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Cross-Talk in the ACS WFC Detectors. II: Using GAIN=2 to Minimize the Effect

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ABSTRACT

Cross talk is observed in images taken with ACS WFC between the four CCD quadrants that correspond to the four amplifiers of the detector array (see Giavalisco 2004). The effect manifests itself as (mostly) negative ghost images placed in locations that are mirror-symmetric to those of the generating sources in adjacent quadrants. Here we show that the apparent flux of the ghost images is significantly reduced when the camera is used with gain setting GAIN=2. This corresponds to an average inverse gain of ~2.0 e^-/DN, which is adequate to sample the read-out noise of the CCDs, whose average value is 5.25 e^-rms. Although the cross talk appears to have negligible photometric effects in most applications and is primarily a cosmetic problem, using the setting GAIN=2 minimizes its effects with no penalty and, in fact, has the added bonus of providing an expanded dynamic range.

1. Introduction

Images obtained with ACS WFC are affected by a small amount of electronic cross talk between the four CCD quadrants that correspond to the four amplifiers of the two detectors. The effect produces electronic "ghost" images in a given quadrant that mirror real images recorded on other quadrants (see Giavalisco 2004 for a full description of the effect). These ghost images, which most often are negative (i.e., they appear as depressions relative to the sky background) are faint in absolute terms. They appear to be additive effects, with no obvious effects on the photometry in most cases. However, even if ghost images produced by cross talk appear to have little structure (i.e., the surface brightness of any given source does not vary much across the ghost image) one can imagine cases when the cross talk can affect photometry, particularly for faint, diffuse sources. For example, this can happen when, due to the relative positions of the real and ghost source and their spatial extent, the subtraction of the local sky fails to take into account the contribution of the ghost image. In practice, the case of sources with their photometry significantly affected by cross talk should be relatively rare, and the cross talk will remain mostly a cosmetic problem. However, it is interesting to explore if there are modes of operation of WFC that minimize or eliminate the effects of cross talk. In this ISR we report the finding that using the gain setting of 2 e^-/DN (GAIN=2) instead of the most commonly used default setting of 1 e^-/DN (GAIN=1) results in the effects of cross talk being smaller. Such a setting essentially has no negative consequences on other aspects of data quality, and thus we recommend that it be adopted as standard setting for all WFC observations.

2. Cross Talk in ACS WFC images

Figure 1 shows an example of the cross talk in one of the images obtained during the Great Observatories Origins Deep Survey (GOODS) program. The image, taken through the F850LP filter, is the stack of 4 individual exposures (each dithered by a few pixels) and has a total integration time of 2120 sec. Source images G1, G2 and G3 recorded on quadrant C produce negative ghost images G1’, G2’, G3’, G1’’, G2’’, G3’’, and G1’’’, G2’’’ and G3’’’ in quadrants A, B and D, respectively. In this particular example, the flux of the ghosts (i.e. the average depression of the background) is approximately ~2 e^-/pixel, about 16% of the average background value of ~12.2 e^-/pixel.

A quantitative description of the cross talk can be found in Giavalisco (2004), including the effects that this phenomenon has on the photometry of both compact and diffuse sources. Here we simply summarize three key features of the cross talk that are most relevant to the observations. Specifically,

1) there seems to be no direct proportionality between the light profile of the sources and the ghosts, which appear as relatively faint depressions of the background of the victim quadrants with approximately constant surface brightness;

2) the intensity of the cross talk, namely the "apparent magnitude" of the ghosts, depends on the background of the images, the sense of the correlation being that images with fainter background show stronger cross talk. Note that this dependence of the cross-talk strength on the sky background induces an apparent dependence on the wavelength, since the background is different in different passbands;

3) the presence and intensity of the cross talk depends on which quadrant hosts the sources and on which quadrant hosts the victims. For example, in Figure 1 sources in quadrant D produce clearly visible ghosts in quadrant C, but much fainter ghosts in quadrant A and B.

Sources in quadrant A and B do not seem to produce any obvious ghosts in the other quadrants.

As discussed in Giavalisco (2004), to the degree that it has been measured, the cross talk behaves like an additive effect, as opposed to a multiplicative one. It has no significant impact on source photometry in most applications. In general, the area affected by cross talk is small for most exposures, e.g. in deep pointings where only few bright objects (if any at all) are present in any given exposure that can act as sources of cross talk (e.g. Figure 1). As mentioned earlier, cases when the cross talk might have an effect on source photometry (for example a bright, extended source that induces cross talk affecting another extended source in a way that is not removed by the sky subtraction) should be rare. It is expected that in such cases photometry can still be carried out using ad-hoc, tailored apertures.

