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# WFC3 TV3 Testing: IR Crosstalk

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## ABSTRACT

*Electronic crosstalk produces a signal in one or more amplifier quadrants in response to a stimulus in another quadrant. In the WFC3 IR camera, the crosstalk arises during the readout and appears as a negative mirror image of the source. Positioned symmetrically opposite the source about the dividing line between each of the coupled readout amplifier quadrants, the crosstalk appears at a lower level than the surrounding background, at the level of  $\sim 1e-06$  that of the source signal. The level is low enough that it should not be an issue for most programs; dithering can help mitigate the effect. This ISR characterizes the position, intensity and shape of the crosstalk effect as seen during TV3 ground testing.*

## Introduction

Crosstalk (CT) in the WFC3 IR channel is a type of electrical interference that occurs during the chip readout: the detected signal experiences variations due to signals present elsewhere in the system. In this case, the act of reading a signal from a source in one quadrant changes the signal levels detected from another quadrant. As a result, a relatively diffuse region of inverse signal is produced in response to a bright target in another quadrant. As shown in Figure 1, the WFC3 IR crosstalk is faint relative to other known effects such as persistence.



Figure 1: From left to right: persistence, crosstalk, and reflectance from the stimulus housing. All three features appear in different parts of the same full-array image.

The detector quadrants are coupled via a shared cable to the Detector Electronics Box (DEB); quads 1 and 2 are paired (upper and lower left) and quads 3 and 4 (lower and upper right) are paired. As a result, the readout from one paired quad produces a voltage change in the other paired quad at the microvolt level, resulting in a CT feature in that other quad. When the source is unsaturated, the CT falls below the level of the background noise; once saturated, the crosstalk level is on the order of the background. In contrast to CT in the UVIS CCDs, the total flux in the source becomes irrelevant once the pixels saturate: at that point, the voltage in the IR focal plane array is pinned and the CT level remains constant.

The CT is expected to be linear up to saturation but due to its low level in WFC3, it is essentially undetectable until there are at least several pixels in a row with a very high signal level. At that point, the CT becomes smeared in the fast readout direction (horizontally), elongated due to the time constant of the CT: the reset time for the voltage to return to the nominal level in the pair quadrant is greater than the readout time for a single pixel. The result of this is that extended high-flux regions produce crosstalk features elongated in the readout direction, as each successive pixel in the readout direction carries a residual voltage change from the prior pixels. The CT does not show any elongation in the vertical direction (slow readout direction).

## Data

The data used in our study were gathered during the Thermal Vacuum test 3 (TV3) at Goddard Space Flight Center (GSFC). The data were acquired on 03/13/2008 and 03/16/2008 via *SMS IR23S01A: Crosstalk Intensity & Location* and *SMS IR23S02A Crosstalk: Gain & Subarrays*. Each SMS specified alternating F160W filter exposures and dark exposures. The dark files taken in these SMS's were not used in reducing the data, instead the best available “superdark” generated from ground data was used (see Table 3). Of the remaining F160W images, the exposures in the SMS IR23S01A alternated between two types of exposures (see Table 1). The first is an unsaturated calibration image that can be used to determine the actual incident flux in the subsequent

saturated images but these were not used in this study. Every other image is intentionally saturated to produce a crosstalk feature. These images had to have saturated stimulus flux levels due to the low crosstalk response. The first 4 images in SMS IR23S02A are all saturated crosstalk images that can be calibrated using images from SMS IR23S01A. The last 2 images are an unsaturated and saturated pair of subarray exposures (see Table 2).

Filename	Array Type	Exposure Time (sec)	Optical Position	Neutral Density Filters	Type
ii231a02r_08073072326_fit.fits	FULLIMAG	38.119781	IR08	ND3,SN2OPEN2	Calibration
ii231a05r_08073073755_fit.fits	FULLIMAG	38.119781	IR08	OPEN1, OPEN2	Saturation
ii231a08r_08073075343_fit.fits	FULLIMAG	38.119781	IR06	ND3,SN2OPEN2	Calibration
ii231a0br_08073080811_fit.fits	FULLIMAG	38.119781	IR06	OPEN1, OPEN2	Saturation
ii231a0er_08073082359_fit.fits	FULLIMAG	38.119781	IR10	ND3,SN2OPEN2	Calibration
ii231a0hr_08073083827_fit.fits	FULLIMAG	38.119781	IR10	OPEN1, OPEN2	Saturation
ii231a0kr_08073085415_fit.fits	FULLIMAG	38.119781	IR02	ND3,SN2OPEN2	Calibration
ii231a0nr_08073090843_fit.fits	FULLIMAG	38.119781	IR02	OPEN1, OPEN2	Saturation
ii231a0qr_08073092649_fit.fits	FULLIMAG	41.052071	IR08	ND2,SN0ND4,SN10	Calibration
ii231a0tr_08073094139_fit.fits	FULLIMAG	41.052071	IR08	ND4,SN0OPEN2	Saturation
ii231a0wr_08073095749_fit.fits	FULLIMAG	41.052071	IR06	ND2,SN0ND4,SN10	Calibration
ii231a0zr_08073101239_fit.fits	FULLIMAG	41.052071	IR06	ND4,SN0OPEN2	Saturation
ii231a12r_08073102849_fit.fits	FULLIMAG	41.052071	IR10	ND2,SN0ND4,SN10	Calibration
ii231a15r_08073104339_fit.fits	FULLIMAG	41.052071	IR10	ND4,SN0OPEN2	Saturation
ii231a18r_08073105949_fit.fits	FULLIMAG	41.052071	IR02	ND2,SN0ND4,SN10	Calibration
ii231a1br_08073111439_fit.fits	FULLIMAG	41.052071	IR02	ND4,SN0OPEN2	Saturation

