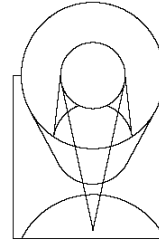




TECHNICAL REPORT



SPACE
TELESCOPE
SCIENCE
INSTITUTE

Operated for NASA by AURA

Title: Cross-talk Characterization of NIRCam Detectors using ISIM CV2 Images	Doc #: JWST-STScI-004361, SM-12 Date: 9 March 2015 Rev: -
Authors: A. Rest Phone: 410 – 338 - 4358	Release Date: 20 July 2015

1 Abstract

We use ISIM CV2 NIRCam dark images to determine the cross-talk between the 4 different amplifiers in NIRCam detectors. In order to minimize the noise in the measurements, we apply a new reduction technique which minimizes the dominant $1/f$ noise contribution. We find cross-talk coefficients with absolute values up to 9×10^{-4} , with uncertainties ranging between 4×10^{-6} and 3.4×10^{-5} , depending on the number of images and hot pixels available for the analysis. The cross-talk values do not show any indication of time variations. We also find cross talk effects in the pixel read out directly after the victim pixels.

2 Introduction

When reading out a detector with different amplifiers, either CCDs or IR detectors, it is normal to expect some electronic cross-talk. In general, a fraction xt_{ab} of the signal $f_a(x_a, y_a)$ of a pixel read out in the “offender” amplifier a gets added to the signal $f_b(x_b, y_b)$ of the pixel in the “victim” amplifier b that is read out at the same time (As we will see later, cross-talk may also affect pixels that are read out immediately after the offended ones). Formally:

$$\Delta f_b(x_b, y_b) = xt_{ab} f_a(x_a, y_a) \quad (1)$$

In most detectors, cross-talk xt_{ab} between amplifiers is less than 1%. It can be seen more easily in images with bright sources, like saturated stars. Until now, cross-talk has not been obvious in NIRCam images, suggesting that the effect is well below the percent level. However, K. Volk recently reported cross-talk on the NIRISS detectors of the order of 0.6%; this prompted us to quantitatively measure, or at least obtain upper limits for the cross-talk in the NIRCam detectors.

Even though the cross-talk occasionally shows a small spatial and/or signal dependence (e.g., the Mosaic 1.1 at the Kitt Peak Mayall 4m telescope), in most cases a single constant xt_{ab} suffices to characterize the effect. Therefore, after the constant xt_{ab} has been determined for a given amplifier pair a, b , cross-talk can be corrected for in a straightforward way:

Operated by the Association of Universities for Research in Astronomy, Inc., for the National Aeronautics and Space Administration under Contract NAS5-03127

$$f_{b,corrected}(x_b, y_b) = f_b(x_b, y_b) - x t_{ab} f_a(x_a, y_a) \quad (2)$$

How the pixels (x_a, y_a) and (x_b, y_b) are paired depends on the detector geometry and read out pattern. For NIRCам, amplifier 2 and 4 are readout in the opposite direction than amplifier 1 and 3, which needs to be taken into account.

Table 1 The first two columns show the SCA name and ID, respectively. The third column shows the number of exposures used for each detector. The Start and End Date columns indicate the date/time range in 2014 from which the images were drawn. The last 4 columns indicate the median number of hot pixels in the different amplifiers for the different detectors.

SCA	SCA ID	Num. Exp.	Start Date	End Date	Hot Pixels per Amplifier			
					1	2	3	4
A1	481	35	08-29T13:20	09-09T03:24	8778	7665	5208	8043
A3	483	32	08-31T16:48	09-09T10:22	2436	3045	3822	2751
A4	484	38	08-29T14:56	09-09T10:43	2541	3717	3066	1554
A5	485	38	08-29T15:20	09-09T11:05	21252	30450	30198	24969
B1	486	11	08-29T15:52	09-03T09:49	5313	7408	6258	6468
B2	487	36	08-29T16:26	09-09T11:49	1554	1911	2037	1302
B3	488	10	08-29T16:56	09-03T10:32	1659	1806	2205	2247
B4	489	34	08-31T00:37	09-09T12:32	1932	2625	2583	2247
B5	490	35	08-29T17:56	09-09T12:54	28833	33789	32382	23772

3 Analysis

3.1 Data Set

For our analysis we use all the ISIM CV2 dark ramps that were used by Karl Misselt from the University of Arizona NIRCам team to produce the dark reference frames. These dark ramps have 108 groups. An overview of the images used is shown in Table 1, together with the total number of pixels suitable for our purposes.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

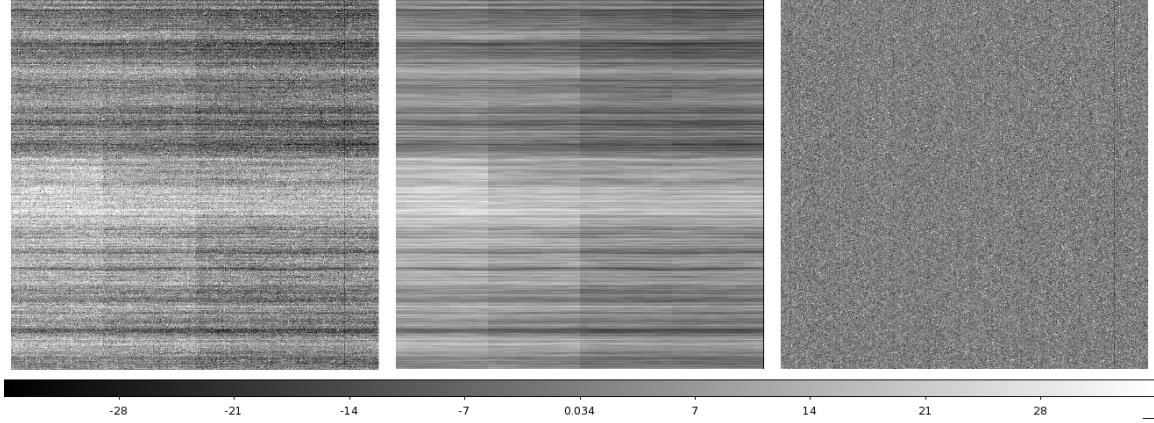


Figure 1 Example of the difference between the last and the first group. The left panel shows the uncorrected image, the middle panel the 1/f correction, and the right panel the corrected image. All panels have the same gray scale.

Table 2 This Table shows for each amplifier a the 3σ clipped weighted mean and its standard deviation of the read noise $\sigma_{RN,a}$ after the 1/f correction is applied as described in §3.2. For each mean, between 10 and 38 images were used (see Table 1).

Detector	$\sigma_{RN,1}$		$\sigma_{RN,2}$		$\sigma_{RN,3}$		$\sigma_{RN,4}$	
	mean	stdev	mean	stdev	mean	stdev	mean	stdev
A1	5.268	0.043	5.299	0.028	5.283	0.011	5.672	0.023
A3	5.369	0.018	4.660	0.012	4.727	0.010	4.578	0.010
A4	5.346	0.010	5.087	0.014	5.211	0.011	5.382	0.010
A5	4.669	0.020	4.588	0.011	4.975	0.016	5.877	0.014
B1	5.518	0.011	5.509	0.012	5.343	0.015	5.424	0.007
B2	4.759	0.009	4.502	0.013	4.764	0.011	4.401	0.011
B3	5.471	0.014	5.560	0.027	4.962	0.023	5.332	0.015
B4	4.737	0.006	4.904	0.012	4.554	0.011	4.420	0.010
B5	5.059	0.011	4.874	0.017	5.091	0.011	5.216	0.020

3.2 Image Reduction

For our analysis we first subtract the first group of the dark ramp from all subsequent groups. This removes all fixed pattern (bias) structures from the images that would render impossible our spatial analysis, at the expense of doubling the readout noise (variance) and injecting some correlated 1/f noise between images (the one of the first image). Since cross-talk is a small effect, it is therefore important to further reduce the noise, in particular the dominant 1/f noise. The left panel of Figure 1 shows the uncorrected difference between the first and last group of a typical ramp, showing the typical 1/f-noise horizontal bands. Also in order to speed up the analysis, we only used one out of every five groups. This means that after subtracting the 1st group from each ramp of 108 groups, we considered only 21 groups.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

Table 3 This table shows for each amplifier a the 3-sigma clipped weighted mean and its standard deviation of the 1/f noise $\sigma_{1/f,a}$ derived from the 1/f correction image described in §3.2. For each mean, between 10 and 38 images were used (see Table 1).

Detector	$\sigma_{1/f,1}$		$\sigma_{1/f,2}$		$\sigma_{1/f,3}$		$\sigma_{1/f,4}$	
	mean	stdev	mean	stdev	mean	stdev	mean	stdev
A1	5.452	0.400	5.415	0.432	5.329	0.401	5.397	0.423
A3	3.783	0.321	3.756	0.298	3.798	0.317	3.820	0.343
A4	3.613	0.307	3.611	0.264	3.632	0.265	3.867	0.312
A5	6.302	0.562	6.696	0.528	6.525	0.528	6.514	0.566
B1	6.743	0.703	6.670	0.694	6.702	0.639	6.795	0.682
B2	5.469	0.463	5.505	0.497	5.907	0.496	5.717	0.525
B3	4.855	0.343	5.052	0.380	4.959	0.344	5.090	0.317
B4	5.325	0.452	5.137	0.345	5.205	0.457	5.358	0.475
B5	8.051	0.632	7.901	0.541	7.932	0.507	7.828	0.491

To remove the 1/f noise, we determine a correction from the science images alone. This has the advantage that we can use many more pixels per row, and the 1/f correction is not limited by having only 8 reference pixels per row read at a single intermediate frequency. Our original idea was to calculate for each pixel the 3σ -clipped uncertainty-weighted average of the adjacent 100 pixels, located on the same row. In practice, after some experimentation, in order to speed up the reduction process we decided to do this calculation every 50th pixel and set all pixels within 25 pixels to the same value. Since most of the 1/f noise is at low frequencies, and fully dominated by readout noise above 3KHz (corresponding to 30 pixels), this is sufficiently accurate. The middle panel of Figure 1 shows this correction we calculate, and the right panel shows the 1/f corrected (subtracted) image. The resulting image does not show any signs of the 1/f bands and has (nearly) zero average.

In Figure 2, we plot the contribution from the 1/f noise $\sigma_{1/f}$ (calculated as the standard deviation of the correction image) versus the read noise after correction σ_{RN} (calculated as the standard deviation of the corrected image) for the different detectors and amplifiers. The readout noise, after dividing by $\sqrt{2}$ to account for the differential image, ranges between 4 and 6 ADUs, with small variations for each given detector/amplifier. The 1/f noise contribution shows a much stronger variation, ranging overall from 3 to 9 ADU: the 1/f noise therefore appears to contribute an amount of noise larger than the readout noise, especially for Module B. Tables 2 and 3 show the mean σ_{RN} and $\sigma_{1/f}$ for the different detectors and amplifiers derived from all the dark frames used.

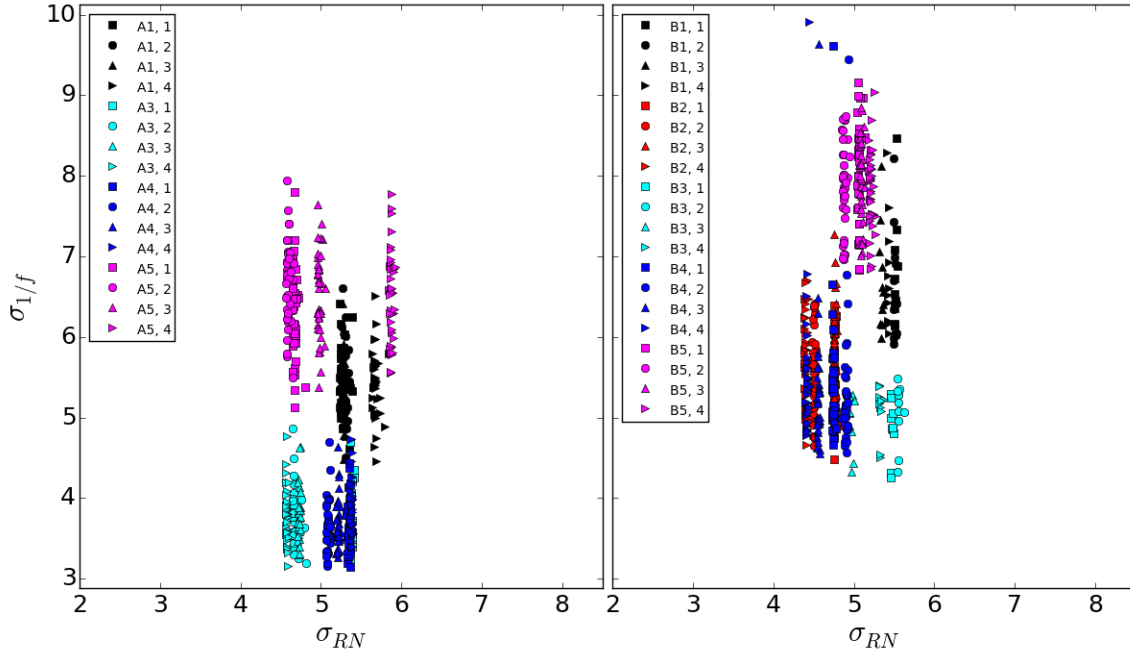


Figure 2 The left and right panel show the $1/f$ noise $\sigma_{1/f}$ versus the read noise σ_{RN} for module A and B, respectively. Amplifiers 1-4 are indicated with squares, circles, triangle, and diamonds, respectively. Different colors indicate different detectors.

