



Instrument Science Report WFC3 2012-02

WFC3/UVIS Crosstalk and Crosstalk Correction

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February 27, 2012

ABSTRACT

We report the results of an analysis of crosstalk in on-orbit data taken with the WFC3/UVIS detector and provide a procedure to correct images for crosstalk. The WFC3/UVIS detector consists of two 2kx4k CCDs. Each CCD is read out simultaneously through two amplifiers, for a total of four amplifiers for the detector. As found during ground tests prior to launch (Baggett, 2009), electronic crosstalk between the amplifiers during readout induces faint, negative, mirror-symmetric ghost images in the other quadrant of the same CCD. Our analysis confirms that crosstalk on-orbit behaves as it did in pre-flight tests on the ground: the crosstalk ghost depends linearly on the strength of the offending signal and there is no crosstalk between the two CCDs. Based on a large set of on-orbit internal dark frames, we measure levels of -2.1×10^{-4} and -2.3×10^{-4} for crosstalk in quadrants B and D, respectively, and -0.6×10^{-4} and -0.8×10^{-4} for crosstalk in quadrants A and C, respectively. This means that for signal levels at full-well, the resulting crosstalk ghost values can reach about $-15e^-/\text{pix}$ in quadrants B and D, and about $-5e^-/\text{pix}$ in quadrants A and C. Due to its mirror-symmetric behavior, crosstalk features will not co-add when combining dithered data acquired with sufficiently large offsets. However, for observers working with small dither-step data or with non-dithered data, we have developed a crosstalk correction procedure. We show that the algorithm successfully removes crosstalk features, restoring the pixels to a mean which is well within 1σ of the mean of surrounding pixels. The standalone code, currently written in IDL, is available for use and can be downloaded from the WFC3 WWW site.

Introduction

The WFC3/UVIS detector has four amplifiers, through which the four quadrants of the detector are read out separately and simultaneously. As the quadrants are read out, electronic crosstalk between the amplifiers is induced and as a result, an imaged source in one quadrant appears as a faint, mirror-symmetric ghost image in the adjacent quadrant. In WFC3/UVIS, the ghost image is negative, so bright features in the “offending” quadrant show up as dark depressions in the “victim” quadrants. Figure 1 shows a full-frame WFC3 UVIS image with quadrants labeled; A and B are on chip1 while C and D are on chip 2. The arrows highlight crosstalk features in quadrant D due to saturated sources in quadrant C.

Magnified views of crosstalk “ghosts” due to a strong offending signal of bleeding columns of saturated stars in Figure 1 are shown in Figures 2 and 3.

Prior to deployment of WFC3 on board HST during Servicing Mission 4, crosstalk in the WFC3/UVIS flight detector was studied in detail using thermal-vacuum data taken with the integrated instrument on the ground (Baggett 2009). The main findings included the following: Bright sources in a CCD quadrant generated a low-level mirror negative image of those sources in the quadrant adjoining the target quadrant on the same chip; crosstalk was linear, negative, and appeared at the level of $\sim 10^{-4}$ to 10^{-5} in nominal gain ($1.5 \text{ e}^-/\text{DN}$), full-frame 4-amp readouts; the higher levels of crosstalk occurred for targets imaged in quadrants A or C and the lower level of crosstalk for targets placed in quadrants B or D.

In this paper we quantify crosstalk in post-SM4 WFC3/UVIS images and compare the results with those obtained from pre-flight data. Crosstalk features may be removed when combining dithered data provided the dither offsets were large enough to prevent the features from overlapping: with each shift in pointing, the crosstalk features shift in the direction opposite to the target shift. For observers working with small-offset dithered frames or with non-dithered frames containing saturated sources, we develop a standalone procedure to purge crosstalk ghosts from WFC3/UVIS images and demonstrate the effectiveness of the correction in a sample of images exhibiting prominent crosstalk ghosts.

Quantifying crosstalk in WFC3/UVIS images

We quantify crosstalk along the lines similar to those employed by Suchkov et al. 2010 for crosstalk characterization of the WFC detector of the Advanced Camera for Surveys (ACS), using on-orbit dark frames. In dark frames, the offending signals responsible for crosstalk ghosts are produced by cosmic rays and hot pixels. In external images, the targets in the detector’s field of view provide additional source of offending signal. However, external images in general are less useful for the purposes of crosstalk quantification because it is difficult or even impossible to decouple brightness variations due to crosstalk from that of a target overlapping the crosstalk. In dark frames, the overwhelming majority of pixels represent just a fairly smooth, well-

quantified background generated by dark current. As a result, it is relatively easy to isolate and measure crosstalk ghost images of cosmic ray hits and hot pixels against that background and use them for crosstalk quantification. We implement this idea as follows.