3. Cross-Talk with the GAIN=2 setting

The strength of the cross talk is significantly weaker in images acquired with gain setting GAIN=2 than in images taken with the GAIN=1 setting. This is qualitatively seen in Figure 2, which shows two indentical exposures of the same field (F606W, Texp=22.5 sec), except that the former has been acquired with GAIN=1 (2a) and the second with GAIN=2 (2b). Cross talk ghosts are observed in the GAIN=1 image, but not in the GAIN=2 one.

A quantitative analysis supports this visual inspection. A measure of the extent of the cross talk is provided by the correlation between the flux in the pixels of the source image and the flux in the pixels of the victim image at the corresponding mirror-symmetric positions. Thus, one way to measure this correlation from the data is to look at the distribution of flux values in the victim pixels for a given value of the flux in the source pixels. Only pixels that recorded sky background in the victim image are useful for this analysis. The mode and the median of such a distribution are relatively unaffected by pixels that recorded sources, and provide an estimate of the effective background in the presence of cross talk (i.e. the true sky background plus the additive component due to the cross talk, as a function of the source flux).

We have carried out such an analysis using a data set consisting of three pairs of identical images in terms of the target, the sky background, exposure time and passband (with one exception, see Table 1 for details), except that one image of each pair has been acquired with GAIN=1 and the other with GAIN=2. Two additional pairs of images that differ by the adopted passbands have also been considered. The images target the stellar cluster 47 Tucanae and have been acquired as part of the calibration program ID 9018. Figure 3 shows the plots of the mode and of the median of the background flux in victim image pixels as a function of the flux in the source image pixels acquired with both the GAIN=1 (hollow symbols) and the GAIN=2 (filled symbols) gain setting. In order to minimize the bias to both estimators from pixels that have recorded sources, only victim pixels whose flux is less than three standard deviations from the sky background (as measured in each quadrant) have been considered in the analysis. The horizontal lines in the plots show the global sky background in the victim quadrant, estimated using the mode. Note that, on average, the data points are higher than the global background. This is due to the fact that the data points are relative to a distribution of pixel values from relatively small samples that include pixels effected by sources, which bias the distribution towards values higher than the sky background. Also, in general, local and global background differ by a small amount.

From the plots it is evident that ghost images acquired with GAIN=1 have systematically lower background, i.e. less electrons per pixels, than images taken with GAIN=2. In no case are the GAIN=1 images observed to have higher background (in units of electrons per pixel) than the GAIN=2 ones. In other words, the effects of cross talk are stronger when the WFC is operated with GAIN=1 than when GAIN=2 is used. The plots also show that the flux deficiency generally increases as a function of the flux in the source pixels. The fact that member images of pairs (A4-B4) and (A5-B5) use different passbands is inconsequential to this analysis. As Giavalisco (2004) showed, the strength of the cross talk decreases with increasing sky background. However, in this case the exposure time (5 sec) is too short to result in a significant background difference between the members of the pairs, given the intrinsic scatter of the cross talk phenomenon. The difference in the strength of the cross talk between the gain settings in each pair is not due to the different passbands adopted.

Other typical features of the ACS cross talk (see Giavalisco 2004) are also observed in the plots. Firstly, the cross talk is a small effect in absolute terms, i.e. the depression of the background (i.e. the flux of the ghost images) consists of only a few electrons per pixel for a very wide range of flux of the sources. Secondly, the cross talk is characterized by some degree of noise, namely it does not happen with the same strength everywhere for a given source flux. This can also be observed qualitatively from Figure 1, where some sources do generate ghosts (e.g. galaxies G1 and G2 in the Figure), but others do not (e.g. galaxy G4). Thirdly, the plots also show that sources in quadrant D generate a stronger cross talk in quadrant C than sources in C do in D. This is also qualitatively observed in Figure 1. Finally, it can be noticed from the plots that cross talk tends to increase in strength with increasing source flux in both types of images. The plots suggest that in the GAIN=1 images this happens for source flux values somewhere between 10^3 and $3x10^3$ e^-/pixel, while for the GAIN=2 images the same effect occurs for values of the source flux roughly an order of magnitude larger.

In conclusion, while the use of GAIN=2 does not eliminate the cross talk, it appreciably reduces its strength and makes its appearance occur at larger values of the source flux compared to the case of GAIN=1.