3.3 Hot Pixels

We can determine the cross-talk using pixels that have a significantly higher count than the average. One choice is cosmic rays, another choice is hot pixels. For our analysis we choose hot pixels, since they usually represent a stable characteristic of the detector. We identify hot pixels with the following recipe:

- We use a set of 10 dark ramps for each detector
- For each dark, we subtract the first group from the last group, and then identify all pixels with more than 600 counts as hot pixel candidates. We note that the typical dark signal is on the order of 20 counts in the long wavelength detectors, and significantly smaller than 10 counts in the short wavelength detectors.
- A candidate is selected as a hot pixel if it is found in at least 50% of the ramps.

The # of hot pixels varies strongly with detector and amplifier (see Table 1), which has an impact on the uncertainty of the cross-talk determination.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

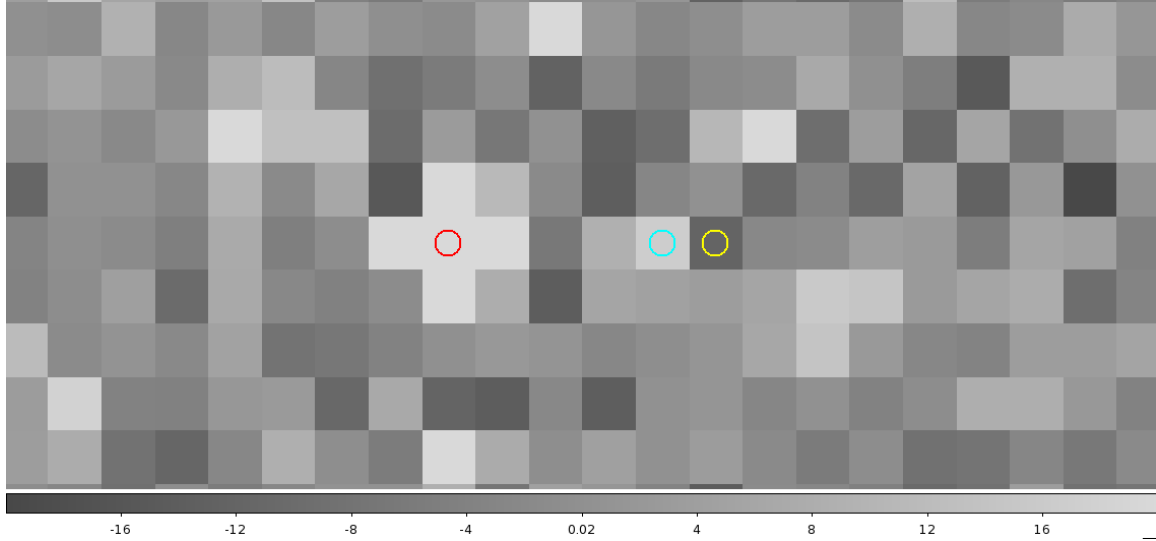


Figure 3 Example of the cross-talk between amplifier 1 and 2 of the BLONG detector. The transition between amplifier 1 and 2 is between the columns at $x = 511$ and 512 . The hot pixel is at $x_1 = 509$ (red circle). The corresponding position $x_2 = 514$ is marked with a yellow circle, and the pixel read out directly after at $x_2 = 513$ with a cyan circle.

3.4 Calculating the Cross-talk

The first step to calculate the cross-talk is to determine the position of the pixel (x_b, y_b) in the victim amplifier b that is read out at the same time as the hot pixel at (x_a, y_a) in the offender amplifier a . Due to the setup of the NIRCcam amplifiers, $y_b = y_a$. Amplifier 1 and 3 are read out to the right (i.e., pixels are read out along the positive x-axis direction) whereas amplifier 2 and 4 are read out towards the left (i.e., pixels are read out along the negative x-axis direction). Therefore we consider 2 cases, with the convention that the first pixel read out in the image has $(x, y) = (0, 0)$:

for a in $[1, 3]$

$$\Delta x = x_a - (a - 1) \times 512 \quad (3)$$

$$x_b = (b - 1) \times 512 + \Delta x \quad (4)$$

for a in $[2, 4]$

$$\Delta x = a \times 512 - x_a \quad (5)$$

$$x_b = b \times 512 - \Delta x \quad (6)$$

An example is shown in Figure 3: here the hot pixel in amplifier 1 at x_1 is indicated with a red circle. The corresponding pixel in amplifier 2 at position x_2 indicated with a yellow circle shows a somewhat more negative signal than the background. We also note that the pixel readout directly after at position $x_2 - 1$, indicated by a cyan circle, has a somewhat more positive signal.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

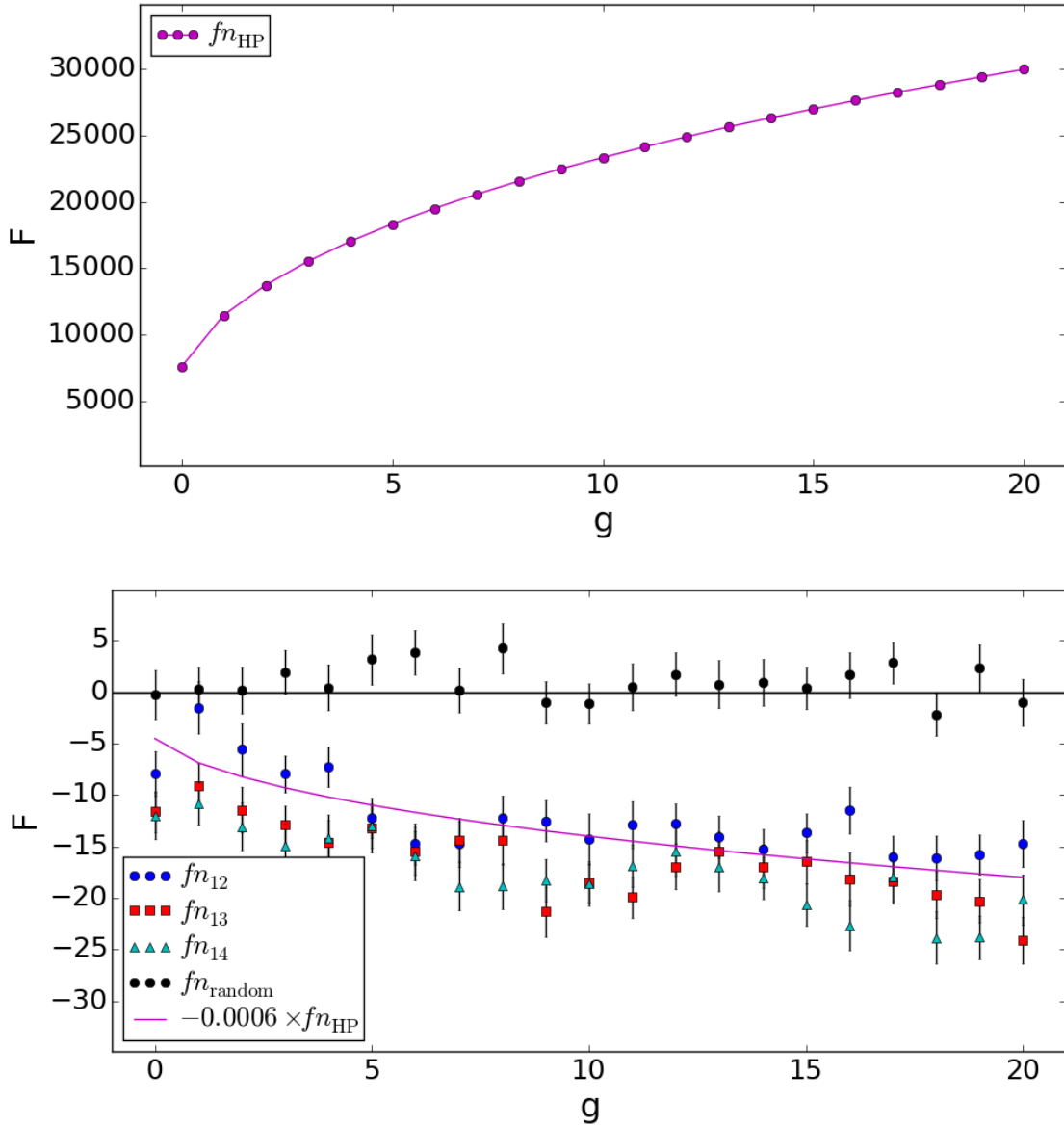


Figure 4 Upper panel: average ramp of all hot pixels after the individual ramps are scaled so that the last group has 30000 counts. Lower panel: average ramp of the victim pixels after the same individual scaling is applied.

However, these signals are often within 3σ of the mean background level. Just for illustration purposes, we scale all hot pixel ramps in amplifier 1 so that the count in the last group is 30,000 ADUs, and average them to derive a representative hot pixel ramp (upper panel of Figure 4). Then we apply the same scaling factors to the pixel ramps in each of the 3 victim amplifiers that are read out at the same time than the offending pixel, and create an average victim ramp for each of those amplifiers (lower panel of Figure 4). For comparison, we also plot a line showing the hot pixel counts multiplied by an ad-hoc

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

factor -0.0006. Finally, as a control, we do the same scaling and averaging for a randomly selected pixel. The plot illustrates that for offender amplifier 1 of SCA A1, the cross-talk values are about -0.065%. For the victim this corresponds to about 35 ADUs at offending saturation level (55,000 ADUs). We note that the non-linear shape of the hot pixel ramp is conserved in the victim pixel signal, which represents both a strong confirmation and, at least in principle, a complication requiring an ad-hoc non-linearity correction even at low signal levels.

Since the shape is preserved, for a given hot pixel at (x_a, y_a) , we can calculate the cross-talk $xt_{ab,0}$ (where '0' indicates the victim pixel, read out at the same time as the offender pixel) independently on the intensity of the signal, using the relation

$$xt_{ab,0}(x_a, y_a) = \frac{f(x_b, y_b)}{f(x_a, y_a)} \quad (7)$$

We also investigate the pixels next to the victim at (x_b, y_b) :

$$xt_{ab,+1}(x_a, y_a) = \frac{f(x_b + 1, y_b)}{f(x_a, y_a)} \quad (8)$$

$$xt_{ab,-1}(x_a, y_a) = \frac{f(x_b - 1, y_b)}{f(x_a, y_a)} \quad (9)$$

$$xt_{ab,+2}(x_a, y_a) = \frac{f(x_b + 2, y_b)}{f(x_a, y_a)} \quad (10)$$

$$xt_{ab,-2}(x_a, y_a) = \frac{f(x_b - 2, y_b)}{f(x_a, y_a)} \quad (11)$$

We want to determine if the readout direction has an impact on the cross-talk. Therefore we define as $xt_{ab,post}$ the cross talk for the pixel that is read out directly after (x_b, y_b) , and as $xt_{ab,pre}$ the one that is read out directly before:

$$xt_{ab,post} = \begin{cases} xt_{ab,+1} & \text{for } b \text{ in } [1, 3] \\ xt_{ab,-1} & \text{for } b \text{ in } [2, 4] \end{cases} \quad (12)$$

$$xt_{ab,pre} = \begin{cases} xt_{ab,-1} & \text{for } b \text{ in } [1, 3] \\ xt_{ab,+1} & \text{for } b \text{ in } [2, 4] \end{cases} \quad (13)$$

For NIRCcam detectors, it is always true that $y_b = y_a$ and we can assume for our dark frames that the signal $f(x_b, y_b) \ll f(x_a, y_a)$ and is close to zero. This means that the uncertainty in $f(x_b, y_b)$, after 1/f correction, is read noise dominated, and therefore the uncertainty in xt_{ab} can be estimated as:

$$\sigma_{xt,ab} = \frac{\sigma_{RN,b}}{f(x_a, y_a)} \quad (14)$$

We can use this uncertainty for all cross-talk values $xt_{ab,k}$ (see Equation 7 to 13) associated with a given offender hot pixel at (x_a, y_a) .

3.5 Calculating the Cross-talk for a Given Image and Group

For any given image i , group g , and amplifier a we can now calculate the cross-talk values $XT_{ab,k}(i,g)$ by calculating the 3-sigma clipped weighted average of $xt_{ab,k}(x_b,y_b)$ for all hot pixels in amplifier a . Figure 5 shows an example of the cross-talk values $XT_{1b,0}(i,g)$ (blue points) for amplifier 1 as offender, together with $XT_{1b,k}(i,g)$ for the first ($k = \text{post} - \text{blue}$, pre - black) and second $k = \pm 2$ (black) adjacent pixels. The plot shows that only the pixels that are read-out at the same time ($XT_{1b,0}(i,g)$) or immediately after ($XT_{1b,\text{post}}(i,g)$) the offending pixel show cross-talk values significantly different from zero. Furthermore, it appears that $XT_{1b,0}(i,g) \approx -XT_{1b,\text{post}}(i,g)$, an unexpected feature which we will investigate further in §3.8.