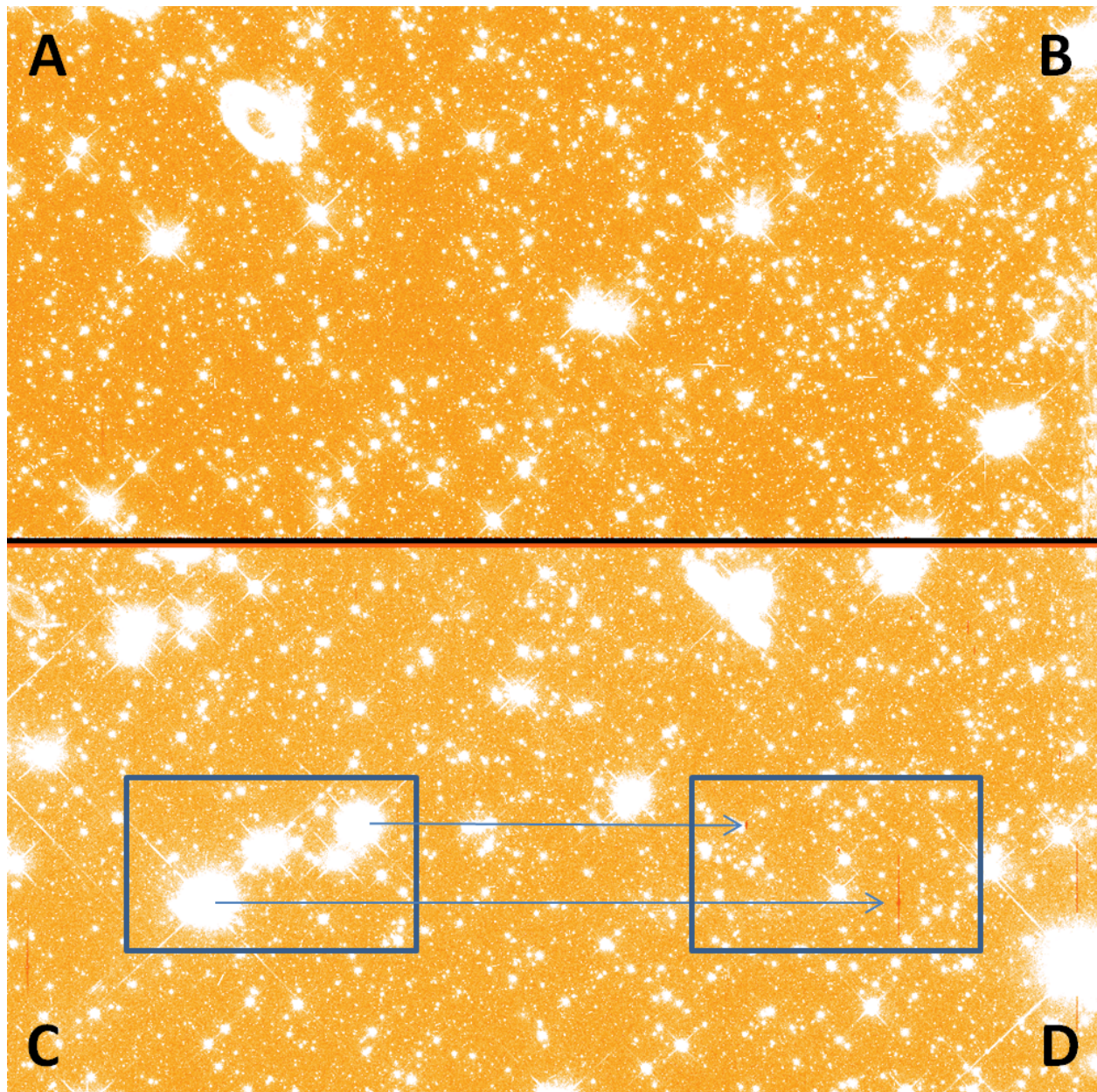


Figure 1. A full-frame 4kx4k WFC3/UVIS image of stars in the field of globular cluster 47 Tuc (program ID 11452, frame iaby01leq), with a hard stretch to highlight the crosstalk. The four readout quadrants are labeled. The rectangular subsection in quadrant C contains several saturated stars; the corresponding mirrored subsection is marked with a rectangle in quadrant D. Two of the crosstalk features in D arising from the saturated stars in C are indicated with the arrows.

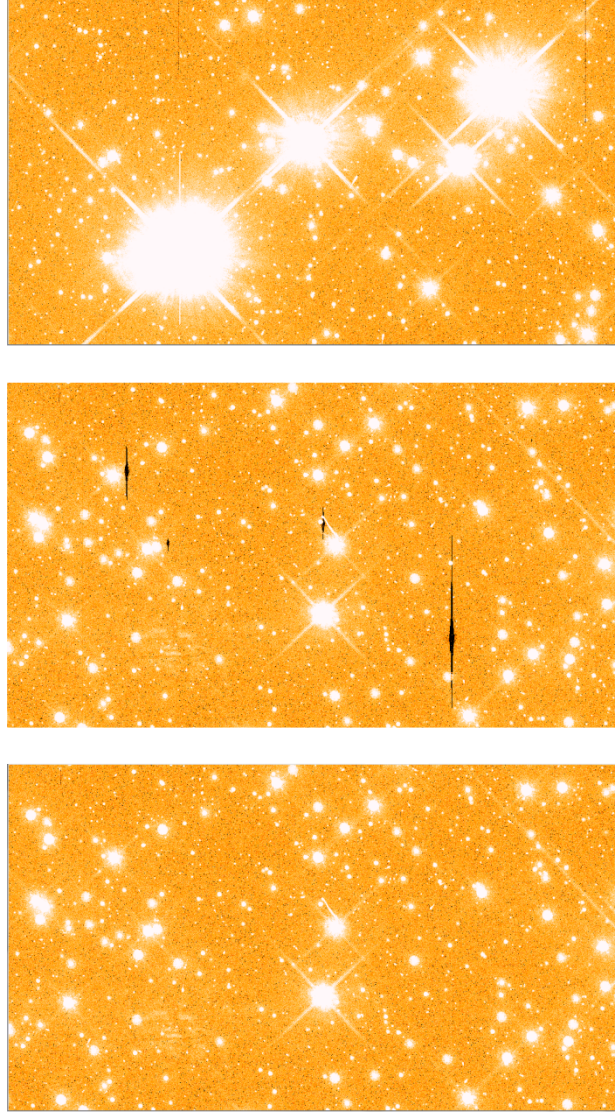


Figure 2. Close-up of the WFC3/UVIS image subsections ($\sim 600 \times \sim 1000$ pix) marked in Figure 1. The bleeding columns of the four saturated bright stars in quadrant C (*top panel*) induce mirror-symmetric crosstalk ghosts in the opposite quadrant D (*middle panel*). The *bottom panel* is the same image as in the middle panel but with crosstalk corrections applied using the algorithm presented in this report.