There are no practical disadvantages in using the GAIN=2 setting when observing with ACS WFC. This mode is as well calibrated as the GAIN=1 setting, and when operated at GAIN=2 WFC provides full sampling of the CCDs' full-well depth (Gilliland 2004). The calibrated values of this gain setting are 2.02, 1.96, 2.04 and 2.01 e^-/DN for the A, B, C and D amplifier, respectively, and the accuracy of the gain ratio between the two modes is known to better than 0.1% (Gilliland 2004). With a read-out noise of 5.33, 4.99, 5.51 and 5.16 e^- rms for the four amplifiers, a gain value of ~2 provides adequate sampling of the noise even in the case of very short exposures taken with the B band or in narrow-band filters, when very little sky background is present (as a comparison, the calibrated read noise for the GAIN=1 setting are 4.97, 4.85, 5.24, and 4.85 e^- rms for the A, B, C, and D amplifier, respectively). In addition to a reduced cross-talk, the GAIN=2 setting also provides the advantage of increased dynamic range in the AD conversion. Furthermore, the photometry of isolated sources from saturated images acquired with GAIN=2 can be easily recovered simply by assuming that the aperture extraction includes all of the pixels bled into during saturation (and nearest neighbors to allow for charge diffusion, see Gilliland 2004 for a discussion). This is not possible using the GAIN=1 setting, because AD conversion saturation occurs before full-well saturation.

Table 1. The data set used in the analysis. Pairs of images (A1-B1) through (A3-B3) are identical in terms of field in the sky (47 Tucanae), exposure time and passband, differing only in the gain setting. Pairs (A4-B4) and (A5-B5) use different filters, but this is inconsequential to the analysis.

Set	Image File	GAIN	Exp Time(sec)	Passband
A1	j8c061vdq_flt.fits	1	22.5	F606W
A2	j8c061vfq_flt.fits	1	22.5	F606W
A3	j8c022qtq_flt.fits	1	20.0	F606W
A4	j8c032xuq_flt.fits	1	5.0	F814W
A5	j8c042sxq_flt.fits	1	5.0	F814W
B1	j8c0c1vbq_flt.fits	2	22.5	F606W
B2	j8c0c1vdq_flt.fits	2	22.5	F606W
B3	j8c0c2ojq_flt.fits	2	20.0	F606W
B4	j8c0a2deq_flt.fits	2	5.0	F606W
B5	j8c0b2uvq_flt.fits	2	5.0	F606W

Figure 1: An example of cross talk in the ACS WFC detectors. The image, obtained during the GOODS program (Giavalisco et al. 2004), is the stack of four z-band exposures taken with a dither stepping of a few pixels (total exposure time is 2120 sec). Because of the cross talk, galaxies G1, G2 and G3, recorded in quadrant C, produce mirror ghost images G1’, G2’, G3’, G1’’, G2’’, G3’’, and G1’’’, G2’’’ and G3’’’ in quadrants D, A and B, respectively. Note that the effect appears stronger in quadrants C and B than in quadrant A, and that sources in quadrant D produce ghosts that follow a similar trend. However, sources in quadrants A and B do not seem as effective in producing ghost images. Also note galaxy G4 in quadrant C, which does not produce an obvious ghost in quadrant C.