In general, the cross-talk values don't show a dependence on the group g . On the other hand, the uncertainties for the cross-talk values for small g are larger since the signal in the hot pixels is smaller for small g (see Equation 14). In Figure 6, we show the reduced χ^2 histograms of 4 randomly selected examples of $XT_{ab,k}(i,g)$ using all detectors, images, and groups. The reduced χ^2 histograms have their peak very close to 1.0 and have a modest width. We conclude therefore that our 1/f-correction (see §3.2) works as expected, and Equation 14 is an excellent estimate of the uncertainty in the cross-talk values. We note that both determining the cross-talk coefficients as well as correcting for the cross-talk needs to be done before any non-linearity correction is applied. The reason is that any non-linearity correction would not correct for the non-linearity of the cross-talk signal itself (see lower panel of Figure 4). Thus the offending hot pixel ramp would be a straight line, whereas the victim pixel ramp would still be non-linear, leading to a signal-dependent cross-talk.

3.6 Final Values of the Cross-talk

For a given SCA, we calculate the final cross-talk values $\overline{XT}_{ab,k}$ as the 3σ -clipped weighted average of all $\overline{XT}_{ab,k}$, for all difference images i and group $g = 20$ (see Figure 7 for an example of SCA A1 and offending amplifier 1). We note that $g = 20$ in the difference image corresponds to group $g = 105$ in the original image (see Section 3.2). The final values of $\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,\text{post}}$ are shown in Tables 5, 6 and Tables 7, 8, ranging from -9×10^{-4} to 8×10^{-4} .

The uncertainty in $\overline{XT}_{ab,k}$ depends mostly on the number of images used and the number of hot pixels in the offender amplifier. Since the number of hot pixels is similar for all amplifiers in a given SCA (see Table 1), the median of these uncertainties is a good estimate of the uncertainties of all \overline{XT} values of a given SCA. The uncertainties range from $\sim 4 \times 10^{-6}$ for the long wavelength SCA's with many hot pixels to $\sim 3.5 \times 10^{-5}$ for SCA B3, which has the lowest number of hot pixels and images. Table 4 lists the minimum, maximum, and median of the uncertainties for $\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,\text{post}}$ in columns 2-4, respectively, for each detector.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

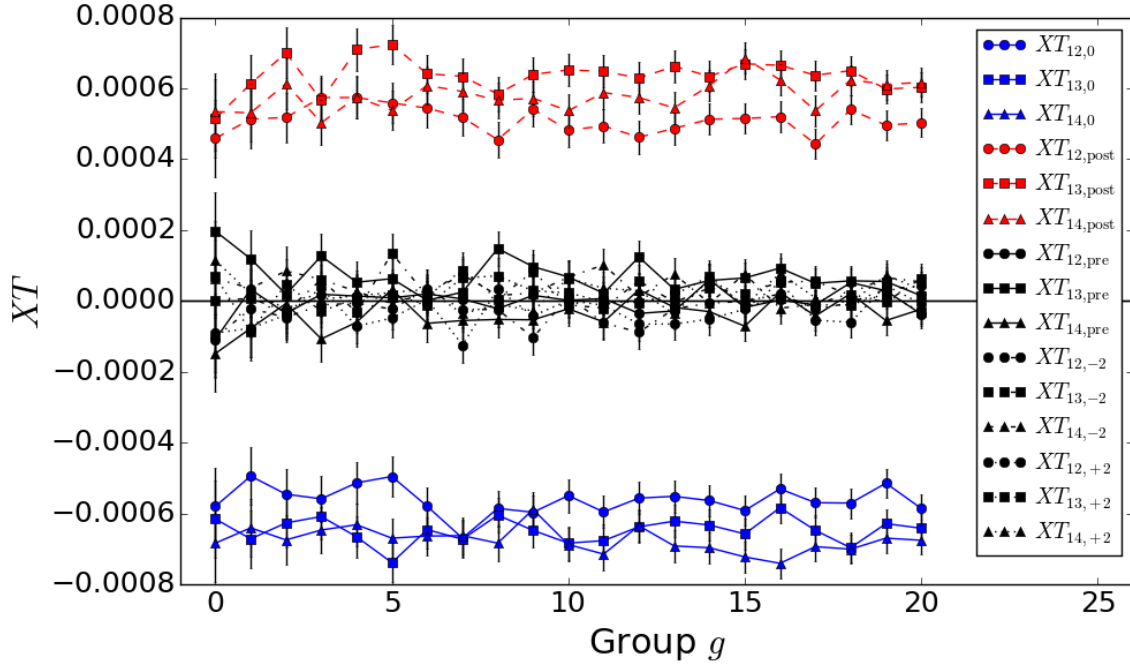


Figure 5 Cross-talk values $XT_{lb,k}$ versus group g for offender amplifier 1 of SCA A1 determined independently from the different groups of an example dark frame, where k is in $[0, \text{post}, \text{pre}, -2, +2]$.

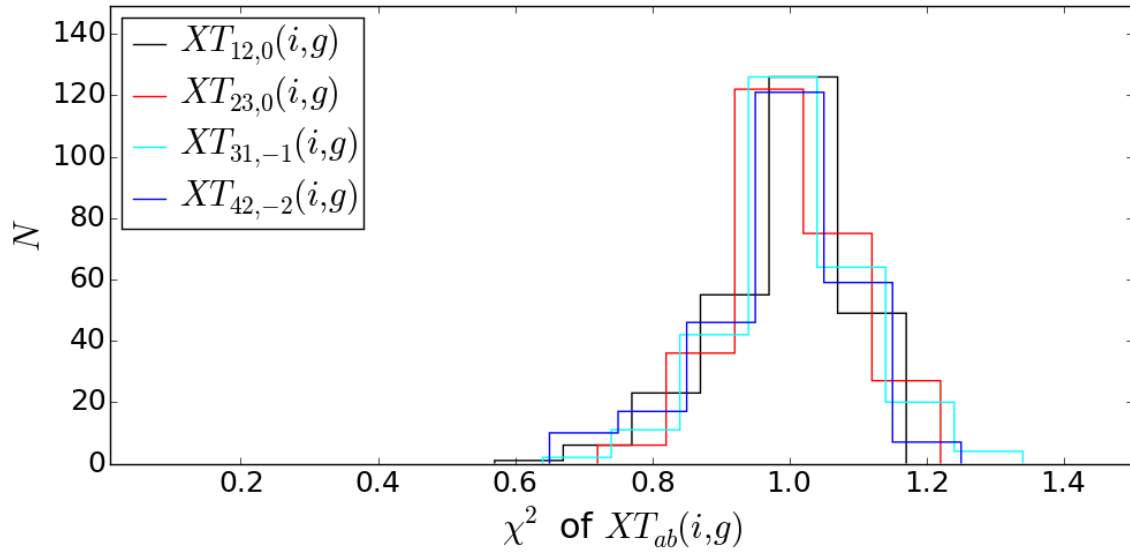


Figure 6: χ^2 histograms of 4 randomly selected examples of cross-talk ($\overline{XT}_{12}(i,g)$, $\overline{XT}_{23}(i,g)$, $\overline{XT}_{31,-1}(i,g)$, $\overline{XT}_{42,-2}(i,g)$) using all detectors, images, and groups.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

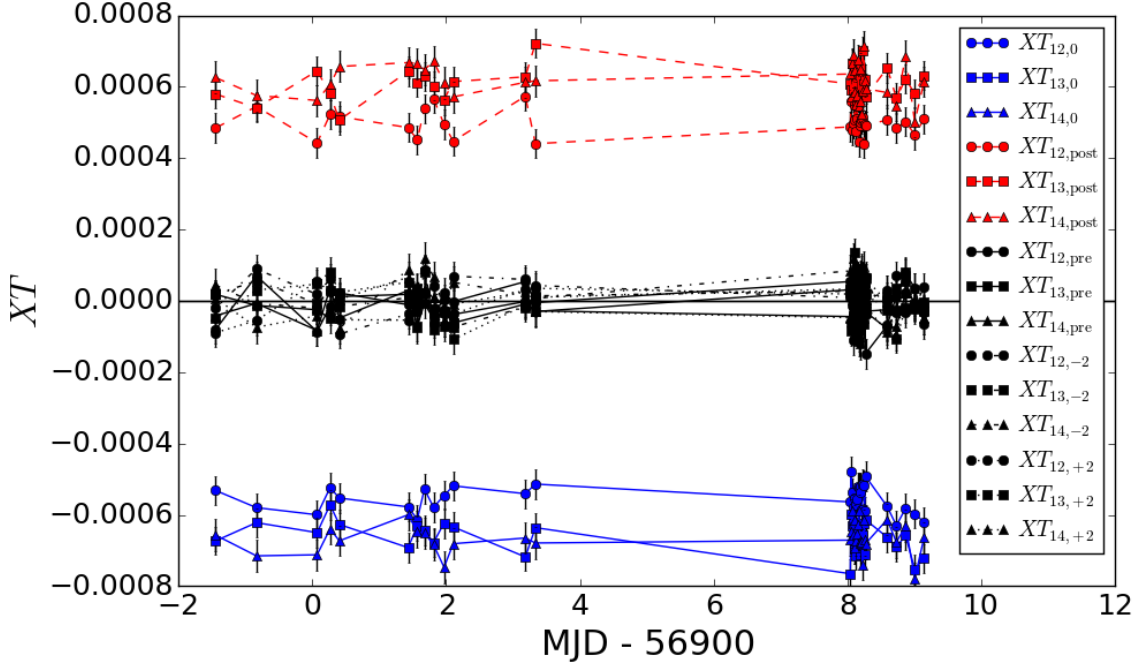


Figure 7 Cross-talk values $\overline{XT}_{1b,k}$ versus MJD for offender amplifier 1 of SCA A1 determined independently from the last group of an example dark frame, where k is in $[0, \text{post}, \text{pre}, -2, +2]$.

3.7 Time Dependence of the Cross-talk

In Figure 7, we show the $\overline{XT}_{ab,k}(i, g)$ values versus MJD of SCA A1 for amplifier $a = 1$ and the last group $g = 20$, the worst offender due to the highest counts. The plot shows no obvious temporal variation in the cross-talk. The same plots for all detectors and offender amplifiers, shown in Figures 10-27, provide similar qualitative results.

Next we will obtain quantitative limits on the time dependence. When we calculate the weighted mean $\overline{XT}_{ab,k}$, we also calculate their standard deviations, and reduced χ^2 . The left panel of Figure 8 shows the χ^2 distributions of $\overline{XT}_{ab,k}$ for k in $[0, \text{post}, -2, +2]$. All χ^2 distributions peak at ~ 1 , indicating that the error propagation has worked. The spread in the χ^2 values can be expected since the averages are done with 10-38 values (since there are 10-38 images per SCA). Most importantly, the χ^2 distributions for the victim pixel that show the cross-talk effect ($\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,\text{post}}$) are not different to the ones from the pixels that do not show the cross-talk effect ($\overline{XT}_{ab,-2}$ and $\overline{XT}_{ab,+2}$). Any true temporal variations of the cross-talk would cause the χ^2 distribution of $\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,\text{post}}$ to skew toward larger values. Table 9 lists the minimum, maximum, and median of the χ^2 for each detector.

The right panel of Figure 9 shows the standard deviations of $\overline{XT}_{ab,k}$ versus $\overline{XT}_{ab,0}$ for k in $[\text{post}, -2, +2]$. The standard deviation depends mainly on the number of hot pixels in the offending amplifier, causing the spread from 2×10^{-5} to 1.5×10^{-4} (see also column 5-7 in Table 4). There is an excellent 1 to 1 correlation between the standard deviations of the

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

different $\overline{XT}_{ab,k}$. Any temporal variation in the cross-talk would increase the standard deviations, and would cause a deviation from this 1 to 1 correlation when comparing victim pixels that show no cross-talk ($\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,post}$) to victim pixels with cross talk ($\overline{XT}_{ab,-2}$ and $\overline{XT}_{ab,+2}$). Furthermore, temporal variations have the strongest contribution in small standard deviations, so if there are significant temporal variations, strong deviations from the 1 to 1 correlation would be seen for small standard deviations, which is not the case (right panel of Figure 8).

We conclude that with the current data there is no evidence for temporal variations in the cross-talk. The standard deviations give upper limits on the temporal variations, and mainly depend on the number of hot pixels in a given SCA and offending amplifier. For the long wavelength SCA's (ALONG and BLONG), the upper limits on variability is 3×10^{-5} . For the short wavelength SCA's, the limits range from 4×10^{-5} to 1.5×10^{-4} . The standard deviations are listed in Table 4 for each SCA.

