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On-orbit Sensitivity of ACS

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Abstract. Ground measurements of all the components of the Advanced Camera for Surveys (ACS) allow one to predict the sensitivity of each instrument. Soon after the installation of ACS we tested the on-orbit sensitivity. We observed spectrophotometric standard stars with the three channels of ACS to calculate the observed-to-predicted count rates ratios. We performed a first order correction of the pre-flight quantum efficiency curve of the detectors to reflect the on-orbit sensitivity measurements. The new curves have been implemented in SYNPHOT which is used by the Exposure Time Calculator. We report the analysis performed for the first order corrections of the sensitivity of the three cameras and the progress in developing an improved sensitivity correction.

1. Introduction

It is important to determine the observed throughput of all three cameras of ACS to determine accurate photometric zero points, to determine the feasibility of and exposure times for science programs and finally to calculate transformations to and from other instruments photometric systems.

The STSDAS package SYNPHOT can calculate the predicted count rates from sensitivity curves for the telescope, ACS mirrors and windows, filters and detectors. Each camera of ACS consists of several components like mirrors, windows, filters and the detectors. Each system was carefully characterized and tested as part of the ground calibration of the instrument. The results in terms of reflectivity, transmittance or quantum efficiency have been used within SYNPHOT to estimate the exposure time for the first ACS observations during the Servicing Mission Orbital Verification (SMOV). However in some cases the pre-flight measurements could have been done with a fairly sparse wavelength resolution, therefore extrapolation, interpolation and sampling errors can be important. In addition, calibration instruments could have had systematic offsets. A reality check is therefore required for each instrument. With the data acquired in the first part of the SMOV, prelaunch estimates of count rates have been compared with observations to derive modification to the input sensitivity curves. These first observations have been used to derive rough corrections to the sensitivity curves. These correction have been implemented into SYNPHOT at the end of August 2002. Further observations obtained during the summer will permit a fine tuning of the corrections and a better estimate for exposure time prediction.

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2. Observations

The observed throughput has been determined using observations of flux standards through a variety of filters (Proposal ID 9029 and 9654, P.I. De Marchi). In particular the spectrophotometric standards GD 71 and GRW +70 5824 have been observed with the WFC and the HRC in April 2002 and July 2002, while for SBC observation of HS 2027+0651 and NGC 6681−STAR 1 have been executed in the same period of time. All the filters have been used for the observations of GD 71, all the broad band filters and the major narrow band filters for the observations of GRW+70. The full set of filters was used for the SBC observation in both epochs.

The star was placed at the center of the aperture and two images have been taken through each filter. The exposure times have been selected to reach, on average a signal to noise ratio of $\sim$350 in the central pixel for broad band filters.

The data acquired in April and July have been used to estimate the first order corrections which have been released at the end of August for all three cameras as new SYNPHOT tables. Subsequent observations of GRW +70 and NGC 6681 in August and September 2002 have been used to improve such corrections and they will be available within the end of 2002.

3. Data Reduction and Analysis

All the images have been processed using the STScI standard ACS pipeline CALACS and the geometric distortion has been corrected running PyDrizzle. Even if a first assessment of the sensitivity of the camera was done just after the data collection, the final reduction was repeated after the L_flats were made available (see Mack et al., this volume). Aperture photometry has been performed in the reduced data, the total counts in a $2.5''$ radius aperture have been corrected by background contamination using a sky level measured in an annulus between $3.5''$ and $5''$. Predicted count rates have been estimated using the pre-launch response curves and the spectra of the standard stars. The spectra give photon rates as a function of wavelength, which are multiplied by the response curves and are integrated over wavelength.

3.1. WFC

For the first order correction the data of April and July 2002 have been used. The application of the L_flats greatly reduced the observed discrepancies between WFC1 and WFC2 response which should be the same after the flat field normalization (Bohlin et al. 2002).

The observed count rates relative to predicted rates are shown in Figure 1, where each bar represents the average result for the two spectrophotometric standards. The figure shows the presence of systematic errors as a function of wavelength. Ground measurement underestimated the performance of the camera from a minimum of 2% in the red to a maximum of 22% in the blue. The results of WFC1 and WFC2 agree within a couple of percent. Since there is a fairly smooth variation with wavelength we believe that the discrepancy is mostly due to an incorrect measurement of the CCD quantum efficiency or mirrors and windows throughput more than to errors in the filter transmission curves.