Table 1: A summary of the files generated from SMS IR23S01A: Crosstalk Intensity & Location. Calibration images are unsaturated. The optical position refers to predefined locations in the field of view.

Filename	Array Type	Exposure Time	Optical Position	Neutral Density Filters	Type
ii232a02r_08076104826_fit.fits	FULLIMAG	38.119781	IR02	ND4,SN0OPEN2	Saturation
ii232a05r_08076110308_fit.fits	FULLIMAG	38.119781	IR10	ND4,SN0OPEN2	Saturation
ii232a08r_08076111749_fit.fits	FULLIMAG	38.119781	IR06	ND4,SN0OPEN2	Saturation
ii232a0br_08076113230_fit.fits	FULLIMAG	38.119781	IR08	ND4,SN0OPEN2	Saturation
ii232a0fr_08076115118_fit.fits	SQ512SUB	87.991699	IR02	ND2,SN0ND4,SN10	Calibration
ii232a0ir_08076120849_fit.fits	SQ512SUB	87.991699	IR02	ND4,SN0OPEN2	Saturation

Table 2: A summary of the files generated from SMS IR23S02A Crosstalk: Gain & Subarrays.

The crosstalk is visible in all the saturated images. The crosstalk location is shown in Figure 2, where the crosstalk has been circled with a white ring. The position of the crosstalk is symmetrically reflected about the horizontal axis through the center of the field of view; physically, this axis is the division between the paired amplifier quadrants.