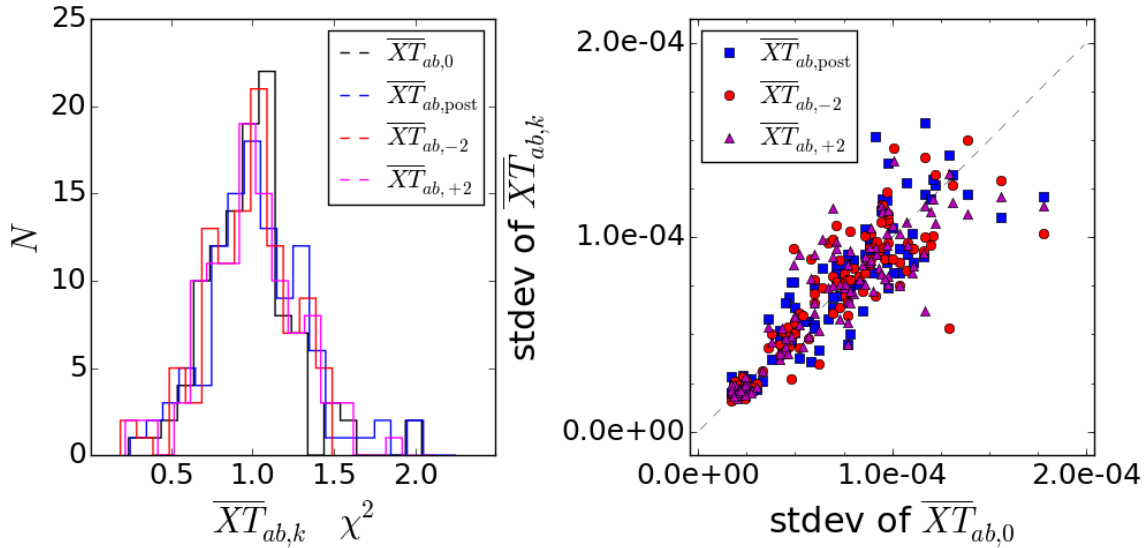


Figure 8 The left and right panels show the χ^2 and standard deviation of the $\overline{XT}_{ab,k}$.

3.8 Dependence of $\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,post}$

In Figure 9 we plot $\overline{XT}_{ab,k}$ versus $\overline{XT}_{ab,0}$ for k in [post, pre, -2, +2], for all detectors. There is a strong dependence $\overline{XT}_{ab,post} \approx -\overline{XT}_{ab,0}$, and no dependence in the other 3 cases. It is interesting to note that all the most negative cross-talk $\overline{XT}_{ab,0}$ values, and consequently the most positive $\overline{XT}_{ab,post}$ values, are caused by offender amplifier $a = 1$ (open red circles, $\overline{XT}_{ab,0} < -2.5 \times 10^{-4}$). Similarly, the 7 most positive cross-talk $\overline{XT}_{ab,0}$ values are from $\overline{XT}_{23,0}$, $\overline{XT}_{32,0}$, $\overline{XT}_{34,0}$, and $\overline{XT}_{43,0}$ of both ALONG and BLONG (indicated with the black rectangle in Figure 9). This means that all strong cross-talk is caused by either offending amplifier 1 or from well-defined offender/victim pairs in the long wavelength SCAs BLONG and ALONG.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

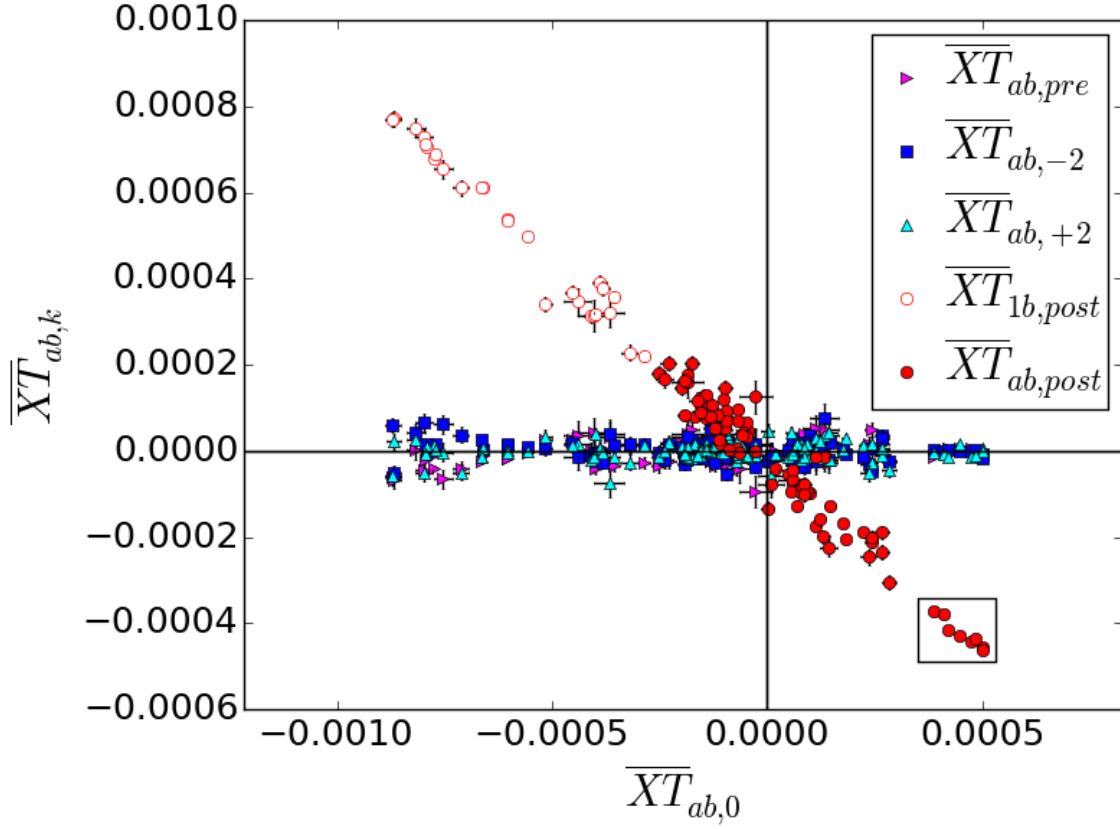


Figure 9 Plot of $\overline{XT}_{ab,k}$ versus $\overline{XT}_{ab,0}$ for k in [post, pre, -2, +2] of all detectors. The $\overline{XT}_{1b,post}$ values for offender amplifier 1 are indicated with the red open circles. The black rectangle indicates large absolute cross-talk values from ALONG and BLONG.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

Table 4 When the weighted mean $\overline{XT}_{ab,0}$ and $\overline{XT}_{ab,post}$ are calculated, their uncertainties, standard deviations, and reduced χ^2 are also derived. This table shows their minimum, maximum, and median for each SCA.

SCA	uncertainty \overline{XT}			stdev \overline{XT}			χ^2 \overline{XT}		
	min	max	median	min	max	median	min	max	median
A1	0.000007	0.000010	0.000007	0.000037	0.000069	0.000046	0.76	1.66	1.06
A3	0.000013	0.000017	0.000015	0.000058	0.000098	0.000085	0.51	1.33	1.01
A4	0.000012	0.000018	0.000013	0.000062	0.000116	0.000080	0.62	1.52	1.01
A5	0.000003	0.000005	0.000004	0.000017	0.000033	0.000024	0.55	1.32	0.94
B1	0.000015	0.000018	0.000017	0.000036	0.000078	0.000055	0.37	2.03	1.03
B2	0.000015	0.000022	0.000019	0.000072	0.000156	0.000113	0.58	1.51	0.97
B3	0.000030	0.000038	0.000033	0.000049	0.000178	0.000112	0.24	2.41	1.05
B4	0.000014	0.000018	0.000015	0.000062	0.000111	0.000090	0.53	1.61	1.01
B5	0.000003	0.000004	0.000004	0.000017	0.000028	0.000022	0.53	1.79	1.03

4 Discussion and Conclusions

After K. Volk discovered cross-talk in the NIRISS SCA on the order of 6×10^{-3} , we investigated if we find the same effect in NIRCам SCAs. We performed our analysis on a data set of long dark images (108 frames) taken during ISIM CV2. After applying a spatial filter to correct for 1/f noise, we used the hot pixels to measure with high S/N the cross-talk between different amplifiers.

We find cross-talk values between -9×10^{-4} and 8×10^{-4} . Our accuracies range between 4×10^{-6} and 3.4×10^{-5} for the final weighted means, depending on the number of images and hot pixels available for the analysis. All reduced χ^2 distributions peak at ~ 1 , indicating that our error propagation works correctly.

We do not find any evidence for temporal variations in the cross-talk down to a conservative limit of 1.5×10^{-4} for all SCAs, and for some SCAs with good statistics even down to 3×10^{-5} . We find that all extreme cross-talk values are either from offender amplifier 1, with the exception of amplifier 2 on victim 3 (\overline{XT}_{23}) or amplifier 3 on victim 2 and 4 (\overline{XT}_{32} , \overline{XT}_{34}) for the two long wavelength SCAs.

Somewhat surprisingly, we find that not only one pixel in the victim amplifier is affected by cross-talk, but two: A given pixel in the offending amplifier affects the pixel in the victim amplifier that is read out at the same time ($\overline{XT}_{ab,0}$), as well as the pixel read out directly afterwards ($\overline{XT}_{ab,post}$). In addition, the effect is inverted in that $\overline{XT}_{ab,post} \approx -\overline{XT}_{ab,0}$. Kevin Volk saw this effect when he analyzed the cross-talk ghost of a snowball in a NIRISS image: The ghost image had a positive and a negative part, which was difficult to explain at that time. With this analysis, it is now clear what caused this effect and that we can correct for it. Even though most of the cross-talk values are small compared to the IPC, their effect still needs to be corrected for. As an example, a saturated pixel produces a ghost image of ~ 40 ADUs in the victim amplifier, for a cross-talk of 8×10^{-4} , well above the 3σ detection limit. This correction can be done by simply applying Equation 2 to the data, using cross-talk coefficients pre-determined from a set of calibration dark frames. The limited CV2 data suggests that there is no temporal variation

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>

To verify that this is the current version.

in the cross-talk on timescales of at least weeks, and therefore occasional revalidation/adjustments of the cross-talk coefficients should be sufficient to ensure the continued validity of the correction.

Table 5 Cross-talk values $\overline{XT}_{ab,\theta}$ for offending amplifier 1 and 2.

SCA	$\overline{XT}_{12,0}$	$\overline{XT}_{13,0}$	$\overline{XT}_{14,0}$	$\overline{XT}_{21,0}$	$\overline{XT}_{23,0}$	$\overline{XT}_{24,0}$
A1	-0.000556	-0.000662	-0.000663	-0.000109	0.000114	-0.000168
A3	-0.000410	-0.000515	-0.000454	-0.000142	0.000002	-0.000192
A4	-0.000286	-0.000398	-0.000355	-0.000029	0.000056	-0.000113
A5	-0.000603	-0.000773	-0.000770	0.000019	0.000387	-0.000048
B1	-0.000712	-0.000868	-0.000870	-0.000098	0.000243	-0.000147
B2	-0.000753	-0.000816	-0.000797	-0.000094	0.000131	-0.000199
B3	-0.000403	-0.000440	-0.000367	-0.000071	0.000010	-0.000066
B4	-0.000320	-0.000390	-0.000381	-0.000045	0.000061	-0.000089
B5	-0.000605	-0.000790	-0.000793	0.000048	0.000473	-0.000056

Table 6 Cross-talk values $\overline{XT}_{ab,\theta}$ for offending amplifier 3 and 4.

SCA	$\overline{XT}_{31,0}$	$\overline{XT}_{32,0}$	$\overline{XT}_{34,0}$	$\overline{XT}_{41,0}$	$\overline{XT}_{42,0}$	$\overline{XT}_{43,0}$
A1	-0.000154	0.000182	0.000223	-0.000185	-0.000100	0.000177
A3	-0.000138	0.000078	0.000071	-0.000133	-0.000068	0.000094
A4	-0.000093	0.000099	0.000147	-0.000098	-0.000048	0.000086
A5	-0.000135	0.000410	0.000446	-0.000155	-0.000069	0.000420
B1	-0.000252	0.000236	0.000283	-0.000230	-0.000192	0.000268
B2	-0.000175	0.000267	0.000242	-0.000238	-0.000160	0.000143
B3	-0.000095	0.000133	0.000113	-0.000186	-0.000027	0.000059
B4	-0.000116	0.000079	0.000124	-0.000156	-0.000120	0.000086
B5	-0.000128	0.000502	0.000500	-0.000142	-0.000058	0.000484

Table 7 Cross-talk values $\overline{XT}_{ab,post}$ for offending amplifier 1 and 2.