In each detector quadrant, we first isolate the background, defined as an area with pixels below a pre-set value selected using the quadrant's pixel distribution. Frames suitable for crosstalk characterization have pixels that follow a quasi-Gaussian distribution peaked near the mean of the distribution. Based on the pixel histogram, we set a lower signal limit for pixels to be considered offending sources and then compute the mean and standard deviation of all pixels

below that limit. The pixels within $\pm 2 \sigma$ of the mean are then used to compute the mean background within each quadrant. Next, we identify in all quadrants the offending pixels within a specified signal range and map them onto the backgrounds of the victim quadrants. Finally, we compute the mean pixel values in the mapped area of each victim quadrant and calculate the crosstalk ghost as the difference between the victim quadrant's mean background and the mean signal in the mapped area.

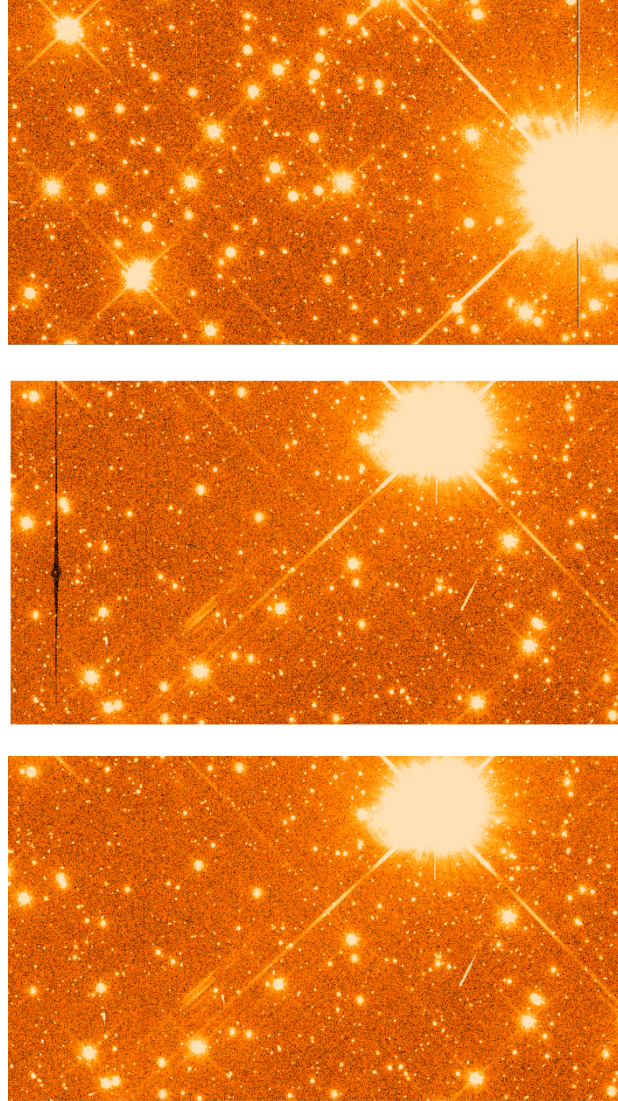


Figure 3. Same set of plots as in Figure 2 except that the crosstalk seen near the left edge in the middle panel is at the left edge of quadrant C and the offending bleeding columns from a bright star are at the mirror-symmetric position in quadrant D, at the right edge of the full-frame image. The image corrected for crosstalk is in the bottom panel.

The code that implements the algorithm described above was applied to compute crosstalk dependence on offending signal in a set of ~ 900 WFC3/UVIS dark frames. The average of all the frames is shown in Figure 4. In each panel in Figure 4, the label $X \rightarrow Y$ refers to the offender $\rightarrow$ victim quadrant pair for that panel. For example, the upper left panel displays crosstalk values generated in quadrant B by offending pixels in quadrant A.