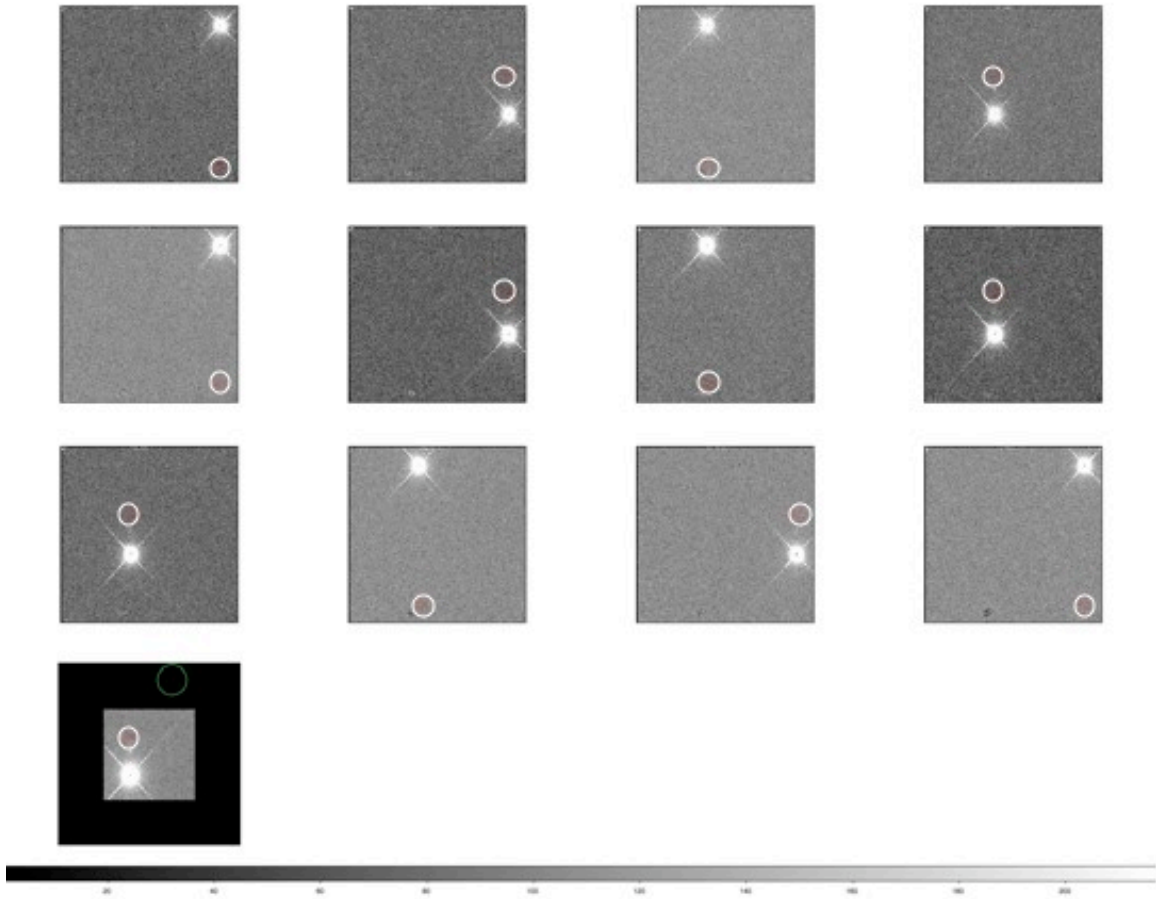


Figure 2: The set of 13 images containing crosstalk features used for this study. All images are full-frame except the last row, which shows a 512 X 512 subarray exposure centered in the field of view. A white ring has been superimposed to mark the approximate position of each crosstalk feature. Note that the crosstalk location is symmetric to the source about the horizontal dividing line separating quadrant 1 from 2 (left upper and lower quadrants) and 3 from 4 (right lower and upper quadrants).

The crosstalk feature itself is faint as shown in Figure 1 but when all the crosstalk regions are viewed side-by-side as in Figure 3 the feature becomes more obvious.