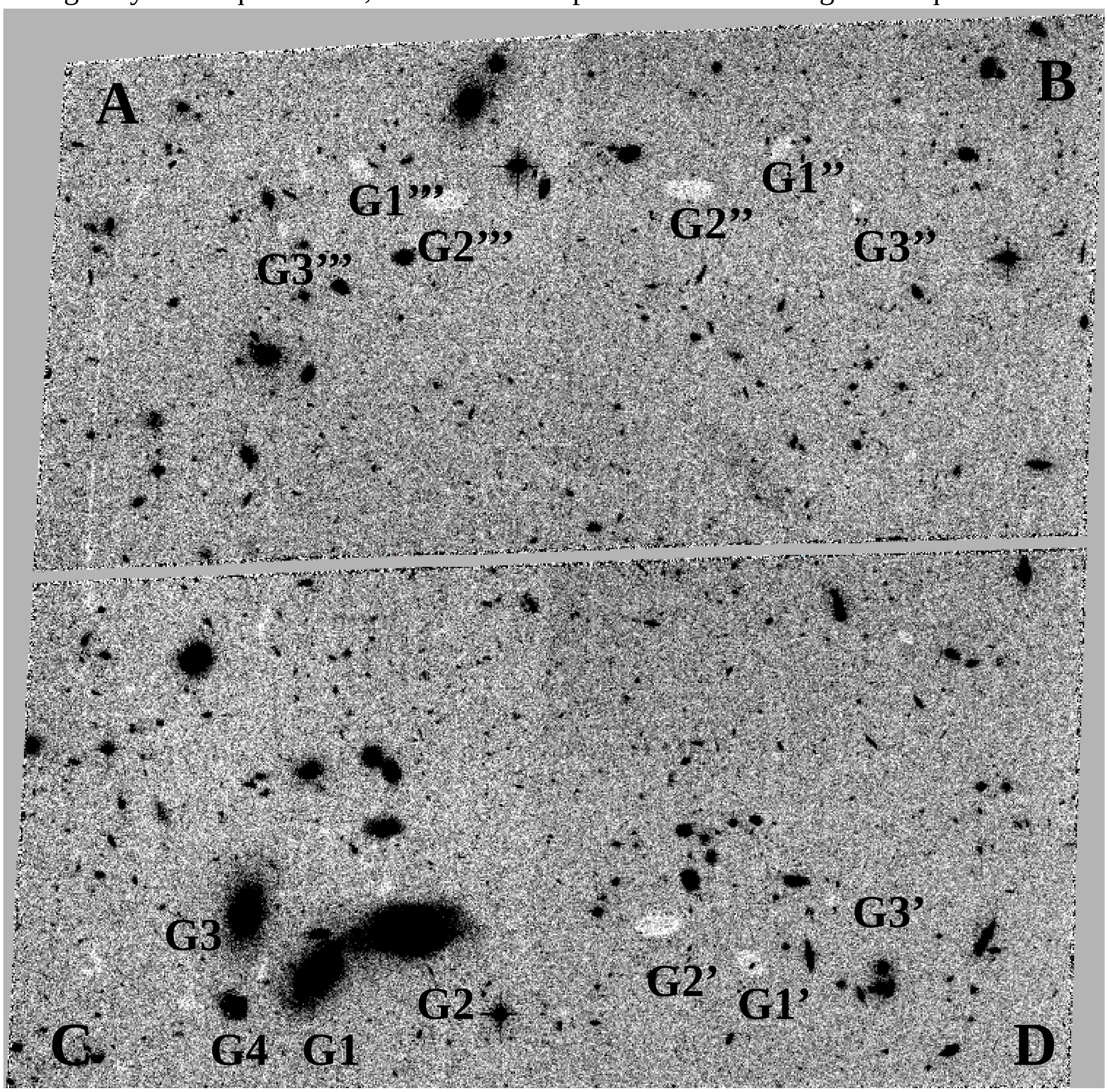


Figure 2: Two exposures through the same filter (F606W) and with the same exposure time (22.5 sec), one acquired with GAIN=1 (top) and the second with GAIN=2 (bottom). Each image comprises quadrant C (left half of the image) and quadrant D (right half of the image) abutted together. Cross talk ghost images are observed in the GAIN=1 image, but not in the GAIN=2 one (green arrows point at sources, red ones point at ghosts).