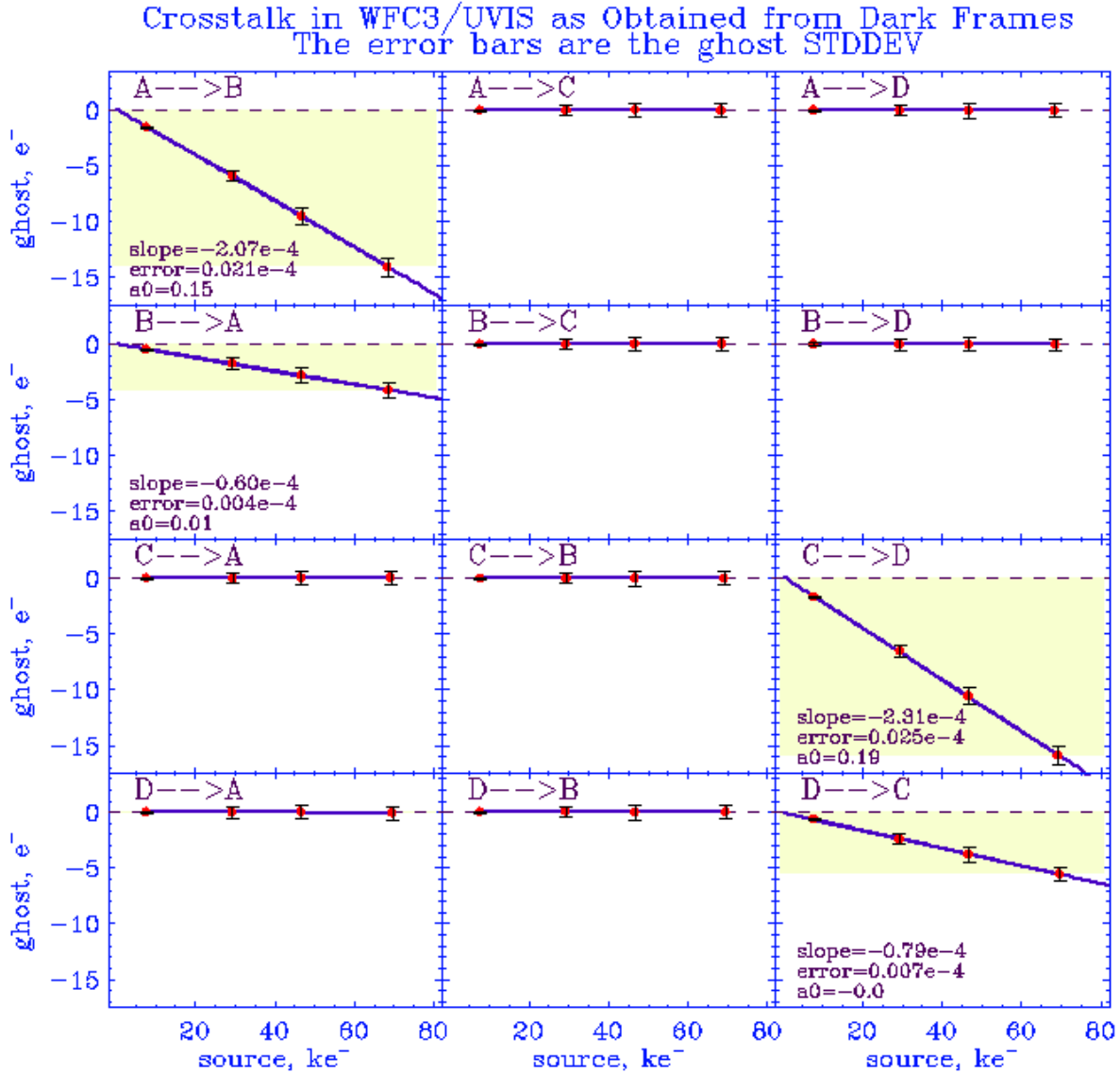


Figure 4. Crosstalk dependence on the strength of offending signal and quadrant pairing as obtained from a set of ~ 900 dark frames. The label $X \rightarrow Y$ refers to the offender and victim quadrant, respectively. Crosstalk induced by sources in the left quadrants (i.e., A and C) is ≈ 3 times stronger than that induced by sources in the right quadrants (B and D), reaching ≈ 15 e^- for source signals near the saturation level. There is no crosstalk between the upper and lower chips.

As seen in Figure 4, in WFC3/UVIS, there is noticeable crosstalk between the quadrants on the same chip and it depends linearly on offending signal. The parameters of that linear relationship are given in Table 1. There is no measurable crosstalk between the quadrants of different chips. Another notable detail is that the magnitude of the crosstalk signal occurring in the left quadrants, i.e., A and C, is about a third of that in the right quadrants, B and D. These results are in good agreement with those obtained in the pre-flight crosstalk study (Baggett 2009), implying that, with regard to crosstalk, there were no significant changes in the WFC/UVIS detector electronics since the pre-flight crosstalk data were obtained.

Correcting WFC3/UVIS images for crosstalk

Given the linearity of crosstalk dependence on offending signal, it is rather straightforward to develop a robust algorithm for crosstalk correction. The effect of a procedure based on code implementing such an algorithm on an example image is demonstrated in Figure 2 and Figure 3. The bottom panels in these Figures show quadrants D and C, respectively, corrected for crosstalk using the correction parameters from Table 1. The crosstalk ghosts seen in the original images as black vertical streaks (middle panels in those Figures), which are due to the bleeding columns of bright saturated stars in the offending quadrants C and D, totally disappear in the corrected images. Additional images illustrating the results of the correction algorithm as applied to other amps and target fields are shown in the Appendix. A more quantitative illustration of the correction effect for the images in Figures 2 and 3 is given in Figures 5 and 6. The plots demonstrate that the proposed procedure provides nearly perfect correction for crosstalk. Furthermore, as shown in Table 2, pixel statistics measured on corrected images show that the average within the cleaned crosstalk areas fall within 1σ of the average of the surrounding (non-crosstalk) areas.

Table 1. Parameters of linear regression derived from dark frames for crosstalk dependence on source signal

	$A \rightarrow B$	$B \rightarrow A$	$C \rightarrow D$	$D \rightarrow C$
slope, 10^{-4}	-2.075	-0.605	-2.318	-0.797
intercept	0.16	0.02	0.19	-0.04

Table 2. Pixel statistics within crosstalk pixels and in neighboring (background) pixels, before and after correction for crosstalk.