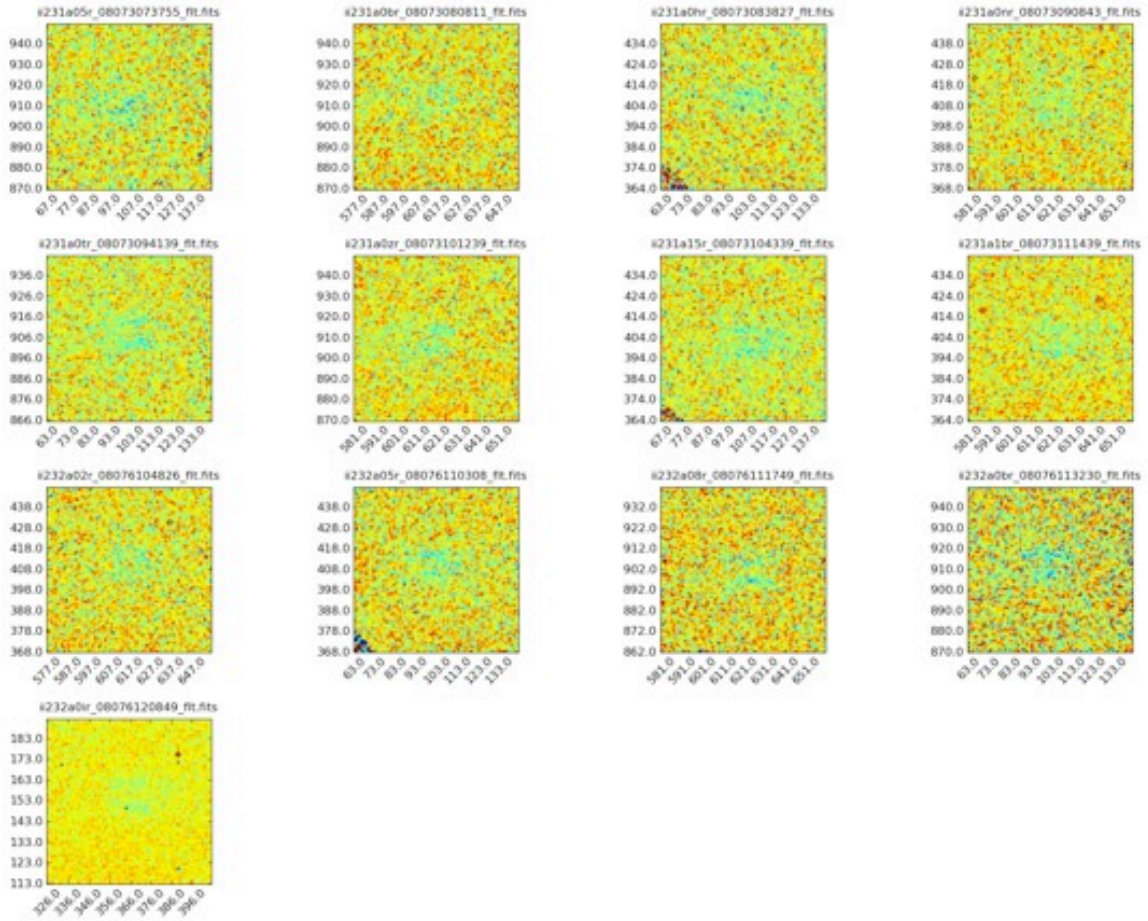


Figure 3: A gallery of all the TV3 crosstalk images used in this study. The size of each displayed image is 100 X 100 pixels. The color scale is from  $-2 \text{ e}^-/\text{sec}$  (dark blue) to  $2 \text{ e}^-/\text{sec}$  (dark red). The dark regions in the lower left of 3 of the image are an unrelated detector artifact

However, since the crosstalk amplitude is so close to the background noise level in the individual images it is difficult to study its characteristic shape. In order to overcome this a “stacked” image was created (see Figure 4). This image is the sum of 12 of the 13 crosstalk images all aligned about the crosstalk center as determined by the PHOT task (the subarray exposure was omitted). In addition to the features we described, there appear to be two vertically separated lobes – the mechanism for this is not understood. In the rest of this ISR we focus on quantifying the amplitude of the crosstalk.

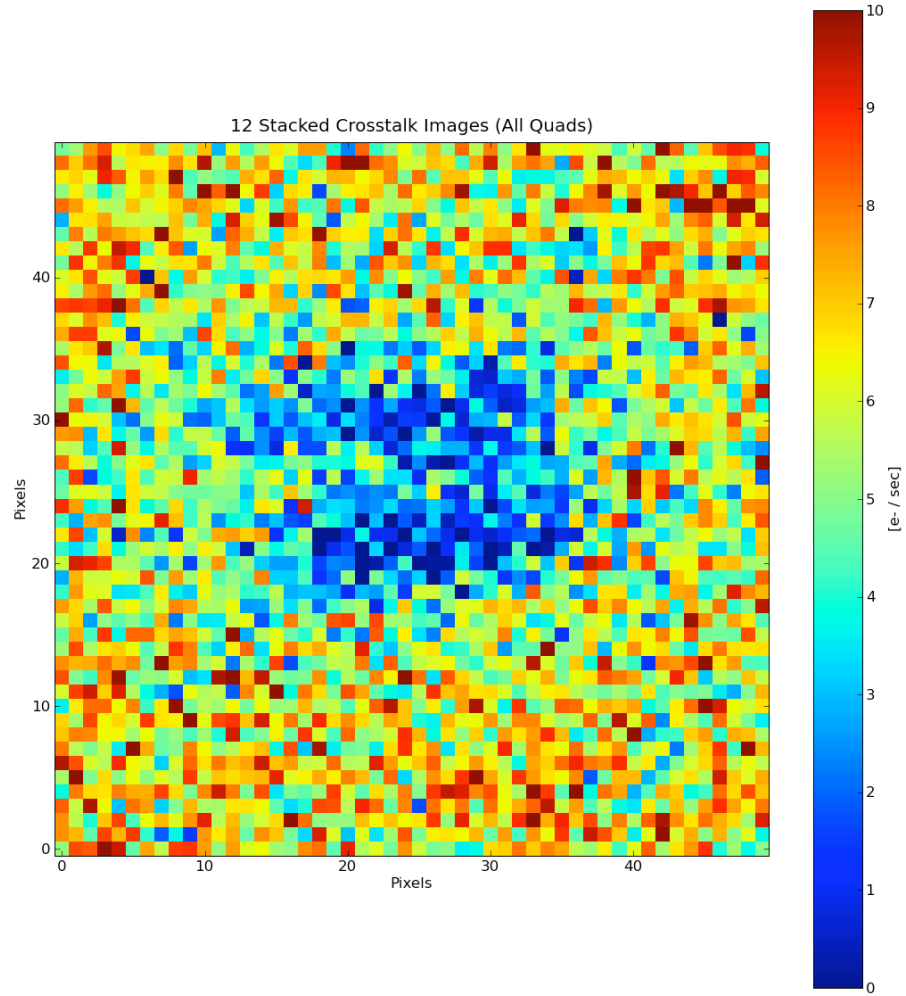


Figure 4. A stacked image containing all the full-array exposures and centered on the crosstalk feature.