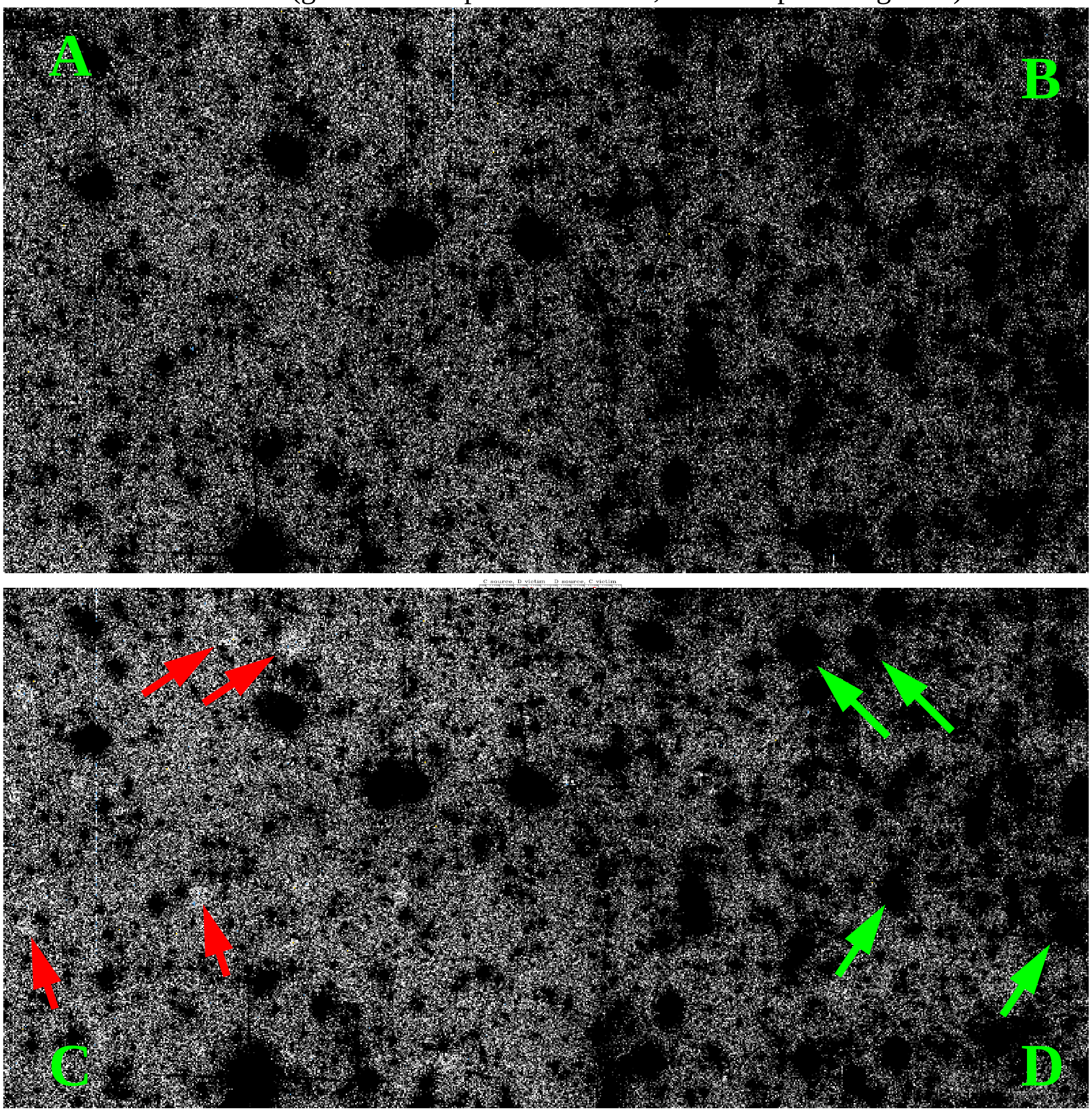


Figure 3: The mode and the median value of background pixels in ghost images as a function of flux in the source pixels for image pair #1 (A1-B1, see Table 1). Source pixel flux is binned in logarithmic bins 0.2 in size. The mode and the median are two estimators of the value of the "effective" background in presence of cross talk, namely the true background plus the ghost images produced by the cross talk. To minimize contamination from sources, only ghost-source pixel combinations in which the ghost pixels do not exceed the sky value (as estimated in each quadrant) by more than 3 times the standard deviation are used in the analysis. Filled symbols are for GAIN=2, hollow ones for GAIN=1. The pixels with GAIN=1 have systematically lower values than those with GAIN=2, an indication that the cross talk is stronger in this case. Their values also decrease as a function of the source pixel value more steeply than in the GAIN=2 case. Shown are the cases when quadrant C acts as the source image and D is the victim one, and vice versa. The horizontal lines show the global sky background of the victim quadrant estimated with the mode.