In order to calculate a correction factor to apply to the sensitivity curve we assign to each ratio in Figure 1 the pivot wavelength of each filter. With such transformation (Figure 2) we can now calculate a correction curve to apply to the predicted response of the camera. We averaged the results obtained with the two standard stars in the two CCDs and fitted a spline function though the points. We needed to contain the fit at the two edges of the spectral range. In the blue side the trend of the two points at $\lambda < 5000$ Å suggested a constant value of 1.23 for $\lambda < 4000$ Å. In the red side we extrapolate the trend of the three measurements at $\lambda > 7500$ Å and set the ratio at 11000 Å to 0.88. Figure 2 shows the derived correction curve for the response.

We have attempted to make the derived response curve smooth; however, in some wavelength regions, there could be a few percent error in the derived curve. We then used the derived curve to correct the pre-flight Quantum Efficiency (QE) curve of the detector. The new CCD QE curve

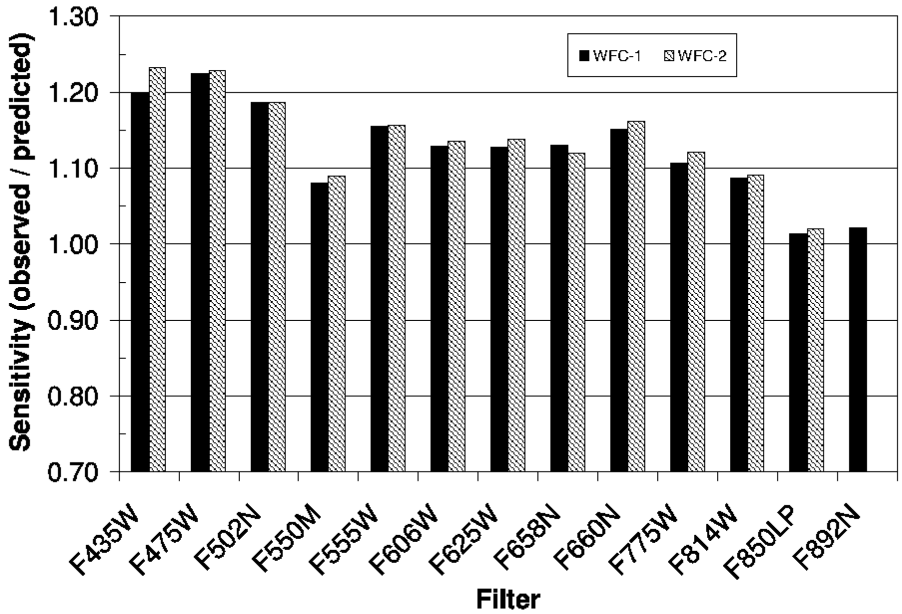

Figure 1. Ratio of observed-to-predicted count rates using our original estimates of response curves. Each bar represents the average results for the two standard stars observed in June and July.

