Instrument Science Report ACS 2016-05

Photometric Aperture Corrections for the ACS/SBC

R.J. Avila, M. Chiaberge

September 30, 2016

Abstract

We present aperture correction tables for the Advanced Camera for Surveys Solar Blind Channel (ACS/SBC). As part of a campaign to improve the instrument calibrations, we observed the white dwarf J132811.4+463050 using three filters (F125LP, F140LP, F150LP). The observed point spread functions (PSFs) contain more flux in the wings than Tiny Tim models, which can underestimate aperture corrections by as much as $\sim 9\%$*, when compared with the observed fluxes. The updated aperture correction tables will be provided to the ReDCaT team so that they can be used in* **`pysynphot`** *and HST's Exposure Time Calculator.*

Introduction

Over the last decade, little work has been done on calibration for the Advanced Camera for Surveys (ACS) Solar Blind Channel (SBC). This report is the second in a series where various aspects of the SBC calibration will be inspected and updated if necessary.

The documentation for radial profiles and encircled energy curves is spotty, unclear, and sometimes contradictory. A search of the literature did not uncover any documents providing aperture correction tables that users can refer to. The ACS Instrument Handbook (Avila et al., 2016) contains figures showing radial profiles and encircled energy curves for two filters, F125LP and F150LP (Figure 1). The provenance of these data is unclear, the most likely origin being ground testing (G. Hartig; priv. comm.). There are versions of these plots that were presented by Tran et al. (2003) at the 2002 HST Calibration Workshop. Those plots come from work done during the service mission observatory verification (SMOV) campaign, where they used observations of the globular cluster NGC 6681 to characterize the on-orbit performance of the SBC. One key piece of information missing from this document is the size of the aperture used to normalize their encircled energy curves. Sirianni et al. (2003) presented work on the measurements of the on-orbit sensitivity of the camera, comparing observed to predicted count rates of stars in the same globular cluster as Tran et al. (2003). Sirianni et al. (2003) state that they used a 2.5″ aperture to compare the observed and predicted count rates, although the absolute flux calibration was normalized using a 4″ aperture. Finally, aperture corrections were provided by the ACS team for use in `pysynphot` (Lim et al., 2015) and the observatory's Exposure Time Calculator (ETC), but it is also not clear how those were obtained.

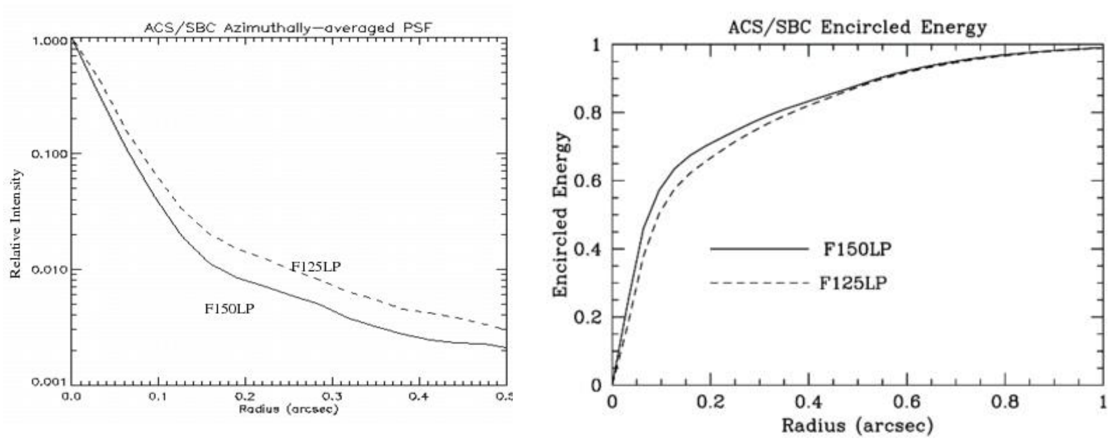

Figure 1: Radial profiles and encircled energy curves found in the ACS Instrument Handbook as of publication of this report. They will be replaced with the results from this work.