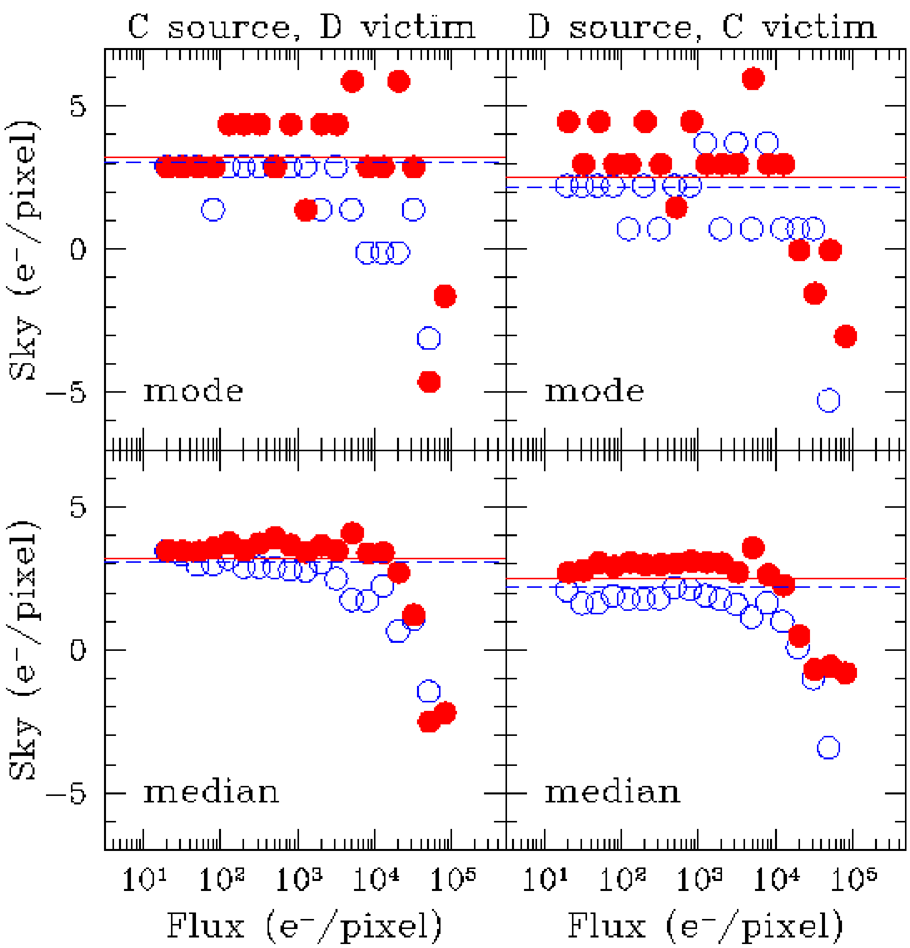


Figure 4: As in Figure 3, for pair #2 (A2-B2).

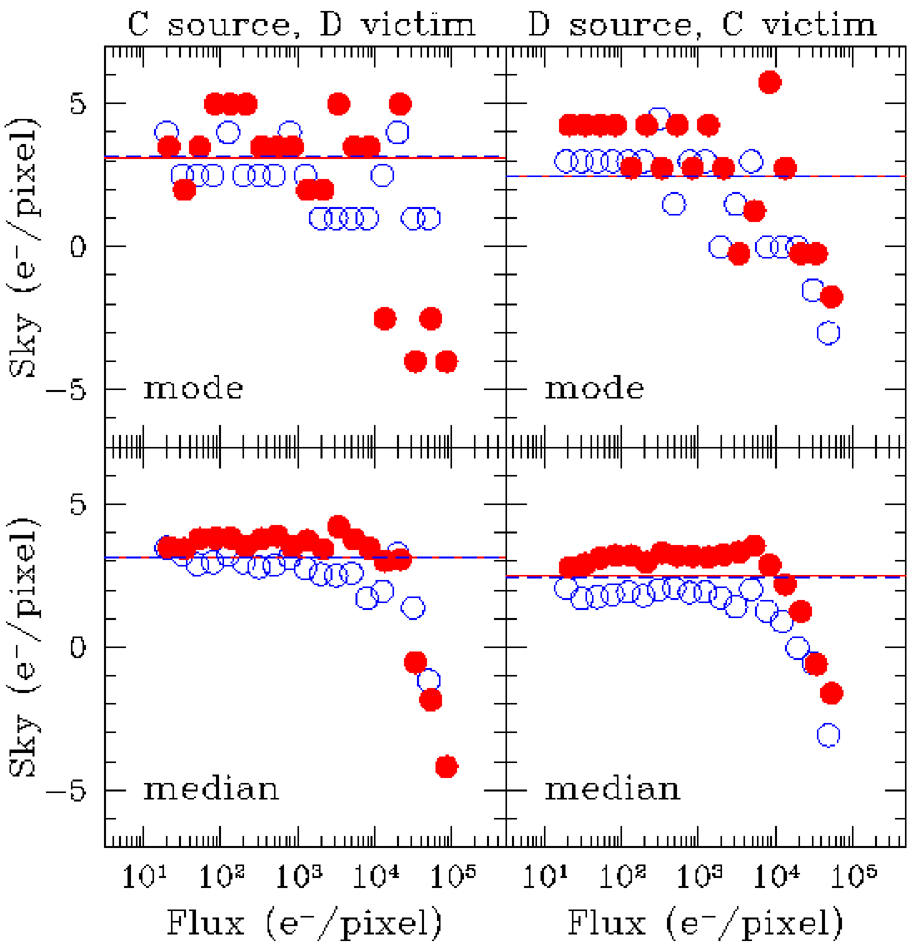


Figure 5: As in Figure 3, for pair #3 (A3-B3).