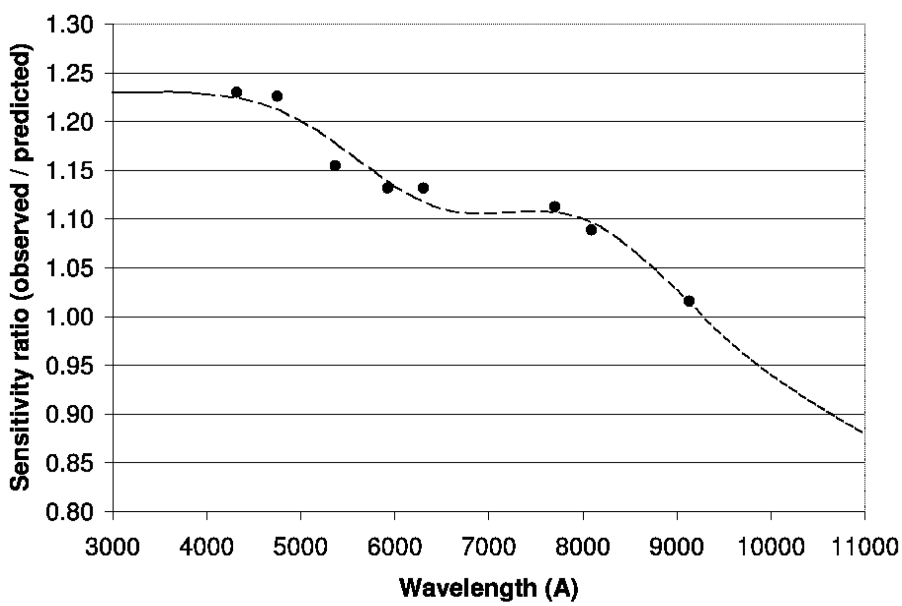

Figure 2. Ratio of observed-to-predicted count rates using our original estimates of the WFC response curves. Circles show the average ratio for the two standard stars and for the two CCDs. The dashed line shows the derived correction curve for the response.

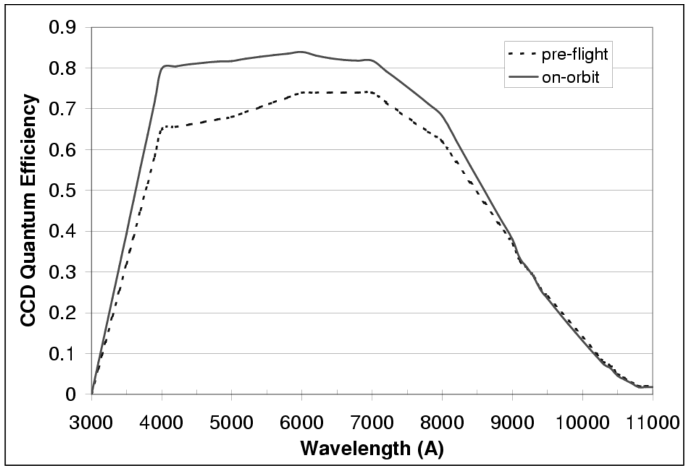

Figure 3. Quantum efficiency curve of the WFC CCDs. Dotted line shows the pre-flight measurement. Solid line shows the on-orbit curve after the sensitivity correction.

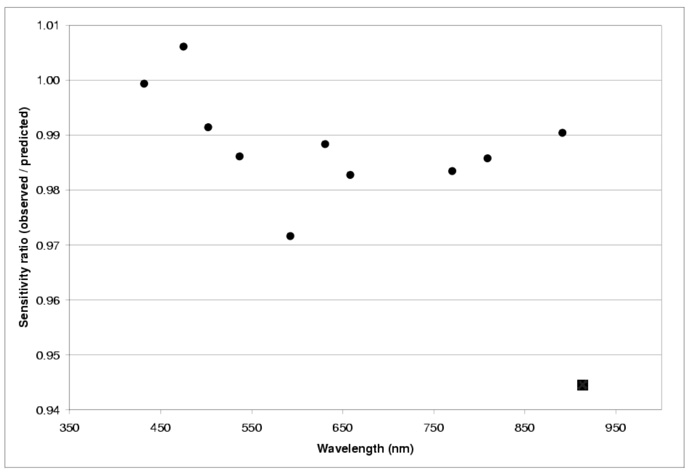

Figure 4. Ratio of observed to predicted count rates using the new WFC detector QE curve

has been implemented in SYNPHOT since late August. The current version of the exposure time calculator (ETC) will use this new curve. The overall accuracy is now better than 5% in all filters.

Subsequent observations of the star GRW+70 in August and September 2002 gave us the opportunity to test the time stability of the sensitivity and to improve the statistics on our measurements. Figure 4 shows the ratio of observed to predicted count rates after application of the correction curve for the response. The residual errors are in general less than 1 or 2%. The two most deviant filters are F606W which shows a residual of almost 3% and the filter F850LP marked as a box in Figure 4. The reason why the filter F850LP shows a residual of almost 6% is that the count rate predictions for the first order correction made in August 2002 where calculated using spectra of the standard stars that did not extend to 11000 Å, the sensitivity limit of the camera, but they were instead truncated at approximatively 10,500 Å. For the new corrections, that will be implemented in SYNPHOT by the end of 2002, a theoretical model of the spectra have been used to cover the missing spectral range.