SCA	$\overline{XT}_{12,post}$	$\overline{XT}_{13,post}$	$\overline{XT}_{14,post}$	$\overline{XT}_{21,post}$	$\overline{XT}_{23,post}$	$\overline{XT}_{24,post}$
A1	0.000500	0.000612	0.000611	0.000017	-0.000173	0.000080
A3	0.000313	0.000341	0.000369	0.000076	-0.000134	0.000083
A4	0.000220	0.000317	0.000359	-0.000001	-0.000093	0.000027
A5	0.000540	0.000680	0.000689	-0.000042	-0.000373	0.000066
B1	0.000611	0.000772	0.000770	0.000054	-0.000211	0.000128
B2	0.000655	0.000751	0.000730	0.000078	-0.000199	0.000146
B3	0.000315	0.000347	0.000321	0.000008	-0.000077	-0.000004
B4	0.000229	0.000391	0.000379	0.000047	-0.000067	0.000004
B5	0.000535	0.000707	0.000712	-0.000053	-0.000442	0.000045

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

Table 8 Cross-talk values $\overline{XT}_{ab,post}$ for offending amplifier 3 and 4.

SCA	$\overline{XT}_{31,post}$	$\overline{XT}_{32,post}$	$\overline{XT}_{34,post}$	$\overline{XT}_{41,post}$	$\overline{XT}_{42,post}$	$\overline{XT}_{43,post}$
A1	0.000108	-0.000203	-0.000188	0.000176	0.000121	-0.000168
A3	0.000111	-0.000097	-0.000128	0.000080	0.000097	-0.000095
A4	0.000092	-0.000098	-0.000129	0.000148	0.000034	-0.000077
A5	0.000110	-0.000379	-0.000429	0.000123	0.000069	-0.000414
B1	0.000179	-0.000246	-0.000304	0.000204	0.000165	-0.000235
B2	0.000205	-0.000189	-0.000200	0.000167	0.000117	-0.000225
B3	0.000069	-0.000014	-0.000014	0.000161	0.000126	-0.000044
B4	0.000084	-0.000080	-0.000158	0.000090	0.000053	-0.000102
B5	0.000106	-0.000457	-0.000461	0.000131	0.000037	-0.000436

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

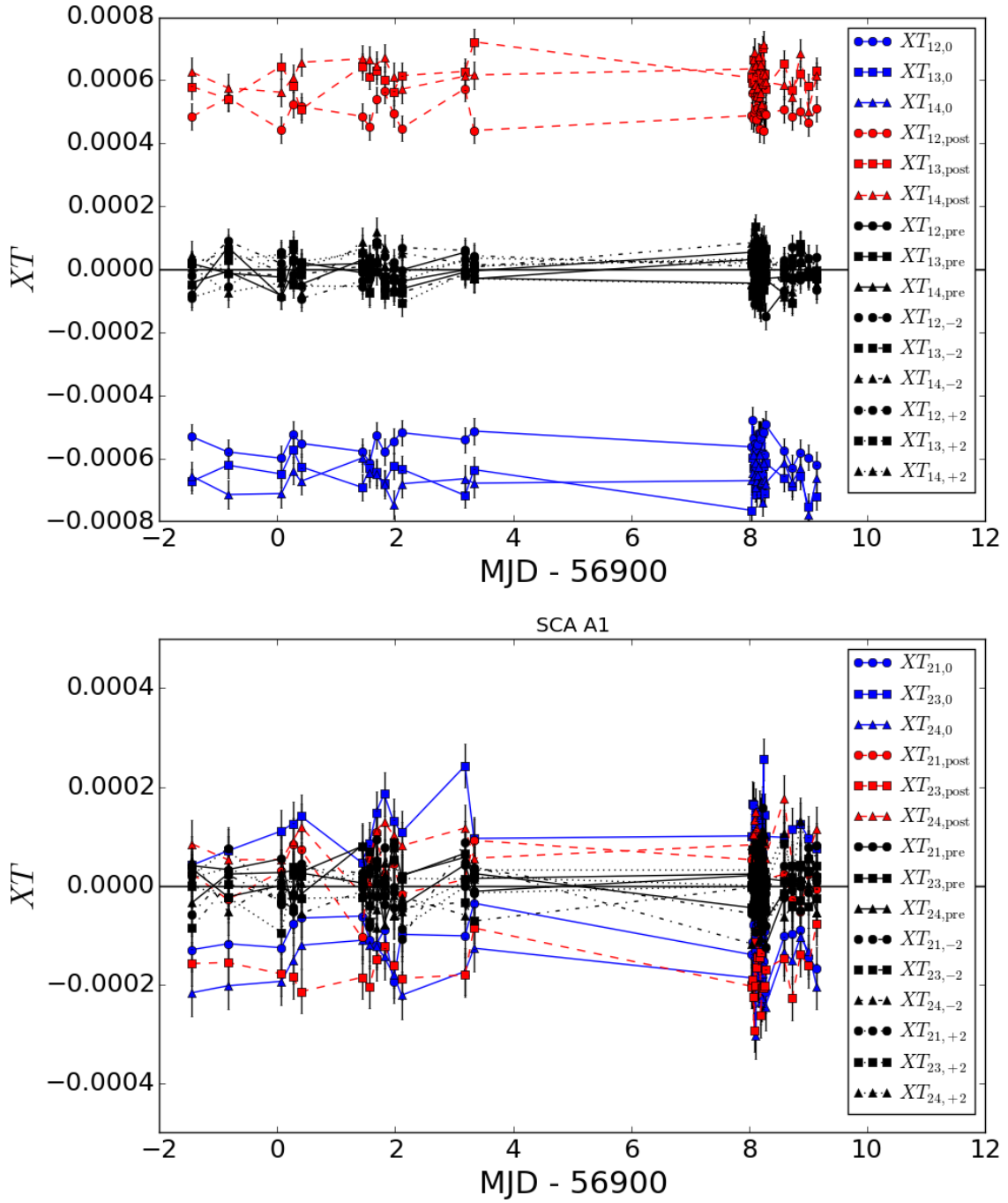


Figure 10 Cross-talk for offending amplifiers 1 and 2 of SCA A1 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

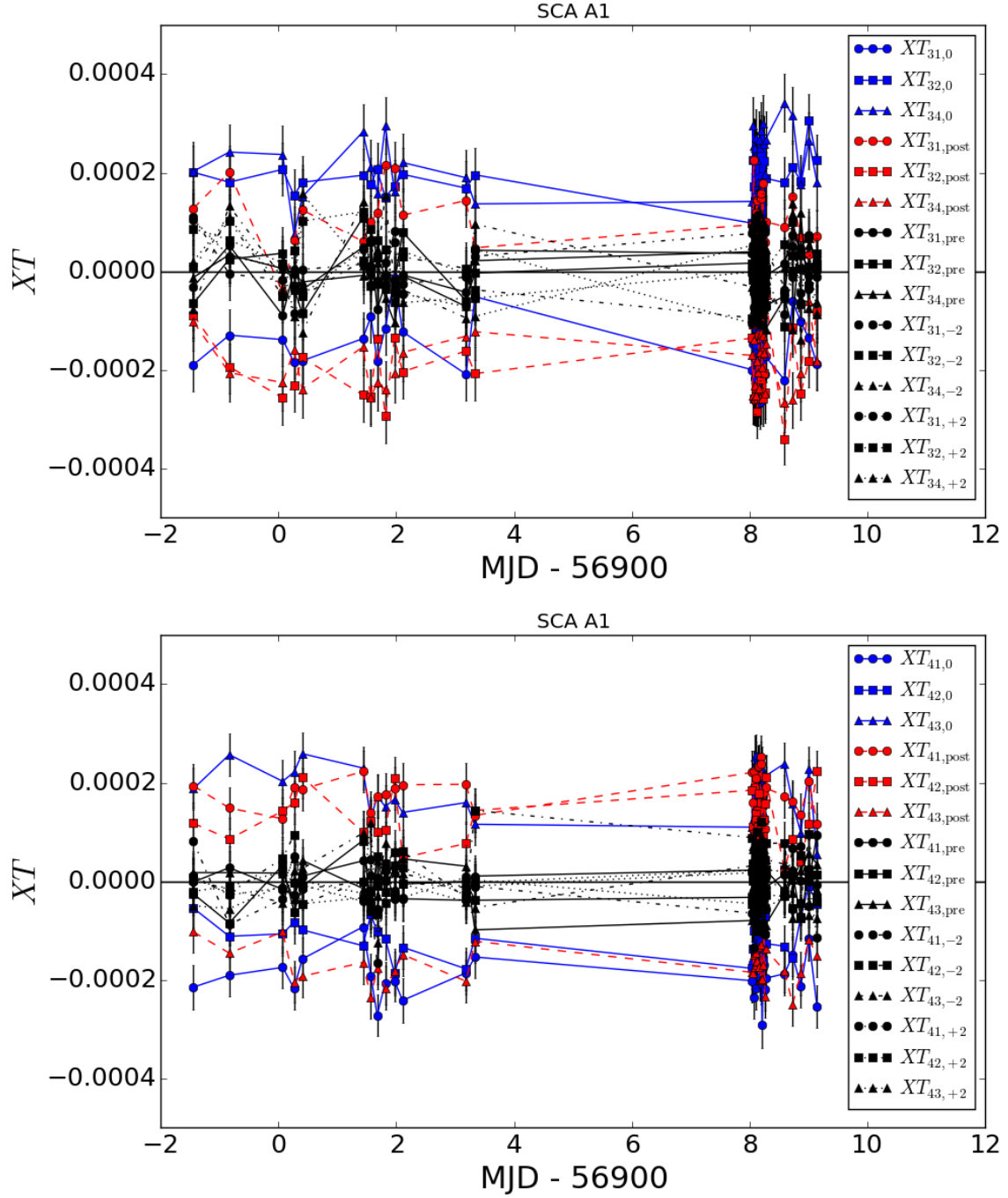


Figure 11 Cross-talk for offending amplifiers 3 and 4 of SCA A1 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

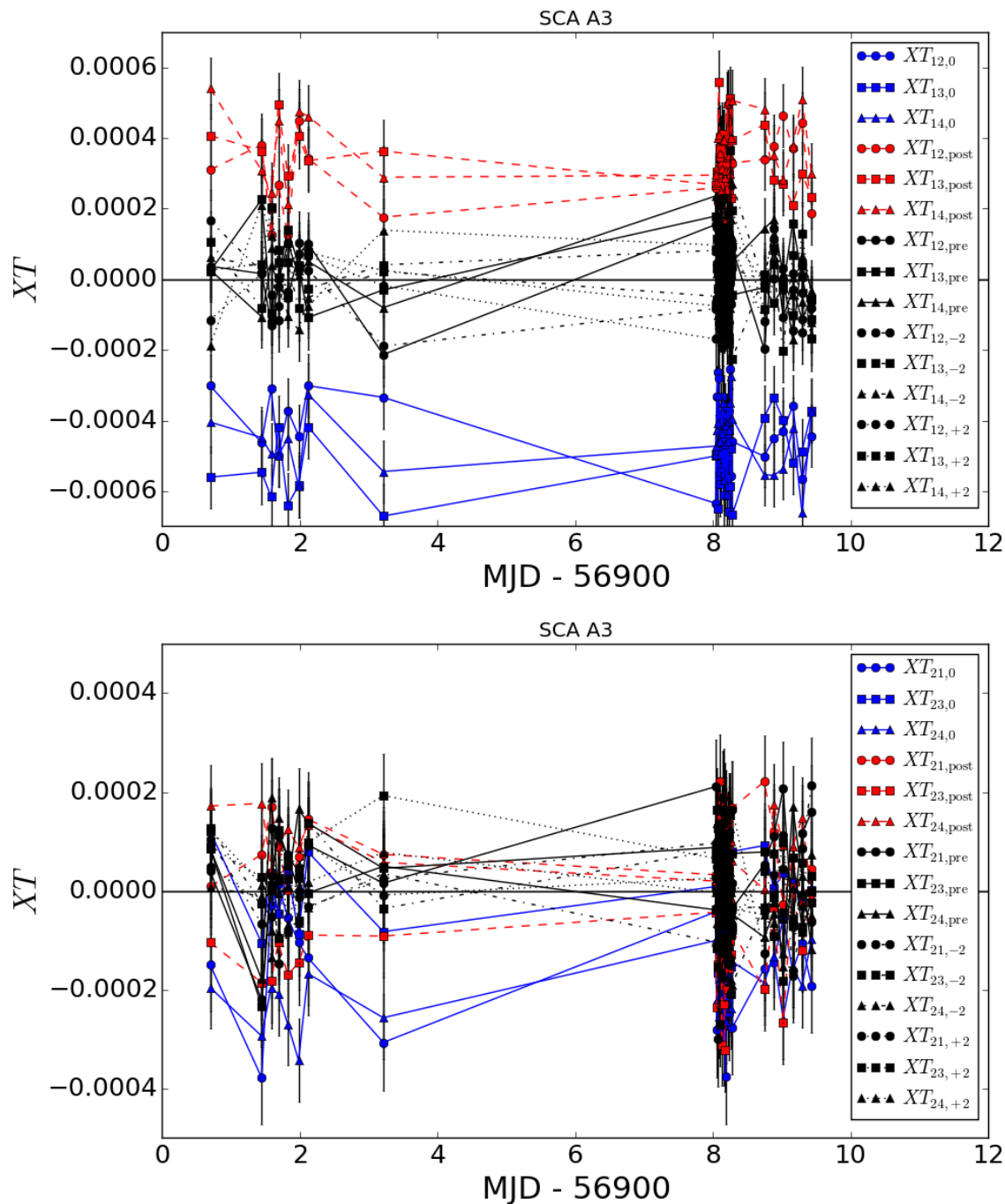


Figure 12 Cross-talk for offending amplifiers 1 and 2 of SCA A3 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