Image section	Npix	Mean		Standard deviation		Min		Max	
		Before	after	Before	after	Before	after	before	after
crosstalk (ibewekahq)	439	32.62	39.49	7.508	7.501	14.77	21.83	52.04	59.1
background1	439	39.31	39.36	7.402	7.401	17.95	18.	61.4	61.52
background2	439	39.53	39.61	7.323	7.324	18.92	18.99	60.7	60.8
background3	441	39.38	39.44	7.292	7.292	20.22	20.28	60.08	60.13
background4	438	39.04	39.11	6.613	6.612	23.02	23.09	57.82	57.9
crosstalk (ibl71nduq)	433	28.83	40.89	8.529	6.78	3.261	23.32	53.13	61.75
background1	439	40.67	40.64	7.449	7.448	22.21	22.15	62.81	62.84
background2	432	41.36	41.4	6.696	6.689	22.97	23.07	59.89	59.88
background3	439	40.71	40.66	6.98	6.982	21.46	21.47	58.29	58.19
background4	438	41.	40.86	7.06	7.06	22.68	22.54	61.69	61.56
crosstalk (ib1f43p7q)	594	40.89	40.74	7.962	7.962	18.28	18.13	72.51	72.36
background1	582	45.26	45.12	9.406	9.405	21.51	21.36	77.16	77.01
background2	598	33.79	33.64	7.339	7.339	14.85	14.69	55.76	55.61
background3	601	28.62	28.47	6.617	6.617	11.48	11.33	48.06	47.91
background4	600	39.66	39.51	7.23	7.23	19.05	18.9	59.5	59.36

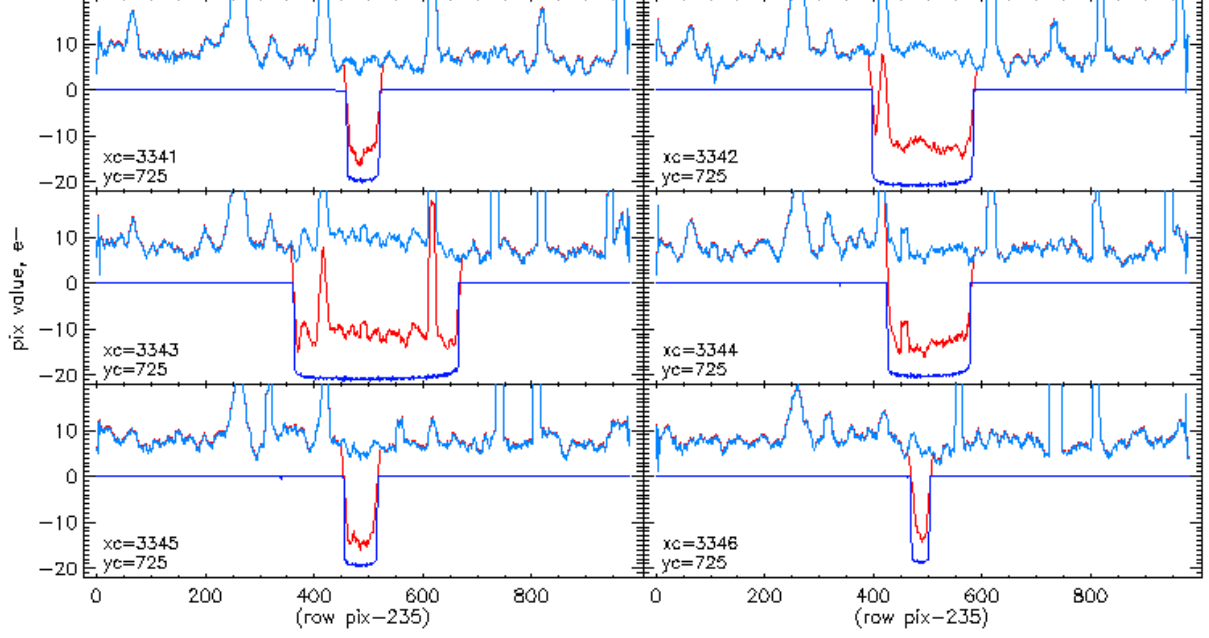


Figure 5. Pixel distribution of columns around the most prominent ghost in Figure 2 that is centered at $xc=3341, yc=725$. The red and light blue lines are for the original and corrected images, respectively, while the dark blue line is the difference between the original and corrected pixel values. Saturated pixels in quadrant C induce crosstalk of up to $20 - 21 e^-$ in quadrant D, consistent with the result shown in Figure . Note that the full-well has been exceeded in this strongly-saturated stellar image (see Gilliland et al., 2010, for maps of full-well depths).