## Data Reduction

The images were processed using the CALWF3 software (ver 1.4.1) with all the calibration switches set to PERFORM except for PHOTCORR, RPTCORR and DRIZCORR. The calibration reference files listed in Table 3 were used in the processing. At the time of processing they were the most up-to-date ground-based files available.

Keyword	Reference File
BPIXTAB	t291659ni_bpx.fits
CCDTAB	t2c16200i_ccd.fits
OSCNTAB	q911321mi_osc.fits
DARKFILE	t6119322i_drk.fits
NLINFILE	sbi18555i_lin.fits
PFLTFILE	sca2026bi_pfl.fits
DFLTFILE	N/A
LFLTFILE	N/A

Table 3: The CALWF3 reference files used in processing the data.

## Crosstalk Aperture Photometry

Performing photometry on a faint extended feature such as crosstalk has two specific complications. The first is defining the extent of a feature with a signal so close to the background. The second challenge is the sensitivity of the photometry to the sky background value.

### *Determining The Aperture Size*

It is difficult to determine the appropriate photometric aperture to completely enclose a faint extended feature such as crosstalk. Visual inspection is difficult because image contrasts, both in grayscale and color, can be misleading. In order to resolve this we looked at averaged 1-D “cross sections” of each crosstalk feature. The advantage to these plots is that they enhance the finer features that can get washed out by contrast settings when looking at the image itself. For each image, horizontal and vertical cross-sections were taken through the center of the crosstalk feature. Each cross-section was then averaged perpendicular to the direction of the cross-section so that a cross-section across all the columns would contain information averaged over the rows in the cross-section and vice versa. The width of the cross-section was equal to the width of the aperture being considered.

This method was used to produce the images in Figure 5 and select the final aperture radius of 20 pixels. These cross-sections allowed us to choose an appropriate aperture size as well as verify the centering of the photometry. It is interesting to note that the secondary vertical “lobe” present in the stacked image is also present in the cross sections. Also, as expected, the features seem to have slightly more extent in the horizontal direction than in the vertical.



