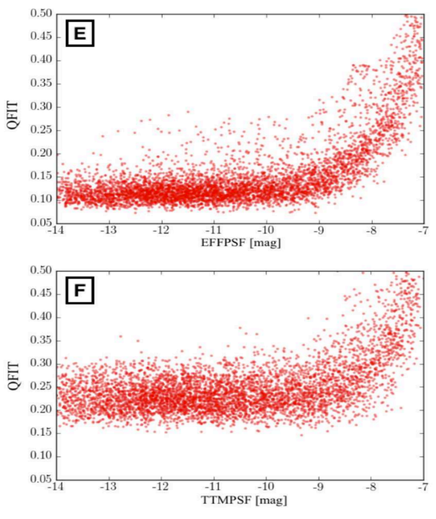
To allow any *HST* user to make the best our of *HST* PSF photometry we:

- Sifted through the entire *HST* archive
- Identified all full-frame ACS/WFC images with sufficient bright, isolated stars for in-image PSF modeling
- Constructed phylograms showing how different the PSF of each image is from any other image
- Derived focus-diverse, spatially-variable empirical PSF models at suitable phylogram locations
- Supported filters (all but F892N):

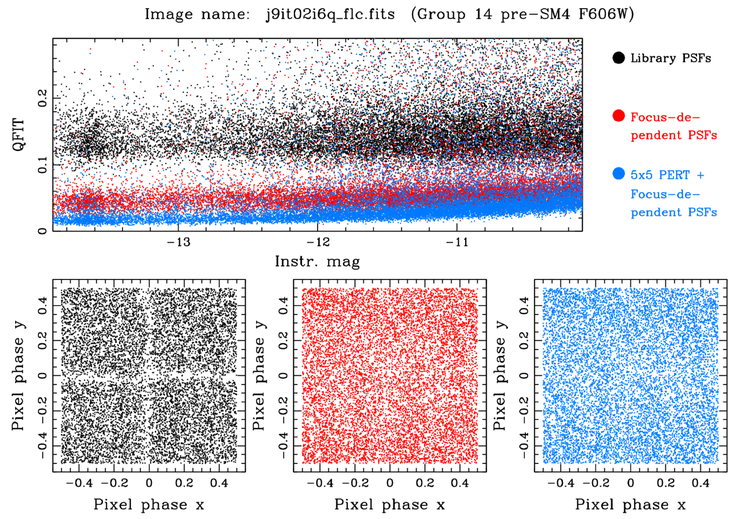
F435W	**F555W**	**F660N**
F475W	**F606W**	**F775W**
F502N	**F625W**	**F814W**
F550M	**F658N**	**F850LP**



(*Left:*) Phylogram plot showing image-by-image differences of the F606W PSF in terms of the total sum of the PSF flux. Points on the phylogram define a "U" shape (which is multimodal on a side) that correlates with different focal lengths. The phylogram is arbitrarily into 18 regions. Stars of the images within each such region are used to fine tune the library, spatially-variable (but focus constant) empirical PSF models to construct high-precision, high-accuracy focus-diverse PSFs. (*Right:*) Residuals of the time-averaged, bottom-left PSF model with respect to the focus-diverse models.



Reproduction from Hoffmann & Anderson (2017 ACS-ISR 17-08, their Fig. 4). These panels show a comparison of the quality-of-fit (QFIT) parameter as a function of instrumental magnitude for sources measured on the same image using library empirical PSFs (EFFPSF, top) and Tiny Tim PSFs (TTIMPSF, bottom). The QFIT tells us how well the PSF shape resambles that of real stars. QFIT=0 means perfect match. It is clear that the library PSFs are superior to Tiny Tim models.



(*Top:*) the QFIT vs. instrumental magnitude for sources in one of the images in the pre-SM4 F606W focus group 14 as measured by the library PSFs (black), the new, focus-diverse PSFs (red), and by further perturbing the focus-diverse models (something you can really just do when many bright stars are available in an image, blue). The improvement of the new, focus-diverse PSF models is obvious: the new PSFs nearly match what can be achieved by state-of-the-art PSF perturbation. (*Bottom:*) Pixel-phase space distribution of sources measured with the library PSFs (*left*), the focus-diverse PSFs (*center*), and the perturbed PSFs (*right*). Pixel-phase errors that are present in extreme focus conditions are completely removed with your new focus-diverse PSF models.

We are developing python tools to make our focus-diverse PSF models easy to use for the *HST* community. For now, you can check Bellini et al. (2018) for more details on the project.