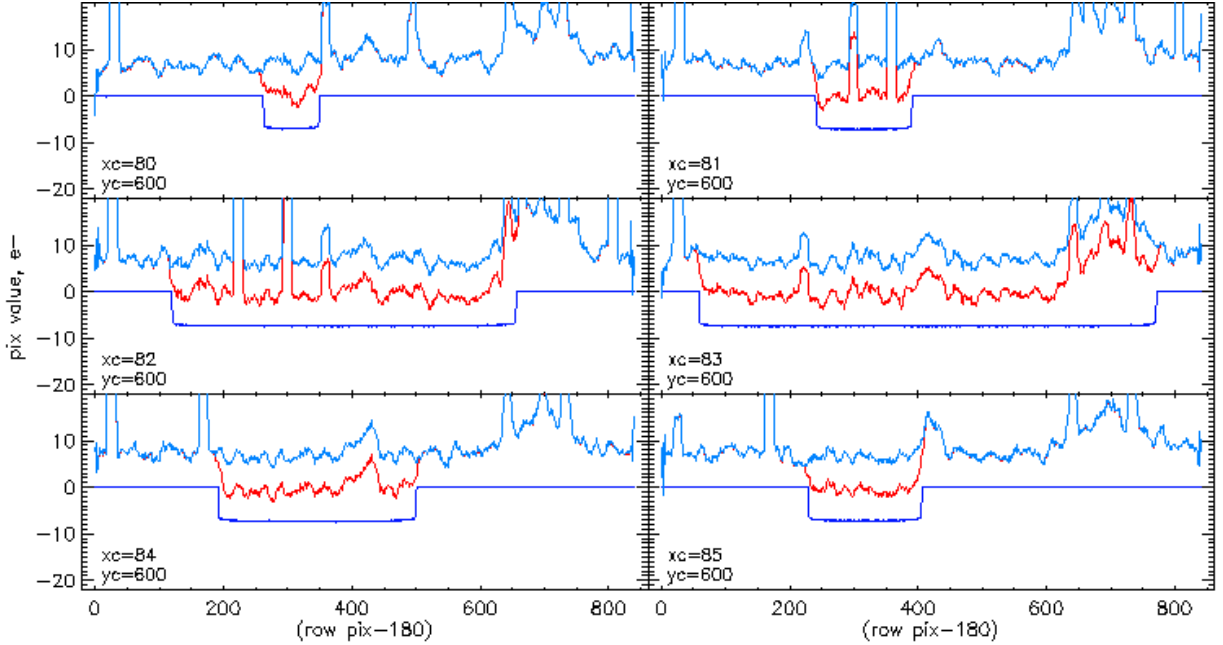


Figure 6. Same as in Figure 5 but for the ghost shown in Figure 3. Crosstalk induced in quadrant C by saturated pixels in quadrant D is ≈ 3 times weaker than that in Figure 5.

Obtaining and running the software

The crosstalk correction algorithm has been developed as an IDL procedure, intended for use on the calibrated (flt) file; the program is available for use as a standalone routine. The code, input parameter file, an example WFC3/UVIS image and the resulting corrected image, as well as a README file can be downloaded from the WFC3 WWW site.

The program `crosstalk_correct_wfc3.pro` performs the correction itself. The code was written assuming that the crosstalk depends linearly on the offending signal and utilizes the linear regression coefficients determined from internal dark frames as described earlier in this report. These coefficients are stored in the input parameter file “allframes_rgr_st.sav”; this file must be present in the working directory when using the correction program. Note that while the correction has been shown to work quite well in a variety of imaging scenarios, it can be less efficient when the image has a very high, non-uniform background across field, such as that due to PSF wings in very crowded stellar fields. Observers using the code will want to verify that the correction is being performed correctly for their specific images. The corrected image is written into the working directory as a fits file with the same name as the original except the first character is changed to ‘x’.

For example, to remove crosstalk from the image `iaby01leq` (shown in Figures 1-3), start IDL and in the working directory containing the program, the .sav file, and the image, type

```
crosstalk_correct_wfc3,'iaby01leq_flt.fits'
```

The resulting crosstalk-cleaned image, `xaby01leq_flt.fits`, will be generated and placed in the working directory. Questions or concerns may be sent to help@stsci.edu.

Conclusions

- Bright targets in WFC3/UVIS frames are mirror-imaged as negative ghosts in the quadrant adjacent to the target quadrant on the same CCD chip. The ghosts are due to electronic crosstalk between the detector amplifiers. The crosstalk ghost values due to signals at full-well reach up to $-5\text{ e}^-/\text{pix}$ (quadrants A and C) and $-15\text{ e}^-/\text{pix}$ (quadrants B and D).
- Confirming the pre-flight crosstalk study results, crosstalk on-orbit is induced only between the quadrants on the same CCD, and it depends linearly on offending signal. There is no crosstalk between the quadrants of different CCDs.
- The proposed correction algorithm assuming crosstalk linearity effectively removes crosstalk ghosts from WFC3/UVIS images to within 1σ of the level of the surrounding pixels.
- While combining dithered images may automatically remove crosstalk features (due to their mirror-symmetry, they shift in a direction opposite to the target shift), crosstalk features may adversely impact the science by increasing the noise in the coadded frame. In addition, some dithered data may have relatively small offsets which result in crosstalk features overlapping and thus co-adding into the final frame.
- For observers wishing to remove crosstalk features from their data, the correction algorithm is available for use and may be downloaded from the WFC3 WWW site.