Several users have also reported that both the encircled energy curves published in the instrument handbook and Tiny Tim models (Krist et al., 2011) do not accurately reproduce the observed wings of the PSF (M. Hayes; A. Bostroem, priv. comm.).

In order to rectify these issues, the ACS Instrument Team decided that a calibration program should be carried out to observe a bright UV source from which aperture corrections could be established.

Observations

To carry out this study, an isolated source is required that is bright enough to achieve reasonable signal to noise and is also safe to observe with the SBC. Due to safety issues, the SBC is prohibited from observing targets brighter than 50 counts/second/pixel (Avila et al., 2016). The currently available calibration data consists of multi-epoch observations of horizontal branch stars in the globular cluster NGC6681. Unfortunately, this data cannot be used for this study because the stars are too crowded, and therefore, contaminate each other's PSF wings. A search of the Sloan Digital Sky Survey DR13 (Albareti et al., 2016) turned up the white dwarf SDSS J132811.45+463050.8, an object previously observed with GALEX. Table 1 shows some relevant information about this object from the GALEX archive[1].

Three external orbits were obtained to observe the target under the CAL/ACS Cycle 23 Program 14408 (PI: Avila). The target was observed using one orbit per filter, employing a 2-pt dither to eliminate bad pixels in post-processing. Each exposure was 1439s long, for a total of 2878s per filter.

GALEX ID	**RA**	**Dec**	$\mathbf{FUV_{ABmag}}$	$\mathbf{T_{eff}}$ [K]
J132811.4+463050	13:28:11.4	+46:30:50.9	17.55	13390

Table 1: Information retrieved from the GALEX archive hosted by MAST.

Image processing

The SBC is a Multi-Anode Microchannel Array (MAMA), a photon-counting detector that is not affected by cosmic rays, read noise or dark current. This makes image processing easier than CCDs. The calibrated FLT images were combined using the `AstroDrizzle` task in the `DrizzlePac` software (Gonzaga et al., 2012). Steps 1 through 6 were turned off since they are not needed, essentially only masking out bad pixels and drizzling the images together. The drizzled images were produced with a plate scale of 0.03″/pix in order to keep the pixel sizes as close to native as possible (0.034×0.032 ″/pixel).

Tiny Tim Models

Model PSFs were created using the Tiny Tim software (Krist et al., 2011), attempting to mimic the observations as closely as possible. The model PSFs were produced using a blackbody spectrum with $T_{\rm eff} = 13390K$ (the temperature same as the white dwarf) and using the same location of the star as on the FLT image. The PSF images are 6.6″ in diameter because that is the maximum Tiny Tim can make for this camera (Krist & Hook, 2004). Images produced by Tiny Tim include detector distortion. To produce a distortion-free PSF, the images were copied into the FLT and drizzled using the same parameters used for the observations.

Photometry

Aperture photometry was performed on the drizzled images using the `photutils` software (Bradley et al., 2016). The position of the star in each image was determined by using the centroid method. The radial profiles were measured by taking the mean of annuli with 0.1″ width. Aperture photometry, with circular apertures from 0.1 to 5.5″, was performed to derive the encircled energy curves.

[1] `http://galex.stsci.edu`

With CCD images it is common to use the mode of the background as the sky value. With MAMA images this is not appropriate because there is little sky and it is quantized due to the photon-counting properties of the detector. Taking the mode gives a background of zero, although even a cursory inspection of the images will reveal this to be inaccurate. Instead, all the exposures should be stacked together without subtracting the sky in the individual images and mean of the background should then be measured on the combined image. No sky subtraction was necessary for the Tiny Tim models since they are produced with zero background.

Figure 2 shows the images of the observed and model PSFs. The observed images show an artifact $\sim 2''$ above and to the left of the star. These are optical ghosts, probably caused by internal reflections in the camera (Collins et al., 2007; ACS Instrument team, 2007). These ghosts contain approximately 1% of the total flux of the star.