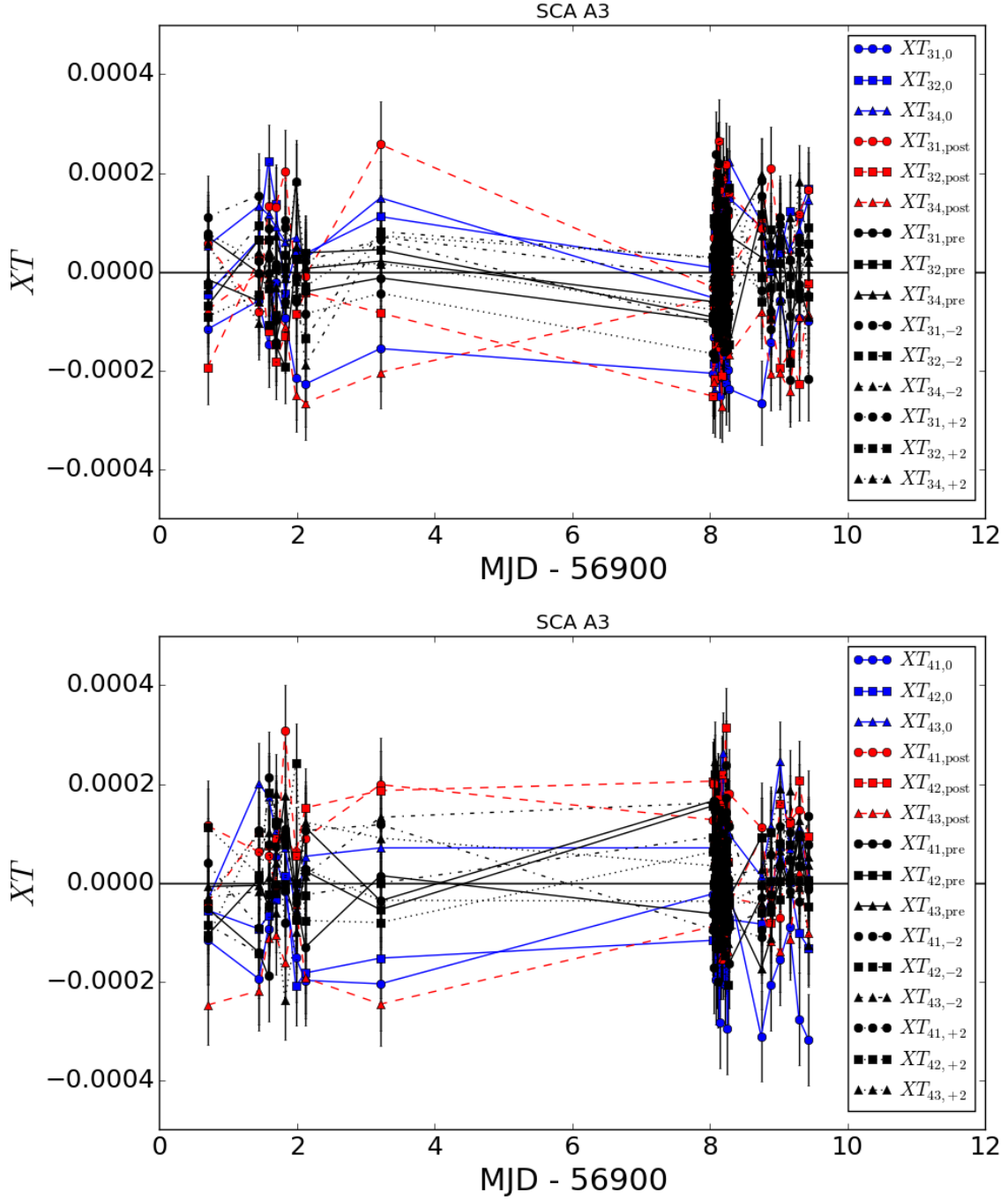


Figure 13 Cross-talk for offending amplifiers 3 and 4 of SCA A3 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

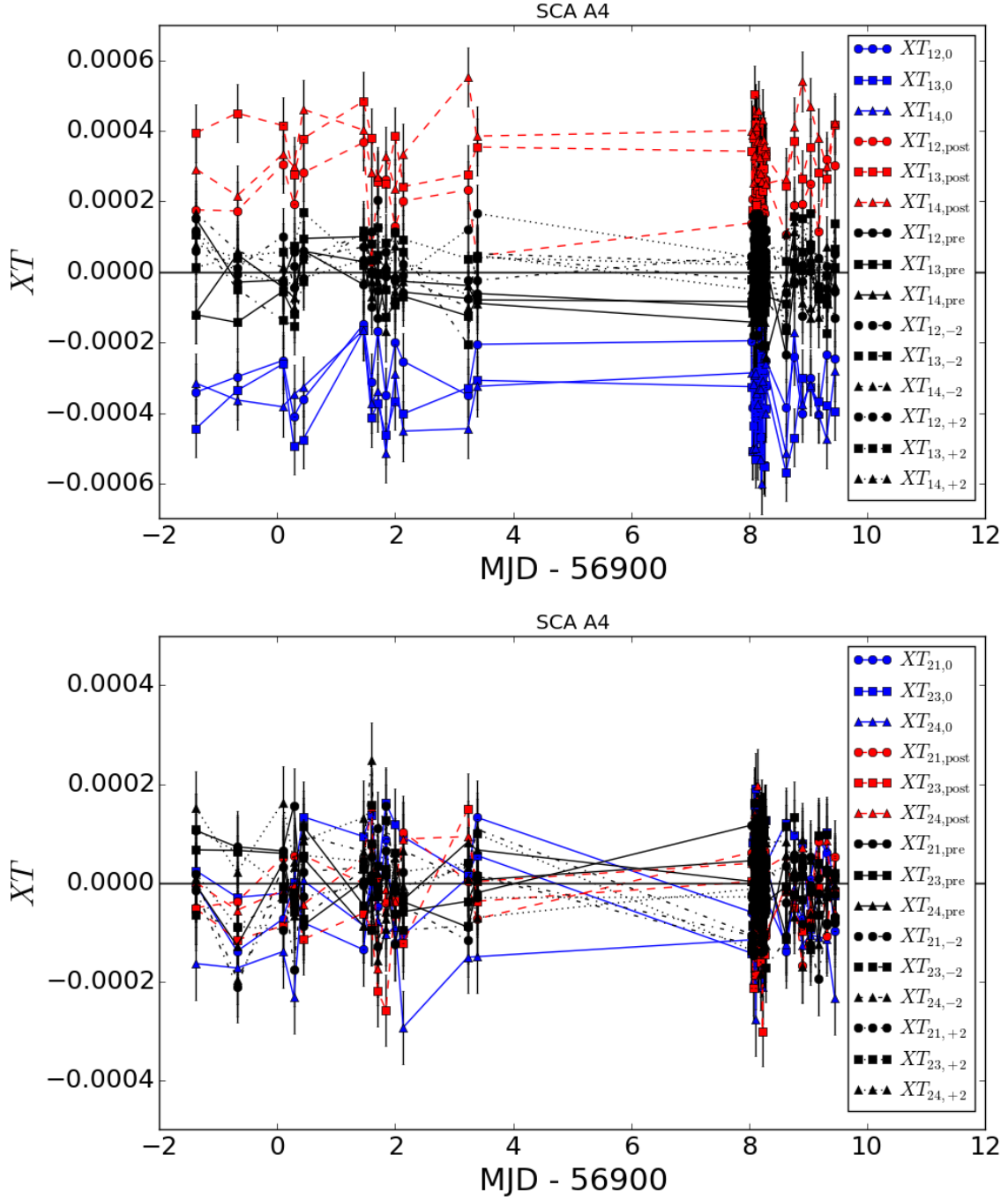


Figure 14 Cross-talk for offending amplifiers 1 and 2 of SCA A4 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

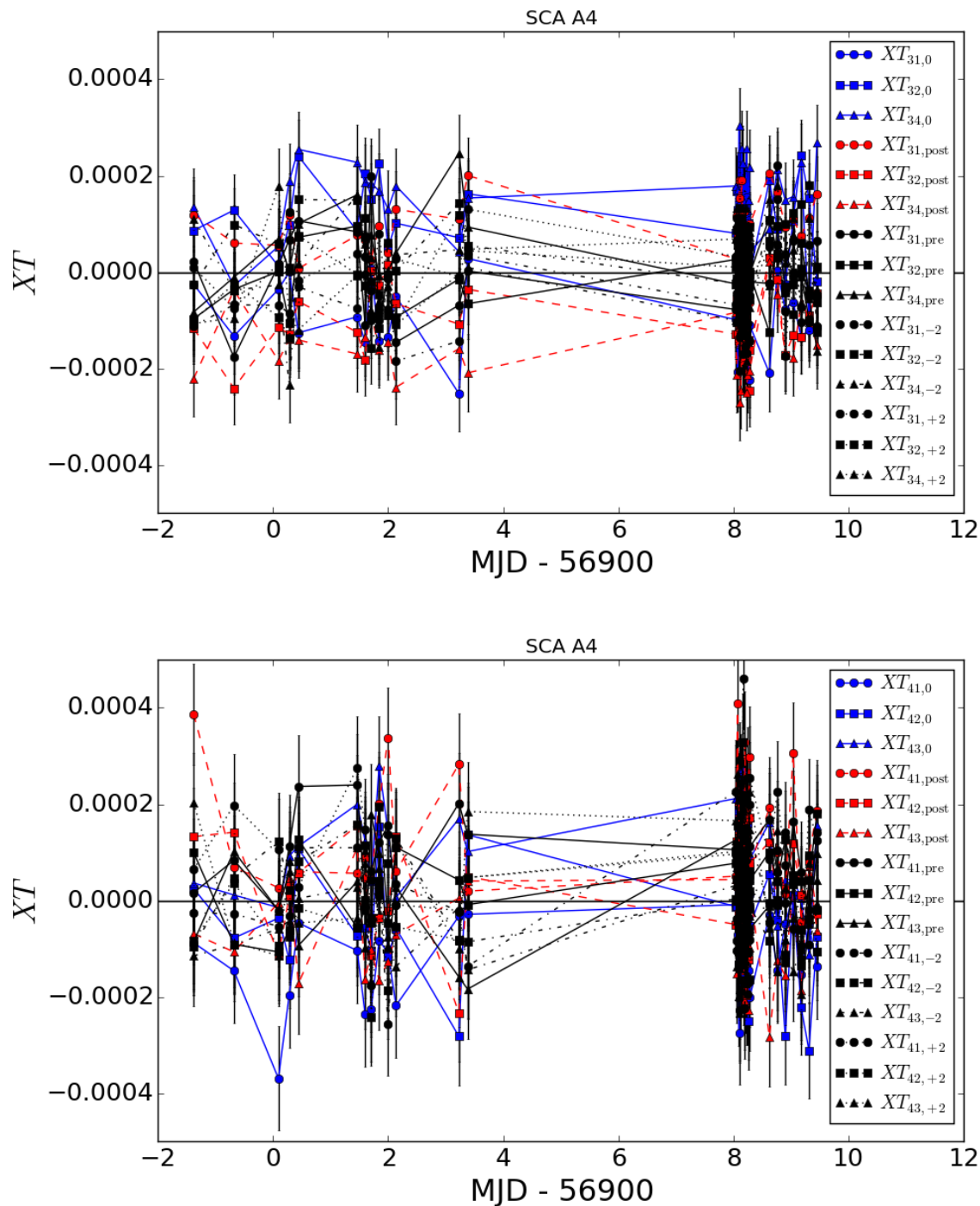


Figure 15 Cross-talk for offending amplifiers 3 and 4 of SCA A4 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