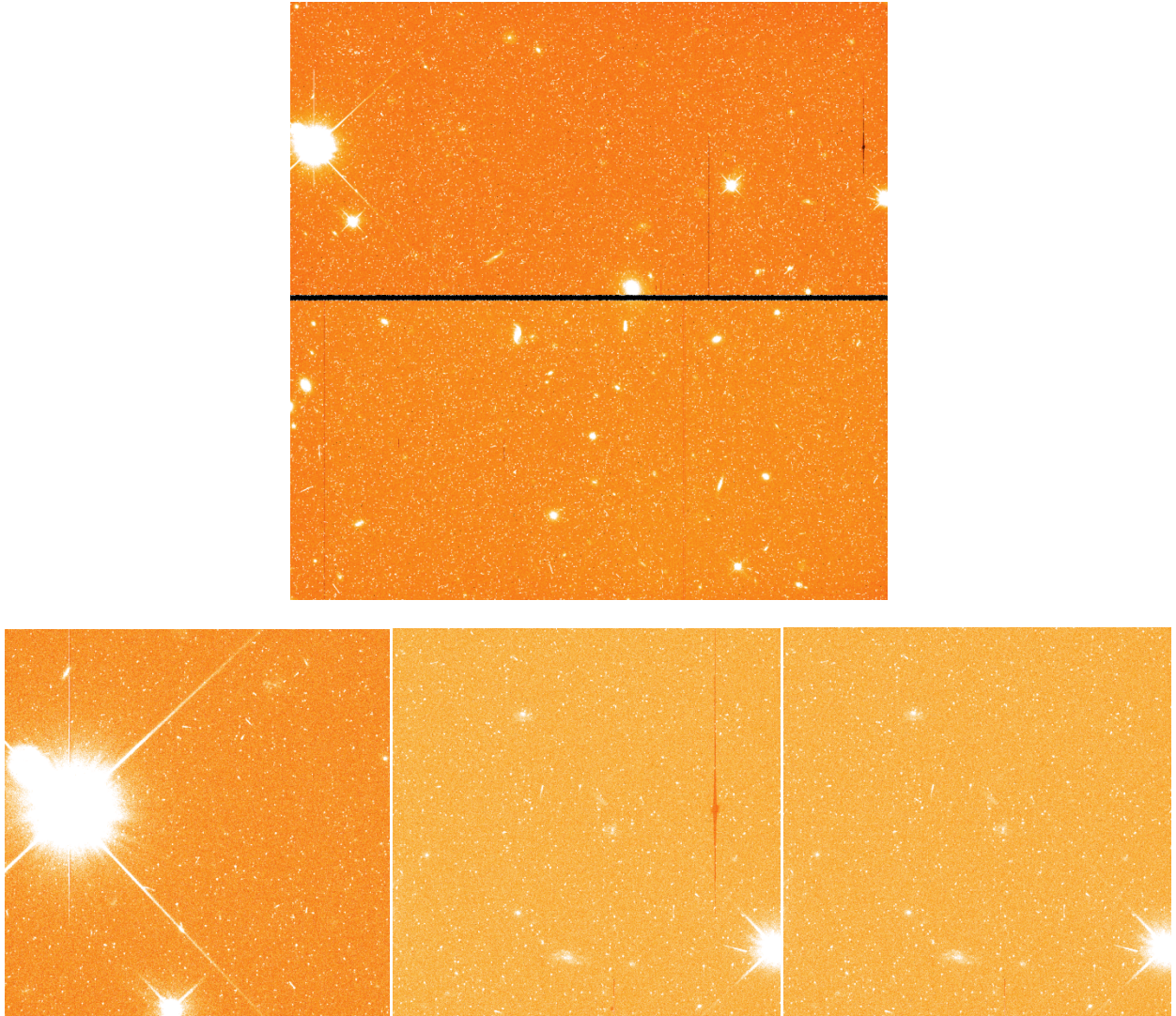
Acknowledgements

We thank Linda Dressel for reviewing the manuscript and providing helpful comments.

References

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- Gilliland, R., Rajan, A., and Deustua, S., 2010, STScI Instrument Science Report, WFC3-ISR 2010-10
- Suchkov, A., Grogin, N., Sirianni, M., Cheng, E., Waczynski, A., & Loose, M. 2010, STScI Instrument Science Report, ACS-ISR 2010-02

Appendix



| Figure 7. At top is the full-frame four-amp image (ibl17nduq, proposal 12286, parallel field); at bottom are 1000x1000 pixel close-ups of the saturated source (*left panel*), mirror image crosstalk (*middle panel*), and crosstalk after correction (*right panel*). A hard color table stretch is used to highlight the crosstalk features.