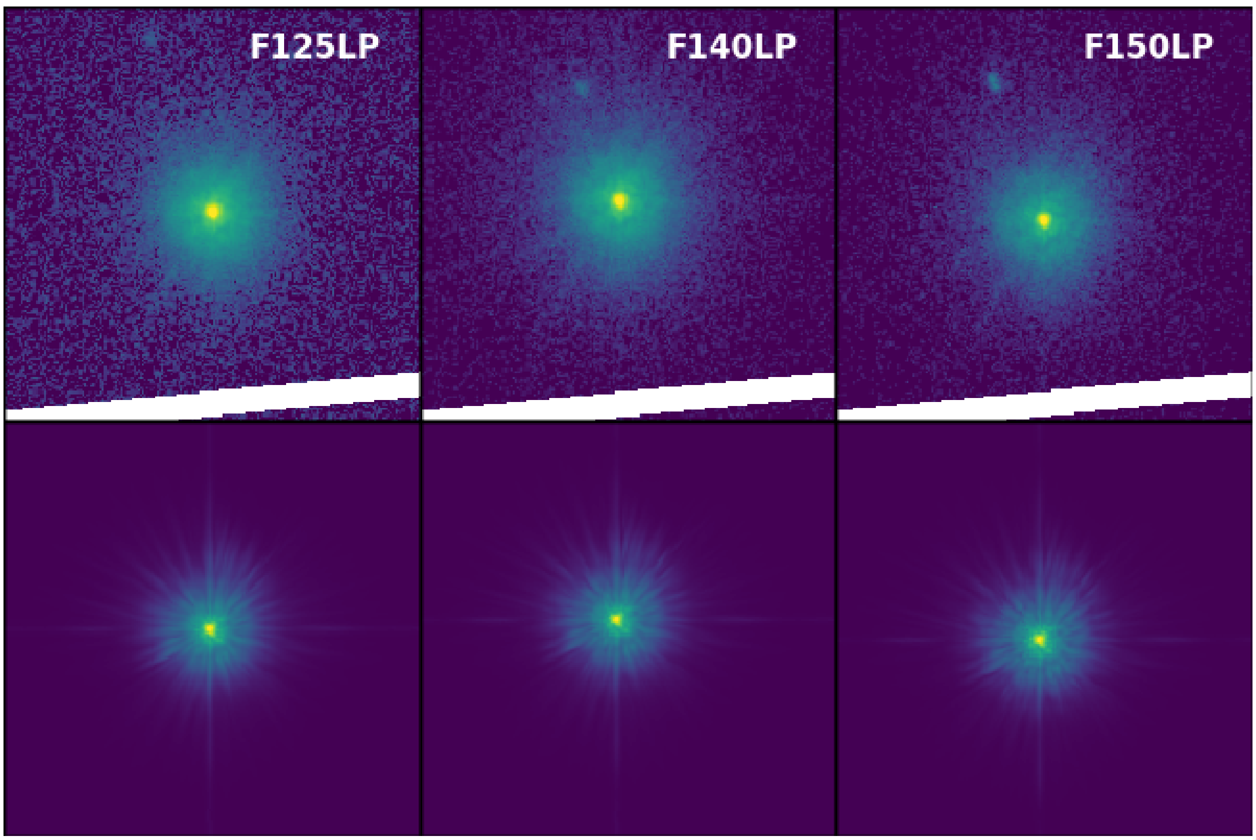

Figure 2: The images of the observed and model PSFs. The top row are the observed, and the bottom are the models. Each box is $6.0''$ on a side. The images are displayed with a log stretch where the minimum is approximately the sky, and the maximum is one quarter of the peak pixel.

The other large artifact visible in the observed images is the large white stripe running across the bottom of the image, about $2.5''$ away from the star. This stripe corresponds to the five dead rows on the MAMA detector. Because there is not information there, `AstroDrizzle` gives those pixels a value of `nan`. Those pixels contain some flux from the star that is not accounted for when deriving the encircled energy curves. To correct for this, we first estimate the amount of missing light in each annular aperture. This is done by taking the average of every annular aperture (masking the ghost where necessary), and multiplying that value by the number of bad pixels that lie within that annulus. The accumulated correction is then added to the circular apertures as they are expanded. Even though the total number of pixels affected by the bad rows increases as the circular apertures grow, the flux contribution from each additional bad pixel decreases. Within a 4″ circular aperture, bad pixels contain 0.13%, 0.10%, and 0.14% of the total flux in F125LP, F140LP, and F150LP respectively.