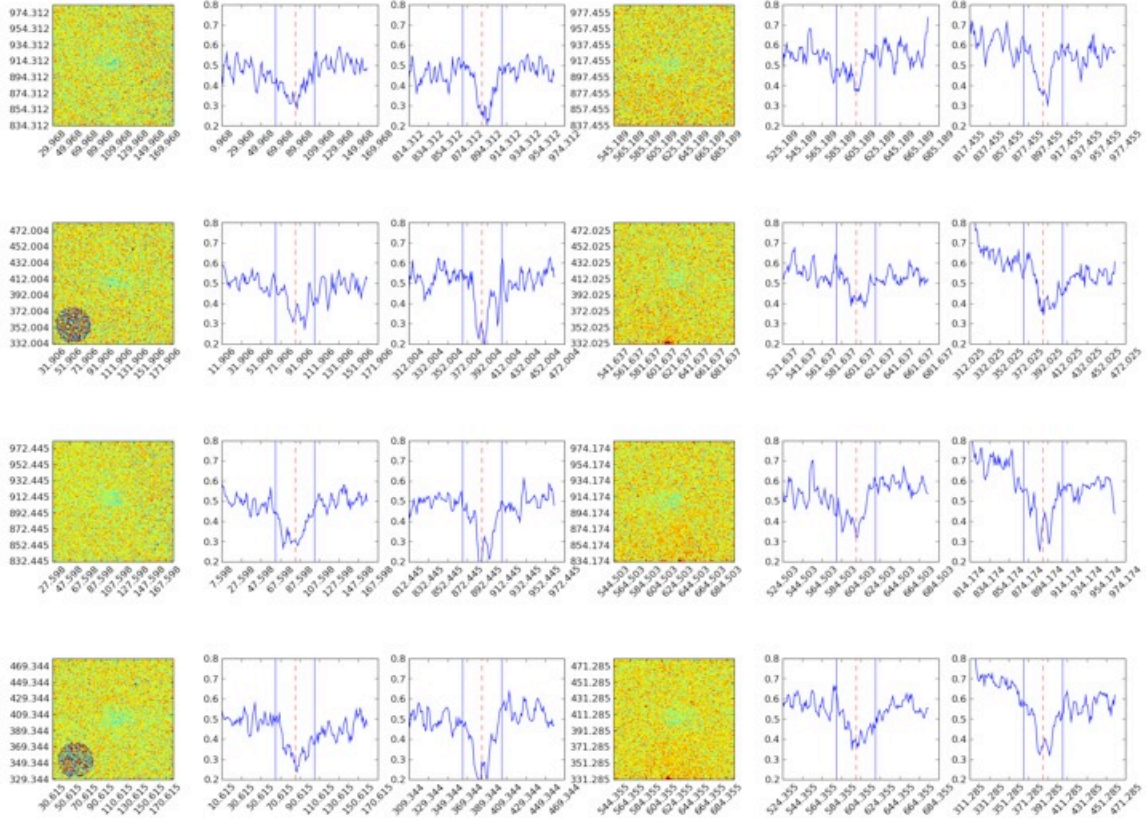


Figure 5: Each set of 3 images shows (from left to right) the crosstalk feature with same contrast as in Figure 2, a horizontal cross-section and a vertical cross-section. The width of the cross-section (bounded by the solid blue lines) is 40 pixels. This corresponds to a PHOT APERTURE radius of 20. The dashed red line shows the center as calculated by PHOT. The circular feature at the lower left corner of two of the images is a region of bad pixels caused by a manufacturing defect. The flux on the cross-sections are in units of  $e^-/s$

### Determining the Sky Value

In aperture photometry, the sky flux is subtracted from the source flux in the aperture to give a more accurate measure of the flux from the source alone. In order to remove the sky counts, the sky value *per pixel* is calculated in a user-specified annulus encircling the aperture. The sky value is then *multiplied by the number of pixels in the source aperture* to give the total sky flux in the aperture. Thus, in a case such as the crosstalk where the total flux contained in the aperture is small and the aperture itself is large, the sky flux can represent a significant portion of the total flux in the aperture. In such a case, the sky must be calculated carefully and our experiments showed that the crosstalk flux was very sensitive to different sky values.

Due to this sensitivity it was necessary to ensure that the sky value PHOT was providing was accurate. To accomplish this, we produced a histogram of all the pixels in each image (see Figure 6). We then compared the mean flux of the histogram with the



sky value provided by PHOT and chose annulus parameters to minimize the difference between the two.