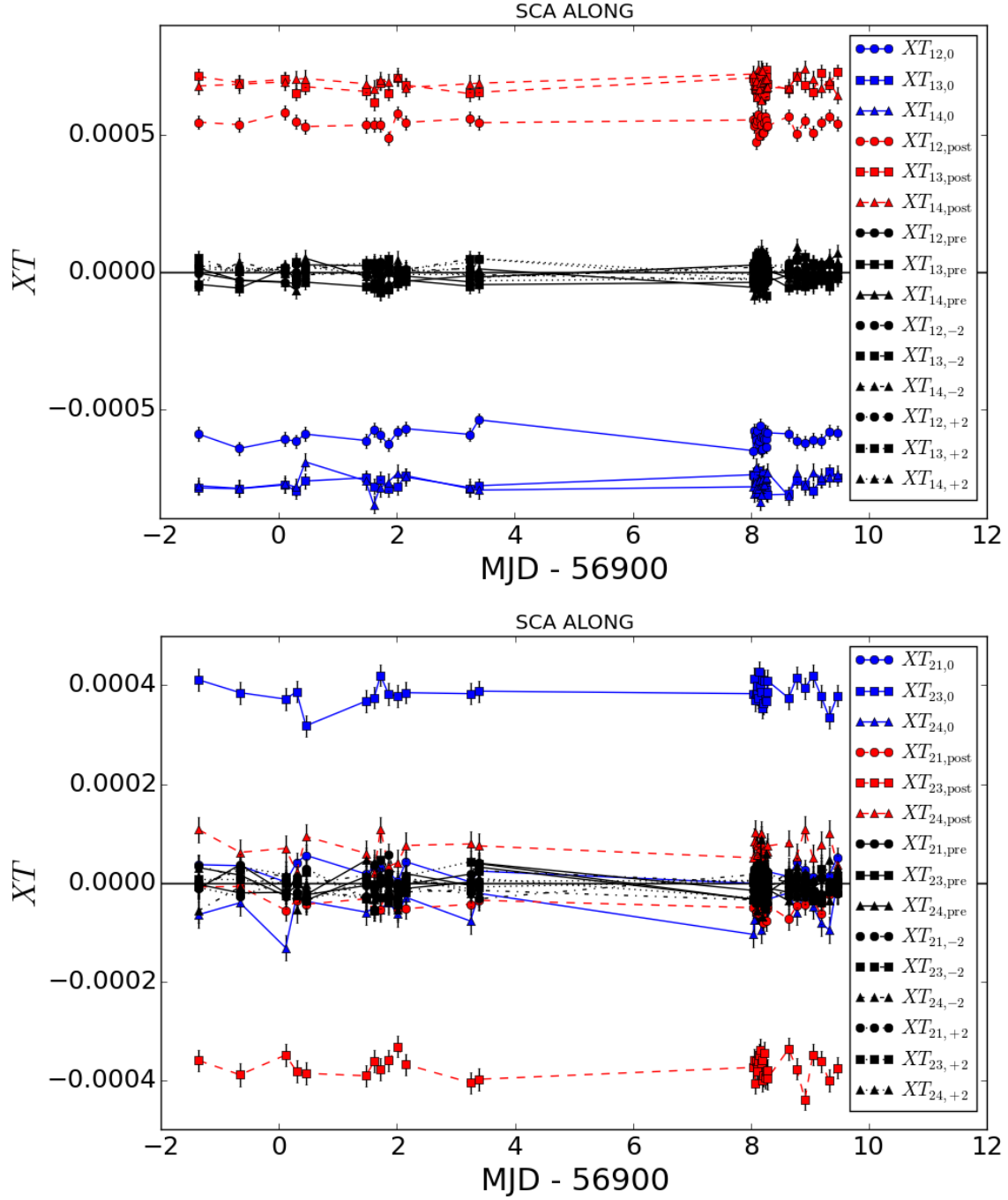


Figure 16 Cross-talk for offending amplifiers 1 and 2 of SCA ALONG are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

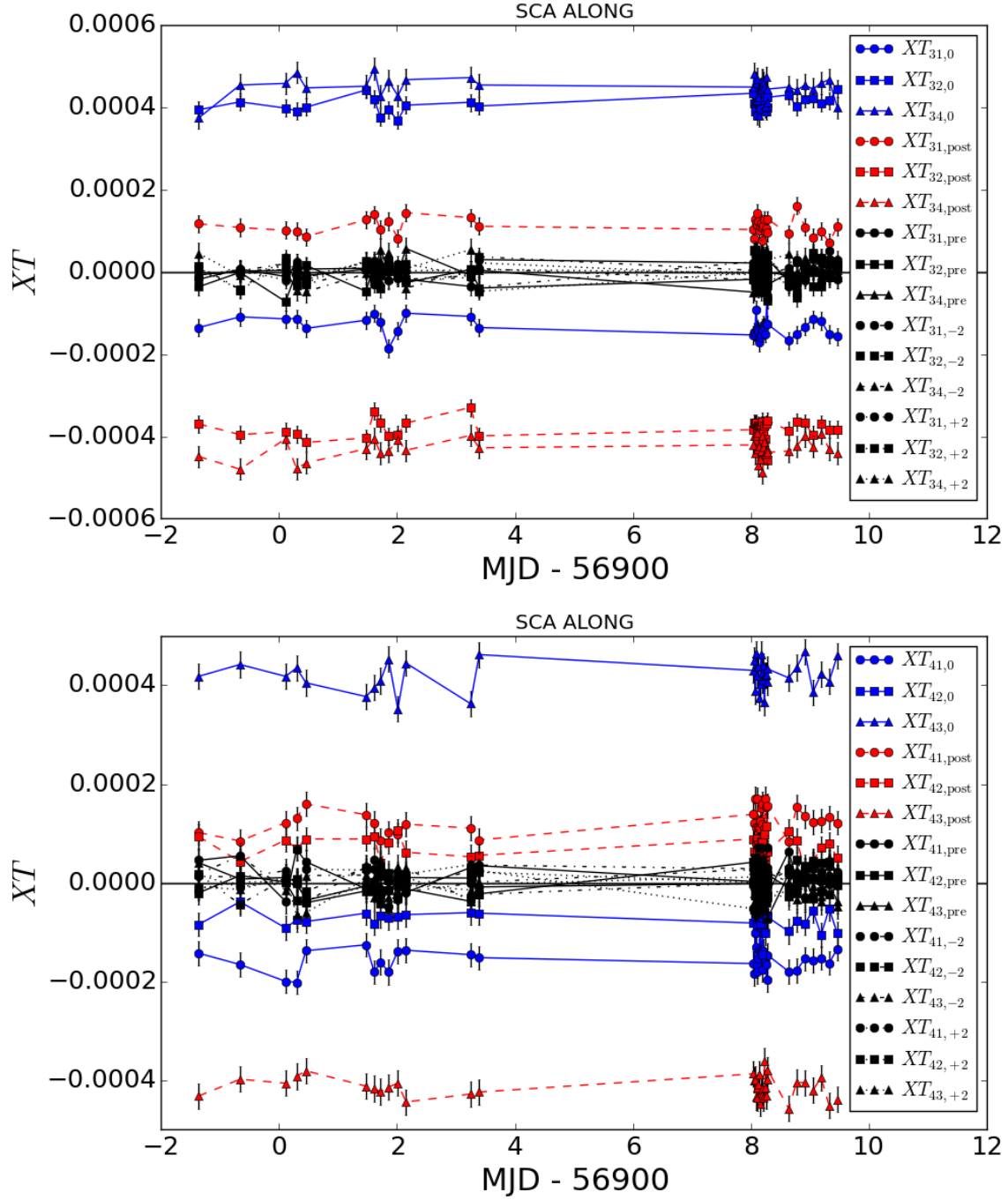


Figure 17 Cross-talk for offending amplifiers 3 and 4 of SCA ALONG are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

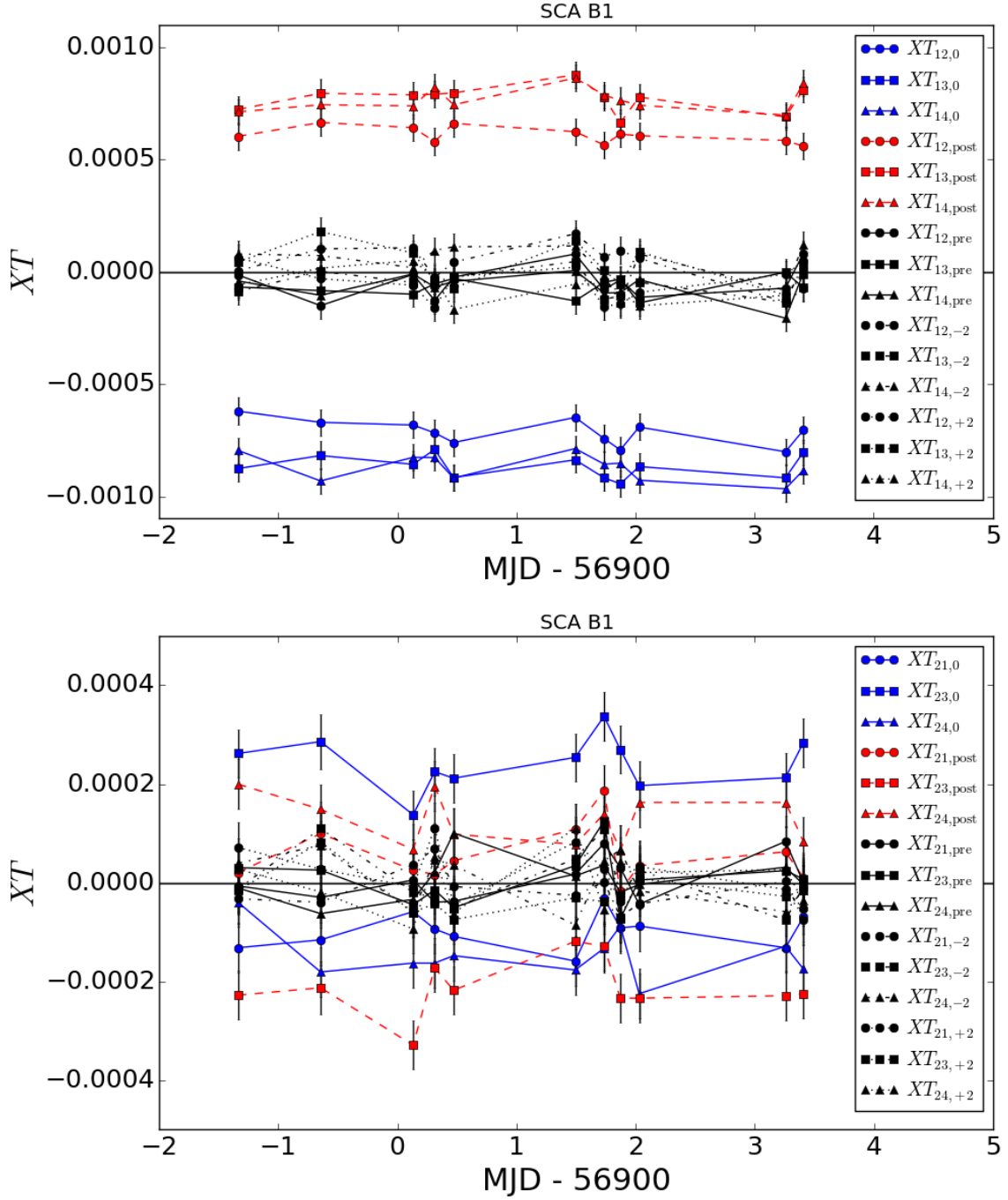


Figure 18 Cross-talk for offending amplifiers 1 and 2 of SCA B1 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

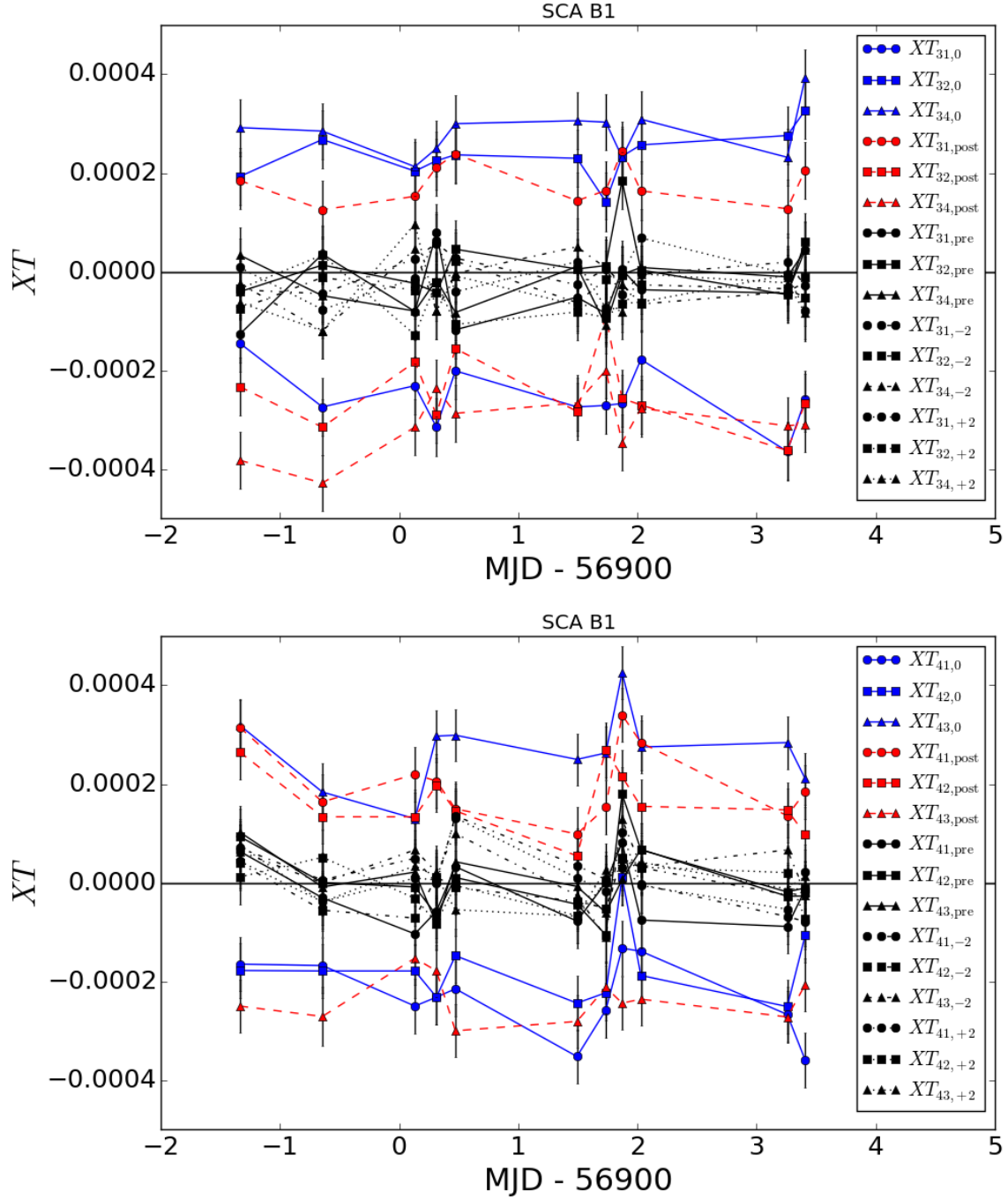


Figure 19 Cross-talk for offending amplifiers 3 and 4 of SCA B1 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