All the scripts used in this study will be published along with this report, so that others can replicate the analysis.

Results

Figure 3 shows the radial profile and encircled energy curves for the observations and the models. The radial profiles have been normalized to the value of the peak pixel. Because of the limited size of the Tiny Tim PSFs, the encircled energy curves are normalized to a 3″ aperture. As can be seen on the left side of Figure 3, the observed profile has broader wings than what is predicted by the model. Note that the optical ghosts show up in these radial profiles of the observed star as bumps between 2″ and 3″, depending on the filter. Tiny Tim does not account for these ghosts.

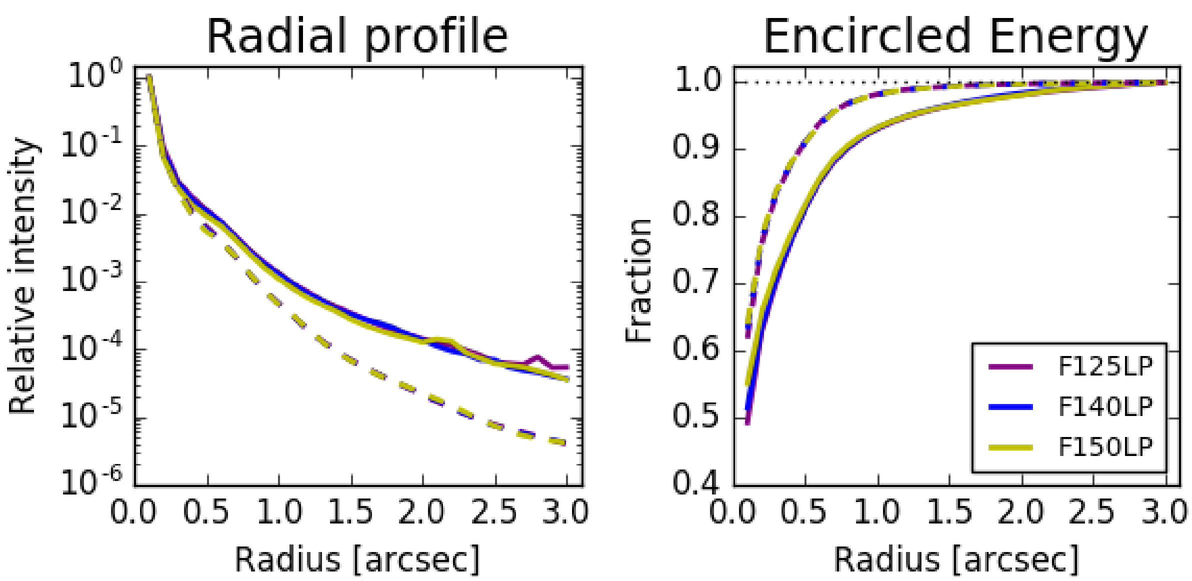

Figure 3: Comparison between observed (solid lines) and Tiny Tim (dashed lines) radial profiles and encircled energy curves. Tiny Tim models of the three filters are so close to each other that they overlap in this figure.

A common use for Tiny Tim models is to extract encircled energy curves. The right hand side of Figure 3 shows that, when using Tiny Tim, the aperture corrections could be underestimated by $\sim 9\%$ at 0.5″, a typical radius used for photometric measurements. This problem is exacerbated by the fact that Tiny Tim models go out to at most $\sim 3.3''$ in radius, while the absolute flux calibration was derived using a 4″ aperture. Considering this, it is advised that users not use Tiny Tim models to generate encircled energy curves or calculate aperture corrections for observations taken with the SBC.

Conclusion

Table 2 presents the aperture corrections derived from this work. The total flux is normalized using a 4″ circular aperture in order to maintain consistency with the method used to calculated the zeropoints, even though the PSF wings extend out beyond that aperture. Measurements show that there is $\sim 1\%$ more light out to 5.5″. Users should refer to this table for aperture corrections of point source photometry. Photometry can be conducted as before, but given these new corrections, SBC photometry will now be brighter.