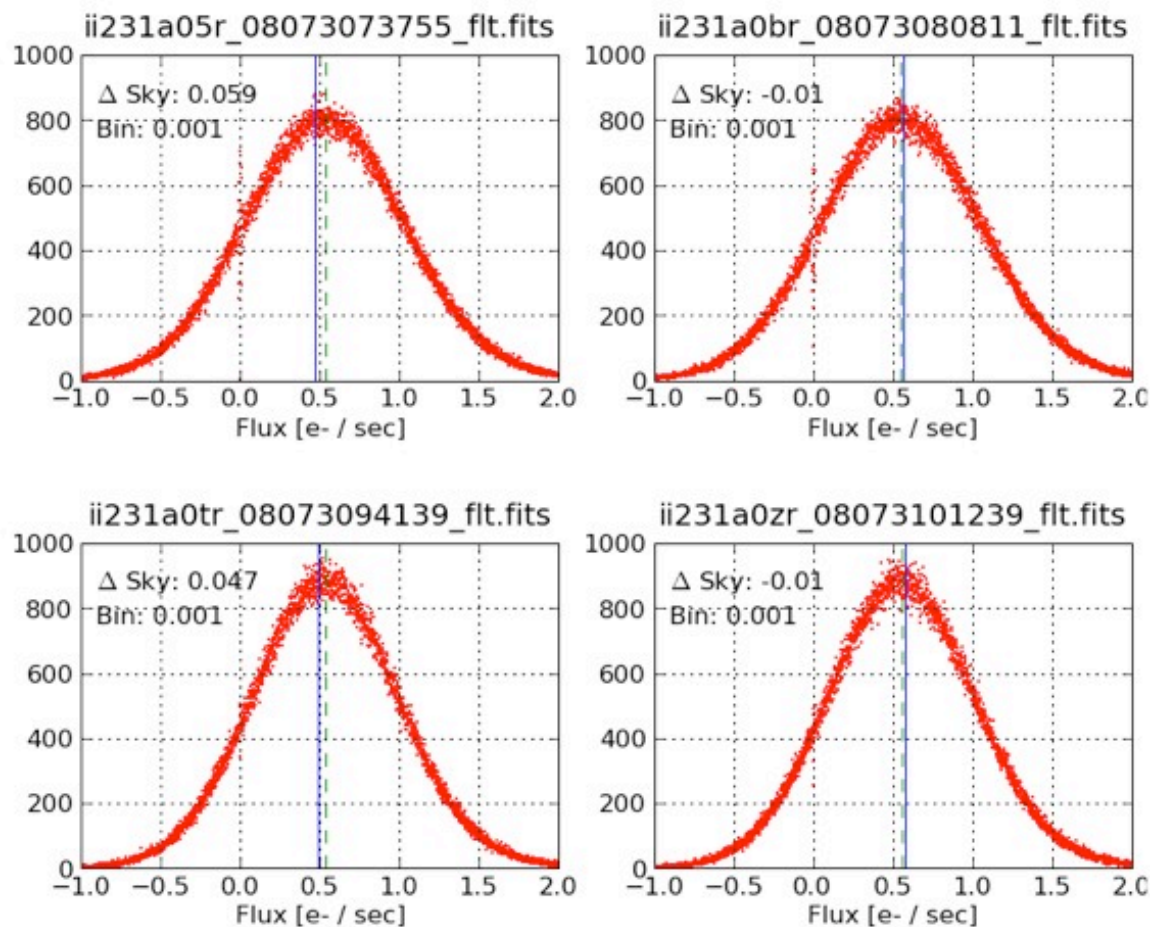


Figure 6: A series of histograms of our data set. Each histogram is taken over the entire image but within a clipped flux range of -1.0 e-/s to 2 e-/s. Each histogram contains 3,000 bins for a bin width of 0.001 e-/sec. The green dashed line is the mean value of the histogram data and the solid blue line is the sky value as calculated by PHOT in the region surrounding the cross talk.

### *Photometric Settings*

Based on these tests, photometry was performed on the crosstalk data with the following parameters. Proper centroiding on the CT features was confirmed by overplotting the derived location and aperture on the images.

Keyword	Value	Comments
Apertures	20	Radius of aperture (pixels)
Annulus	25	Inner radius of sky annulus (pixels)
Dannulus	20	Width of sky annulus (pixels)
Calgorithm	'centroid'	Centroid-based centering algorithm
Emission	'no'	Looks for negative features
Sigma	'INDEF'	No sigma clipping
Datamin	'INDEF'	No minimum data value
Datamax	'INDEF'	No maximum data value

Table 5: PHOT parameters used to generate the crosstalk photometry. The apertures, annulus and dannulus values are all in pixels. All other keywords not listed were left at their default settings.

## Results

As discussed earlier, the amplitude of the CT observed in the WFC3 TV3 ground testing is expected to be predominately correlated with the size of the stimulus, rather than the input flux. The crosstalk flux is plotted against the width of the stimulus fiber in Figure 7, and the results are tabulated in Table 6. The VISIR10c fiber has a width of 10 microns and the VISIR200 fiber has a width of 200 microns. On the detector these fiber widths respectively correspond to an unresolved point source and a 6 pixel source (Brown 2008). Because this is an IR device, there is no inter-pixel contamination (bleeding) from saturated sources as there would be in a CCD detector. This means that the fiber size is directly proportional to the size of the stimulus on the detector. Figure 7 and Table 6 show the expected correlation of a larger total CT within the aperture crosstalk response for a larger source. The saturation level of the detector is 80,000  $e^-$  and the cross talk response per pixel can be estimated from Figure 5 is on the order 0.1  $e^-/s$ , roughly 6 orders of magnitude lower than the saturation level.