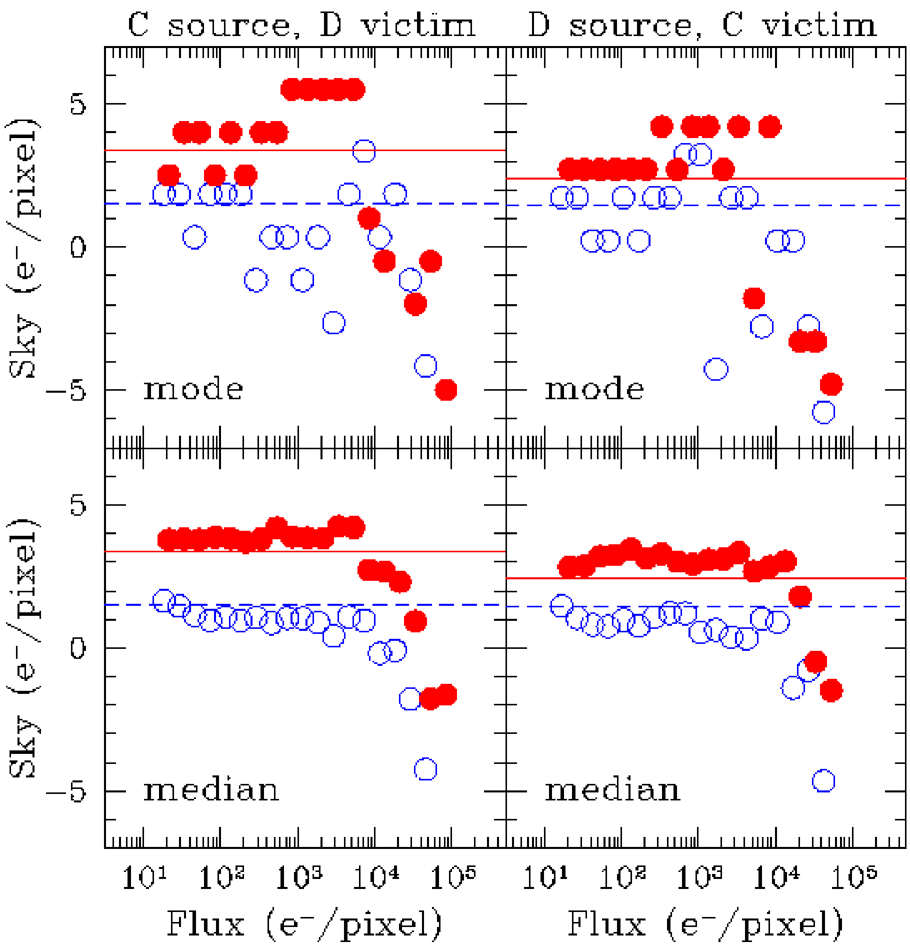


Figure 6: As in Figure 3, for pair #4 (A4-B4). Differently from all the other pairs of images analyzed before, in this case image A4 (GAIN=1) has been taken using the F814W filter and image B4 (GAIN=2) with the F606W. This difference, however, is inconsequential for our analysis.