These changes will be delivered to ReDCaT for use in `pysynphot` lookup tables and delivered to the telescope's Exposure Time Calculator.

These data cannot be used to re-calculate the zeropoints. That requires observations of spectrophotometric standards and, unfortunately, they are all too bright to observe with the SBC. That is a project that will be undertaken in future calibration programs.

Acknowledgements

Thanks to the following ACS team members for providing comments for this report: Jay Anderson, Andrea Bellini, Ralph Bohlin, David Borncamp, Norman Grogin, Pey-Lian Lim and Vera Platais. We would also like to thank Jennifer Mack for her comments. This research made use of Astropy, a community-developed core Python package for Astronomy (Astropy Collaboration et al., 2013). Plots for this report were produced using the Matplotlib python package (Hunter, 2007).

References

ACS Instrument team. 2007, Hubble Space Telescope ACS Anomalies, `http://www.stsci.edu/hst/acs/performance/anomalies/acs_sbc_opticalghosts.html`, accessed: 2014-09-16

Albareti, F. D., et al. 2016, The Thirteenth Data Release of the Sloan Digital Sky Survey: First Spectroscopic Data from the SDSS-IV Survey MApping Nearby Galaxies at Apache Point Observatory, `http://arxiv.org/abs/1608.02013`, arXiv:1608.02013

Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, AAP, 558, A33

Avila, R., et al. 2016, Advanced Camera for Surveys Instrument Handbook for Cycle 24 v. 15.0

Bohlin, R. C. 2016, AJ, 152, 60

Bradley, L., Sipocz, B., Robitaille, T., et al. 2016, astropy/photutils v0.2.2, doi:10.5281/zenodo.155353

Collins, K. A., Grady, C. A., Woodgate, B. E., & Williger, G. M. 2007, Detection of Optical Ghost in the HST ACS Solar Blind Channel Filter 122M, Tech. rep.

Gonzaga, S., Hack, W., Fruchter, A., Mack, J., & eds. 2012, "The DrizzlePac Handbook"

Hunter, J. D. 2007, Computing In Science & Engineering, 9, 90

Krist, J. E., & Hook, R. N. 2004, "The Tiny Tim User's Guide"

Krist, J. E., Hook, R. N., & Stoehr, F. 2011, in Proc. SPIE, Vol. 8127, Optical Modeling and Performance Predictions V, 81270J

Lim, P., Diaz, R., & Laidler, V. 2015, PySynphot User's Guide, `https://pysynphot.readthedocs.io/en/latest/`, accessed: 2014-09-21

Sirianni, M., de Marchi, G., Gilliland, R. L., et al. 2003, in HST Calibration Workshop : Hubble after the Installation of the ACS and the NICMOS Cooling System, ed. S. Arribas, A. Koekemoer, & B. Whitmore, 31

Sirianni, M., Jee, M. J., Benítez, N., et al. 2005, PASP, 117, 1049

Tran, H. D., Meurer, G. R., Ford, H. C., et al. 2003, in Proc. SPIE, Vol. 4854, Future EUV/UV and Visible Space Astrophysics Missions and Instrumentation., ed. J. C. Blades & O. H. W. Siegmund, 686–693

	Radius [arcsec]														
Filter	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	2.0	3.0	4.0	5.0	5.5
F125LP	0.489	0.624	0.696	0.755	0.804	0.844	0.873	0.894	0.909	0.922	0.972	0.991	1.000	1.007	1.010
F140LP	0.510	0.629	0.701	0.756	0.804	0.845	0.875	0.895	0.911	0.923	0.975	0.991	1.000	1.007	1.011
F150LP	0.546	0.651	0.715	0.765	0.809	0.848	0.877	0.898	0.912	0.923	0.971	0.990	1.000	1.008	1.013

Table 2: Updated encircled energy curves derived from this work. Measurements were normalized to $4''$ to coincide with how the zeropoints were derived (Sirianni et al., 2003).