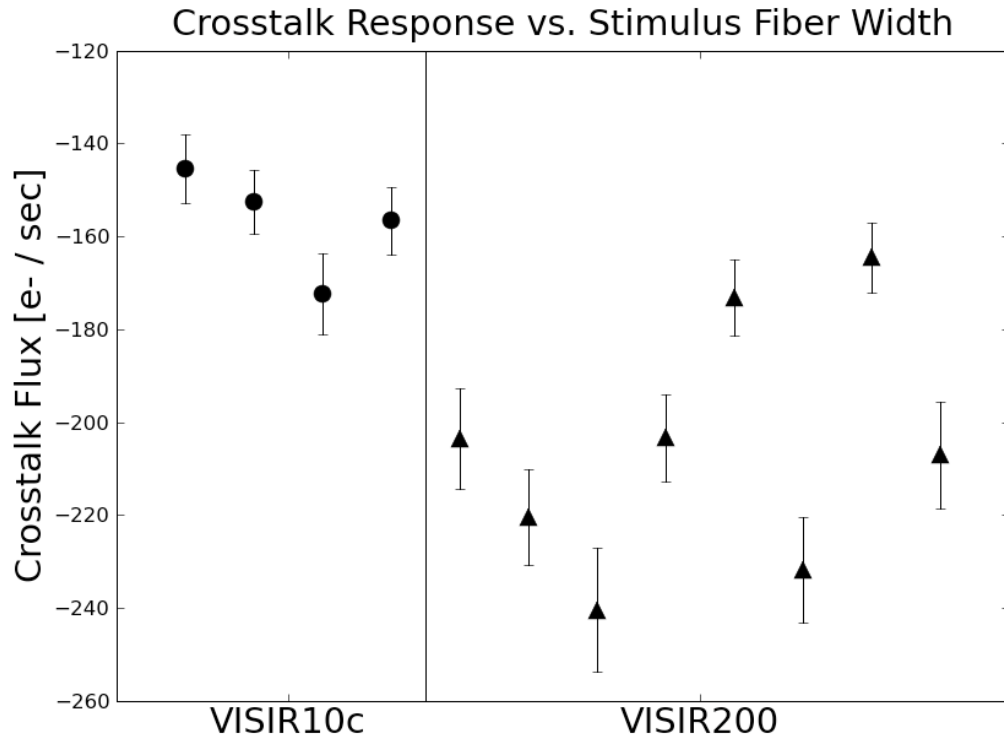


Figure 7: The total crosstalk response within the 20 pixel radius aperture plotted against the different stimulus fiber widths (10 and 200 microns).

Filename	Crosstalk	CT Flux	Fiber
	Flux [e-/s]	Error [e-/s]	
ii231a05r_08073073755_flt.fits	-145.44	-17.33	VISIR10c
ii231a0br_08073080811_flt.fits	-152.66	-15.91	VISIR10c
ii231a0hr_08073083827_flt.fits	-172.41	-20.17	VISIR10c
ii231a0nr_08073090843_flt.fits	-156.58	-16.66	VISIR10c
ii231a0tr_08073094139_flt.fits	-203.46	-23.31	VISIR200
ii231a0zr_08073101239_flt.fits	-220.46	-22.21	VISIR200
ii231a15r_08073104339_flt.fits	-240.40	-28.50	VISIR200
ii231a1br_08073111439_flt.fits	-203.40	-20.09	VISIR200
ii232a02r_08076104826_flt.fits	-160.86	-17.45	VISIR200
ii232a05r_08076110308_flt.fits	-215.17	-24.26	VISIR200
ii232a08r_08076111749_flt.fits	-164.56	-17.15	VISIR200
ii232a0br_08076113230_flt.fits	-207.08	-26.43	VISIR200

Table 6: The tabulated results from Figure 7.

Finally, Figure 8 shows two stacked images of the crosstalk, segregated by fiber width.

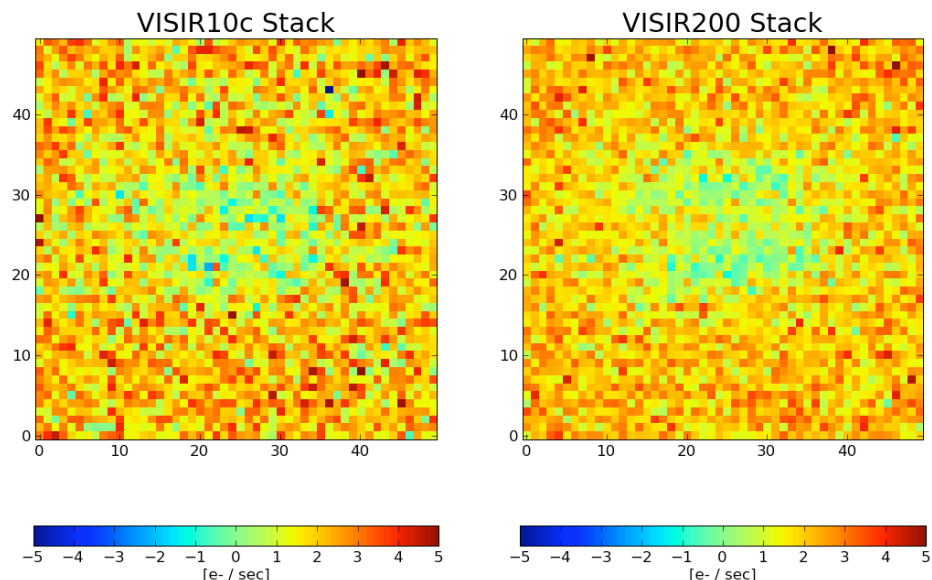


Figure 8: The crosstalk feature for each of the two stimulus fiber widths. The VISIR200 stack is scaled to match the intensity range of the VISIR10c.

## Conclusion

We have presented analysis results based on the TV3 ground test IR crosstalk experiments. The WFC3 IR detector exhibits low-level ( $\sim 1e-06$ ) crosstalk between the electrically-coupled pairs of amplifier quadrants 1/2 and 3/4. The CT arises during readout of the detector, appearing as a negative mirror image of the source, elongated along the fast readout direction. Most programs should not be affected by the CT, because of its very low amplitude. Dithering should help mitigate any adverse effects.

## References

Brown, T., 2008, WFC3 TV3 Testing: IR Channel Throughput, WFC3 ISR 2008-09

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