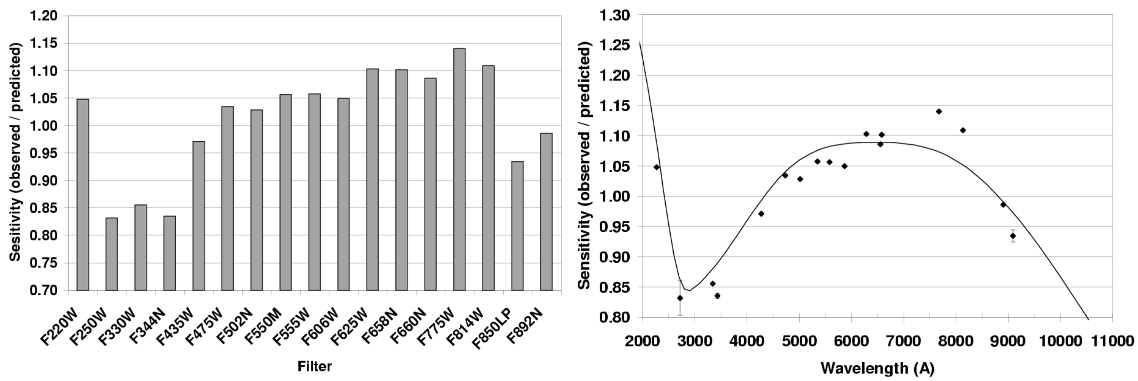

Figure 5. *Left*: ratio of observed-to-predicted count rates using the pre-flight estimates of the response curves for HRC. *Right*: Circle show the average ratio for the two standard stars observed in June and July. The solid line shows the derived correction curve for the response.

3.2. HRC

As for the WFC, only the data collected in April and July were used to calculate the first order correction for the sensitivity curve. Figure 5 shows the observed count rates relative to the predicted rates using the pre-flight response curves. The panel in the left shows the response in each filter, while the right panel shows the same results as a function of the pivot wavelength of the filters. In general the on-orbit sensitivity is higher than expected; between 5 and 14% in the range $\lambda\lambda$ 4500–8500 Å. There is however a well defined dip between 2500 and 3500 Å where the sensitivity is $\sim$15% lower than expected. The solid line in the right panel of the figure shows the derived correction curve for the response. The fitted curve nicely reproduce the overall variations in sensitivity, but residual of 5–8% are still possible in some filters.

As in the previous case we decided to modify the CCD response to reflect the observed sensitivity. The panel in the left in Figure 6 shows the pre-flight detector QE curve and the on-orbit curve after the sensitivity correction. This curve was implemented in SYNPHOT at the end of August 2002.

We repeated the observation of GRW+70 in August and September 2002 with the same instrument configuration. The analysis of the new data shows that the in-flight sensitivity is not affected by variation with time. We used the new observations also to re-test the sensitivity curve with the goal to reduce the residuals and produce a better correction. The right panel of Figure 6 shows the residuals using the average observed counts of GRW+70 in the three repeated observations. The residuals are usually less than 3%. The biggest discrepancy is the filter F850LP for the problem with the spectra used in the initial calibration as explained in the previous paragraph.

New curves will take into account the modification to the spectra of the standard stars at $\lambda >$ 10500 Å and the derived correction will be calculated iteratively to reduce the residuals. As for WFC the new sensitivity curve is expected to be available by the end of year 2002.

3.3. SBC

Observations of HS 2027+0651 and the cluster NGC 6681 have been used to check the on-orbit sensitivity of the SBC. At the moment of writing there are no L_FLAT available for the SBC. The corrections reported in this paper and implemented in SYNPHOT at the end of August are only approximated and might be different from the final version by several percent. Figure 7 shows the observed-to-predicted count rates ratio and the correction for the MAMA quantum efficiency curve.