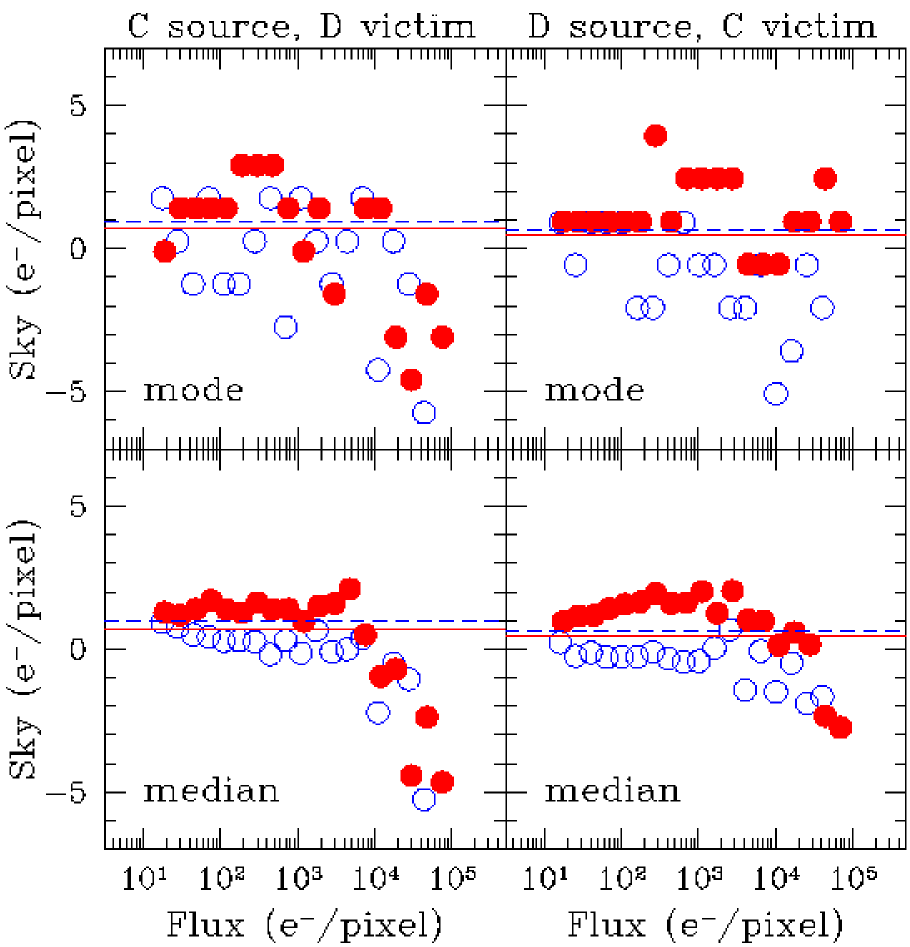
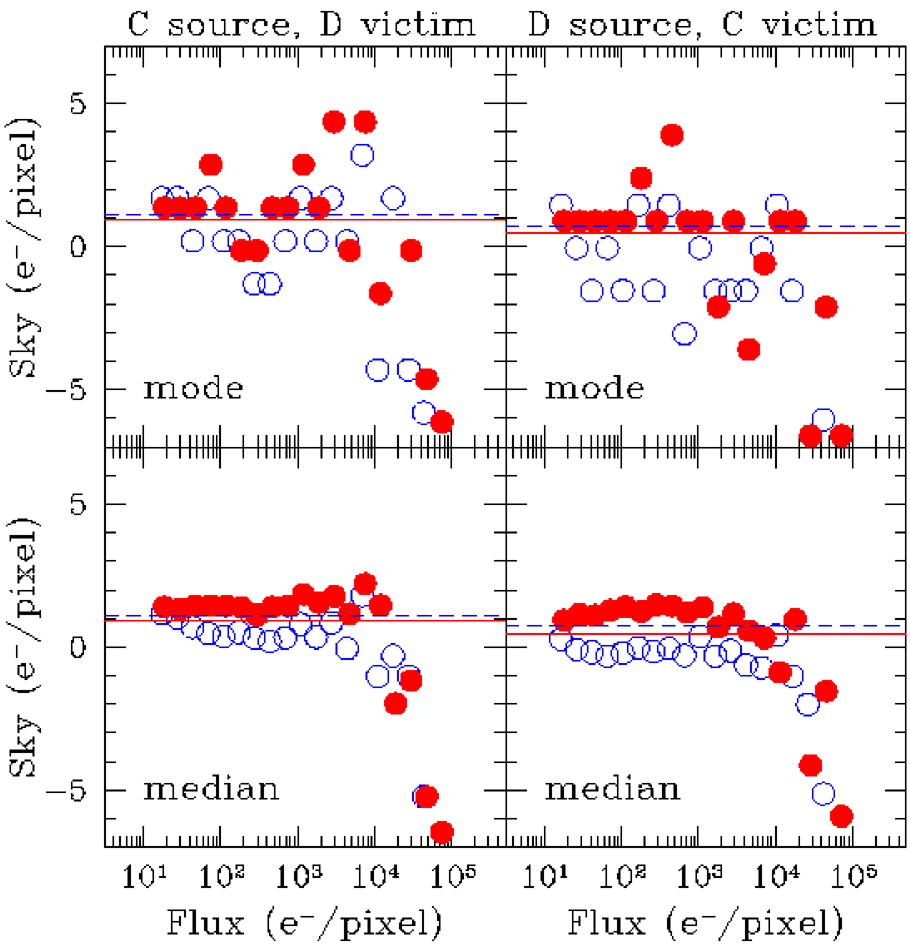


Figure 7: As in Figure 6, for pair #5 (A5-B5).



4. Conclusions

We have shown that when ACS WFC is operated with gain setting GAIN=2 the effects of cross talk among its amplifiers are significantly diminished compared to when it is used with the GAIN=1 setting. While the strength of the cross talk is small in absolute value and has no significant consequences on source photometry in most applications, the effect can be a cosmetic problem, particularly in deep images. Operating the camera with GAIN=2 reduces its presence to the point where it is hardly noticeable. There are no negative consequences of working with this gain setting. This mode is as well calibrated as GAIN=1, provides full sampling of the CCDs' full-well depth, and still provides adequate sampling of the read-out noise. In fact, in addition to reducing the effects of the cross talk, users will benefit from the increased dynamic range and the possibility of recovering photometry of sources in saturated images (for relatively isolated sources).

6. Acknowledgments

We would like to thank Ron Gilliland for many discussions and suggestions on the ACS cross talk.

5. References

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Gilliland, R., 2004, STScI Instrument Science Report, ACS-ISR 2004 - 01.