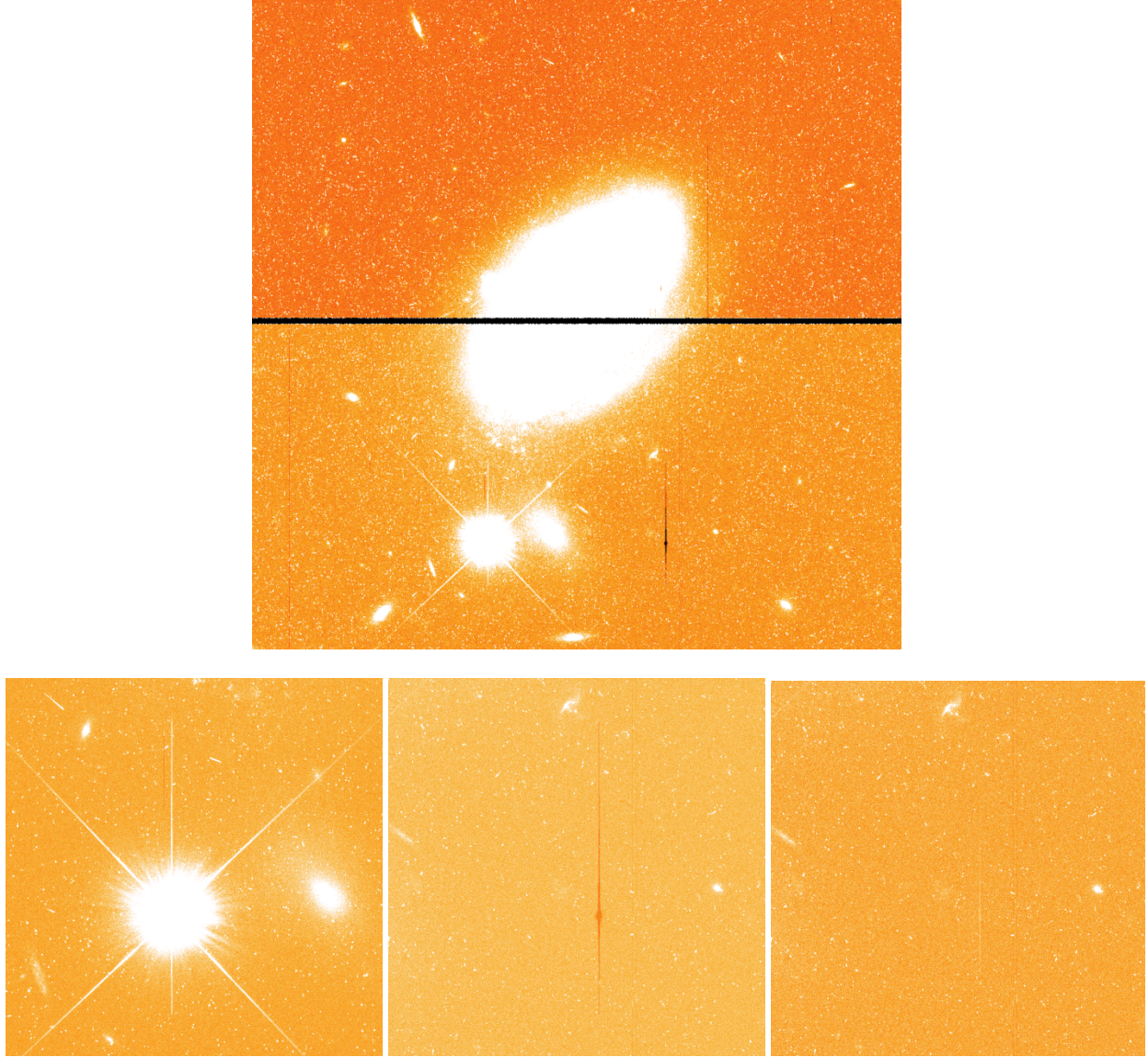


Figure 8. At top is the full-frame four-amp image (ib1f43p7, proposal 11570, NGC 3021); at bottom are 1000x1000 pixel close-ups of the saturated PSF (*left panel*), mirror image crosstalk (*middle panel*), and crosstalk after correction (*right panel*). A hard color table stretch is used to highlight the crosstalk features. A slight residual signal level appears in the corrected crosstalk area but the mean of that area is still within 1σ of the mean of the surrounding (non-crosstalk) pixels. The 1σ here is considerably larger ($\sim 7\text{ e}^-$) than the typical 1σ ($<1\text{ e}^-$) of other data presented in this report.

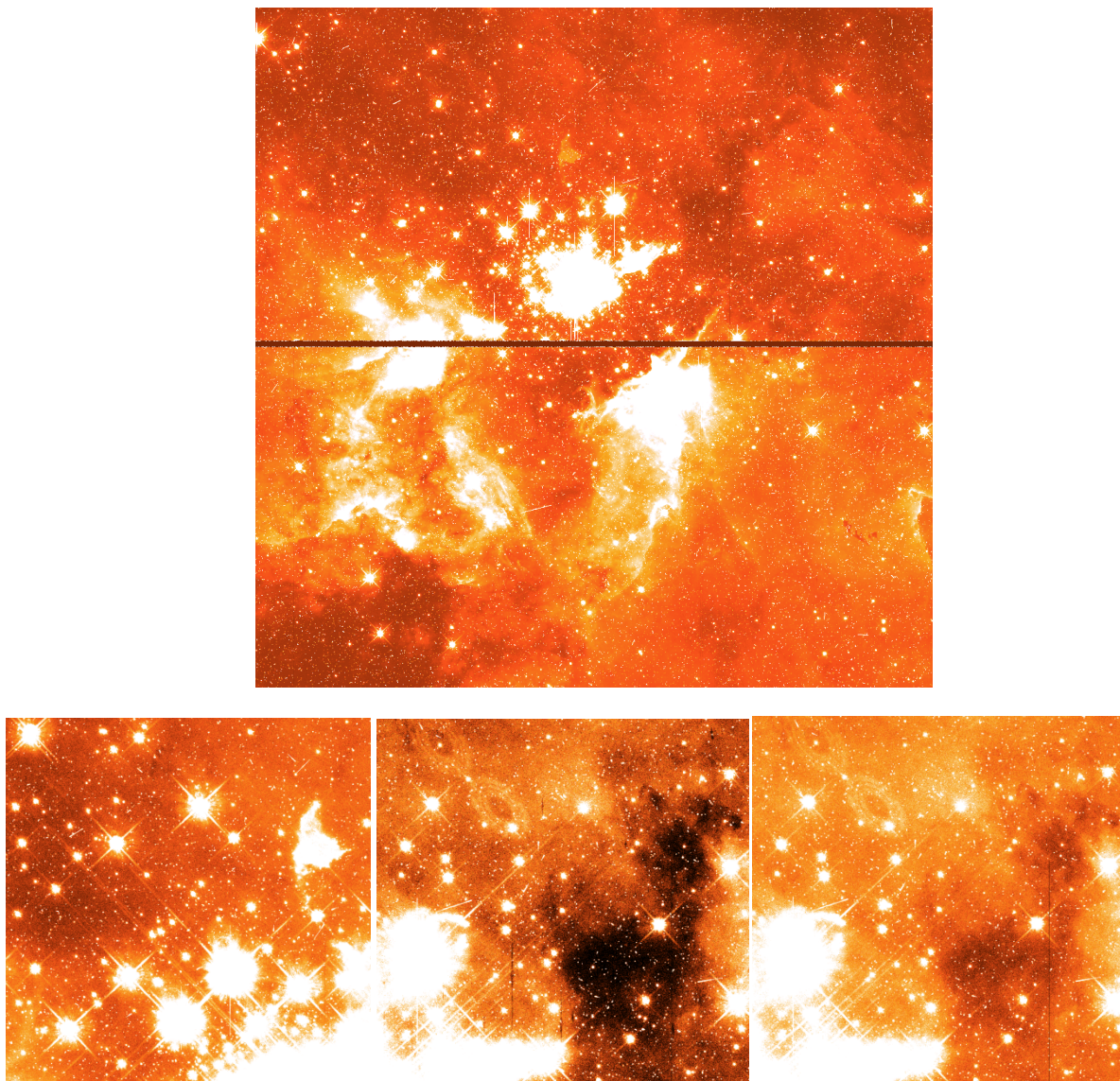


Figure 9. At top is the full-frame four-amp image (ib6wa1azq, proposal 11360, NGC3603); at bottom are 1000x1000 pixel close-ups of the saturated sources (*left panel*), mirror image crosstalks (*middle panel*), and crosstalk after correction (*right panel*). A hard color table stretch is used to highlight the crosstalk features. The figure-8 shape at upper left in the middle and right panels is an optical (not crosstalk) ghost.