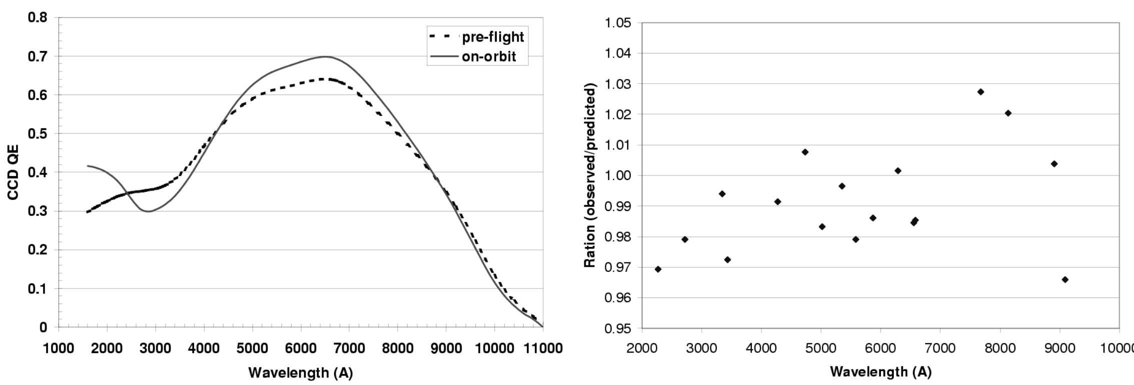

Figure 6. *Left*: pre-flight and corrected quantum efficiency curve for the HRC CCD. *Right*: Ratio of observed to predicted count rates using the new detector QE curve.

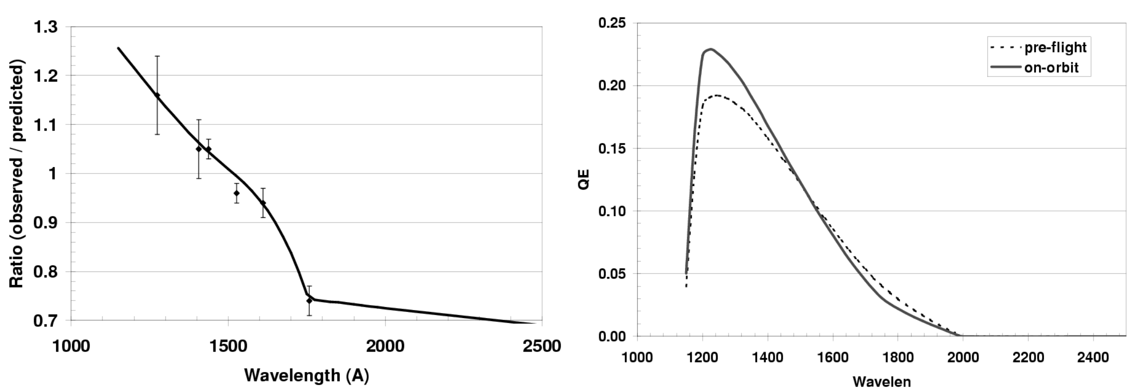

Figure 7. *Left*: Preliminary comparison between observed and predicted count rates using the pre-flight response curve for the SBC. Solid line shows the derived correction. *Right*: Pre-flight and corrected quantum efficiency for the SBC MAMA.

4. Conclusion

We observed spectrophotometric standard stars with the three cameras of ACS to measure the on-orbit sensitivity. The response of the WFC is higher than expected from ground measurement; from a few percent in the red up to $\sim 20\%$ in the blue. The HRC sensibility is higher than expected in the visual and red but it shows an unpredicted dip in the blue. Finally, preliminary analysis on SBC data shows that the on-orbit sensitivity could be higher in the far UV and slightly lower in the near UV with respect to pre-flight estimations.

Corrections of the sensitivity have been applied to the detector quantum efficiency curves. The first corrections, implemented in SYNPHOT at the end of August 2002, reduce the observed-to-predicted discrepancy to less than 5%. Follow up observations of the same standard star in August and September are being used to improve the sensitivity corrections.

Repeated observation the spectrophotometric standards gave us also the opportunity to calculate the on-orbit encircled energy profile on most of the ACS filters. Since all the stars are isolated we were able to perform aperture photometry with aperture radii from 0 to 4 arcsec. The sky level was determined in the external annulus between 5 and 6 arcsec. The result will be used to update the prediction of the ETC and to provide users an estimate of the aperture correction.

Once the final sensitivity correction are available, synthetic zero points will be computed for all filters and transformations to and from other instruments photometric systems will be also calculated (Sirianni et al. 2003).

References

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