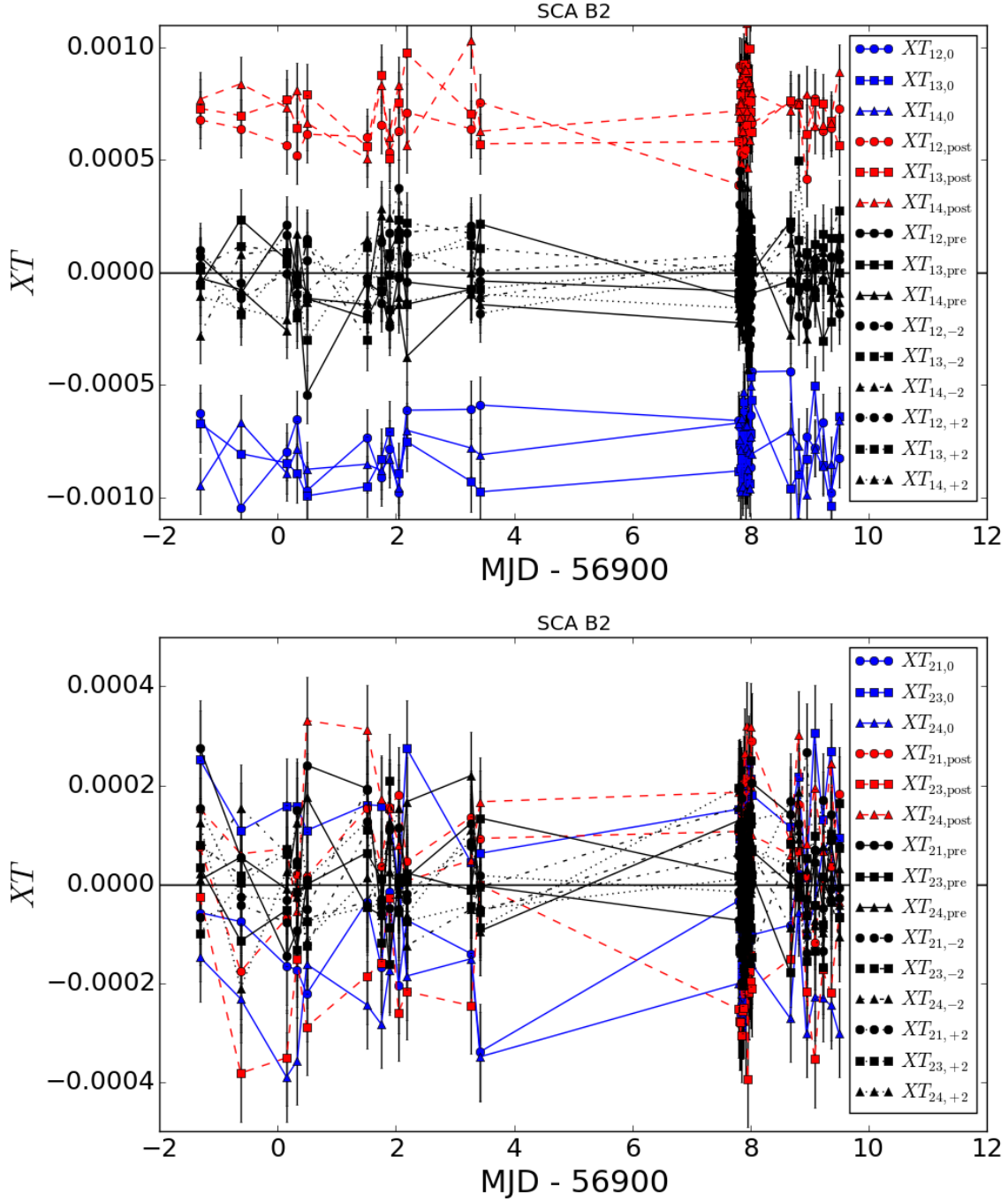


Figure 20 Cross-talk for offending amplifiers 1 and 2 of SCA B2 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

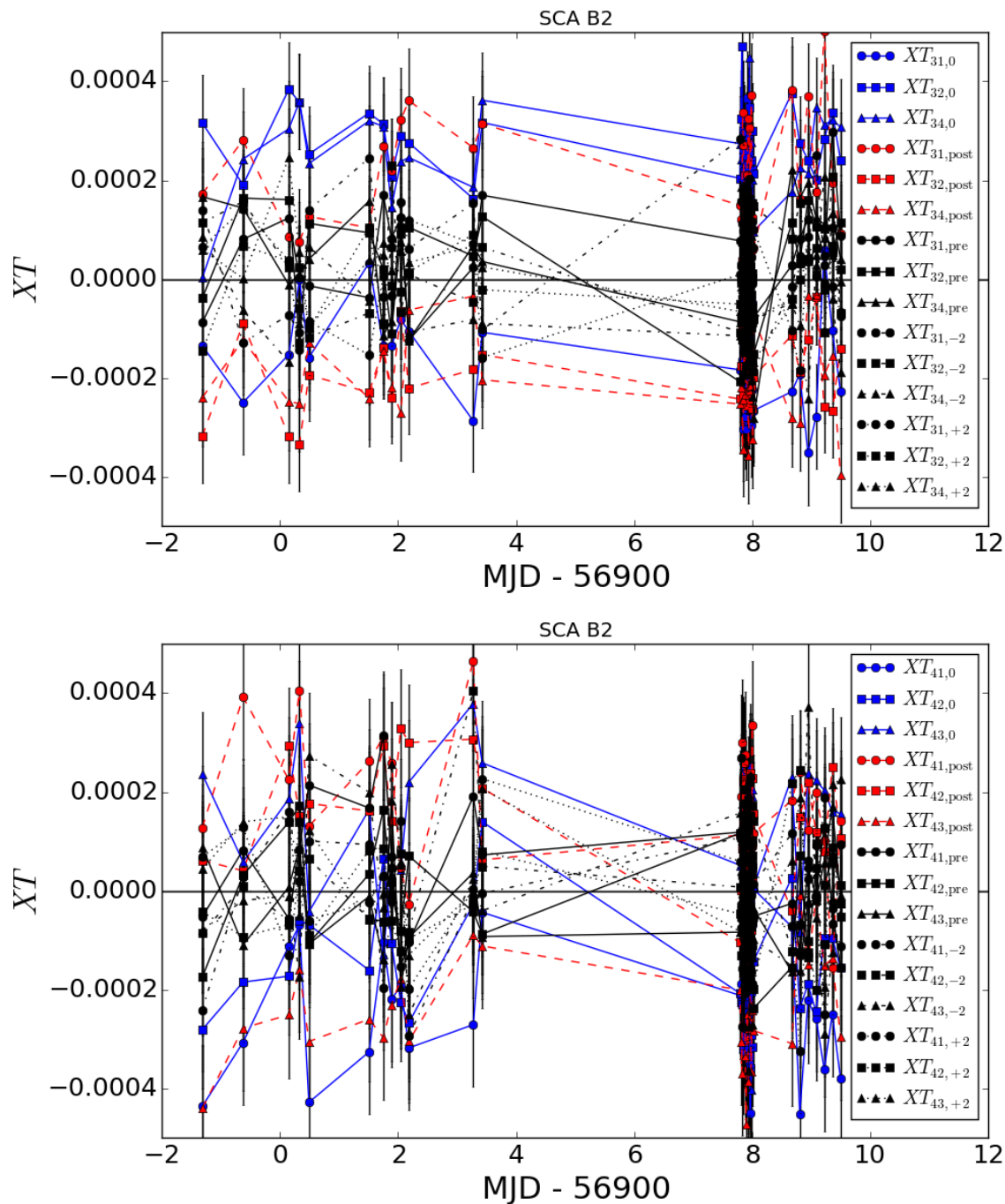


Figure 21 Cross-talk for offending amplifiers 3 and 4 of SCA B2 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

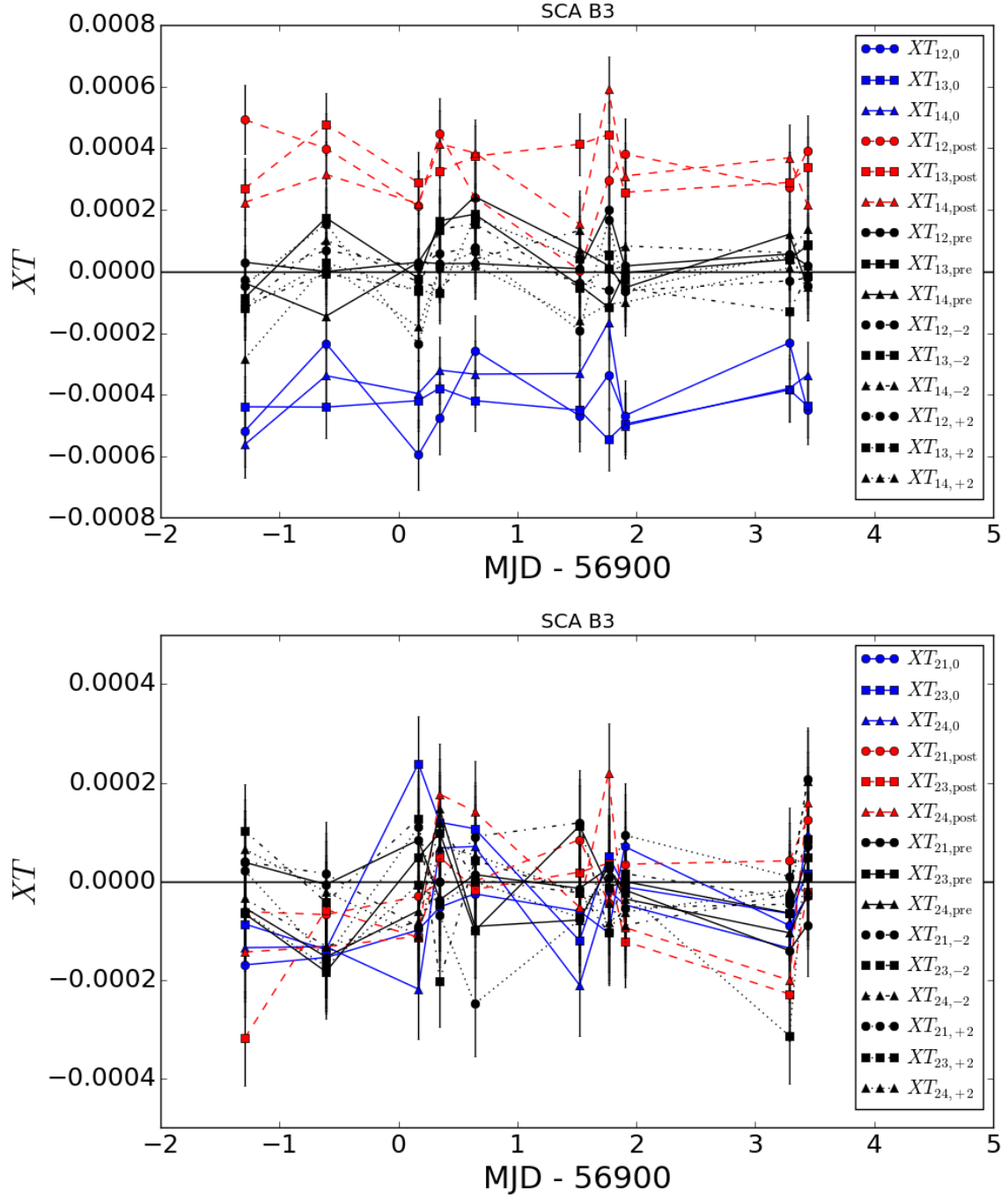


Figure 22 Cross-talk for offending amplifiers 1 and 2 of SCA B3 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

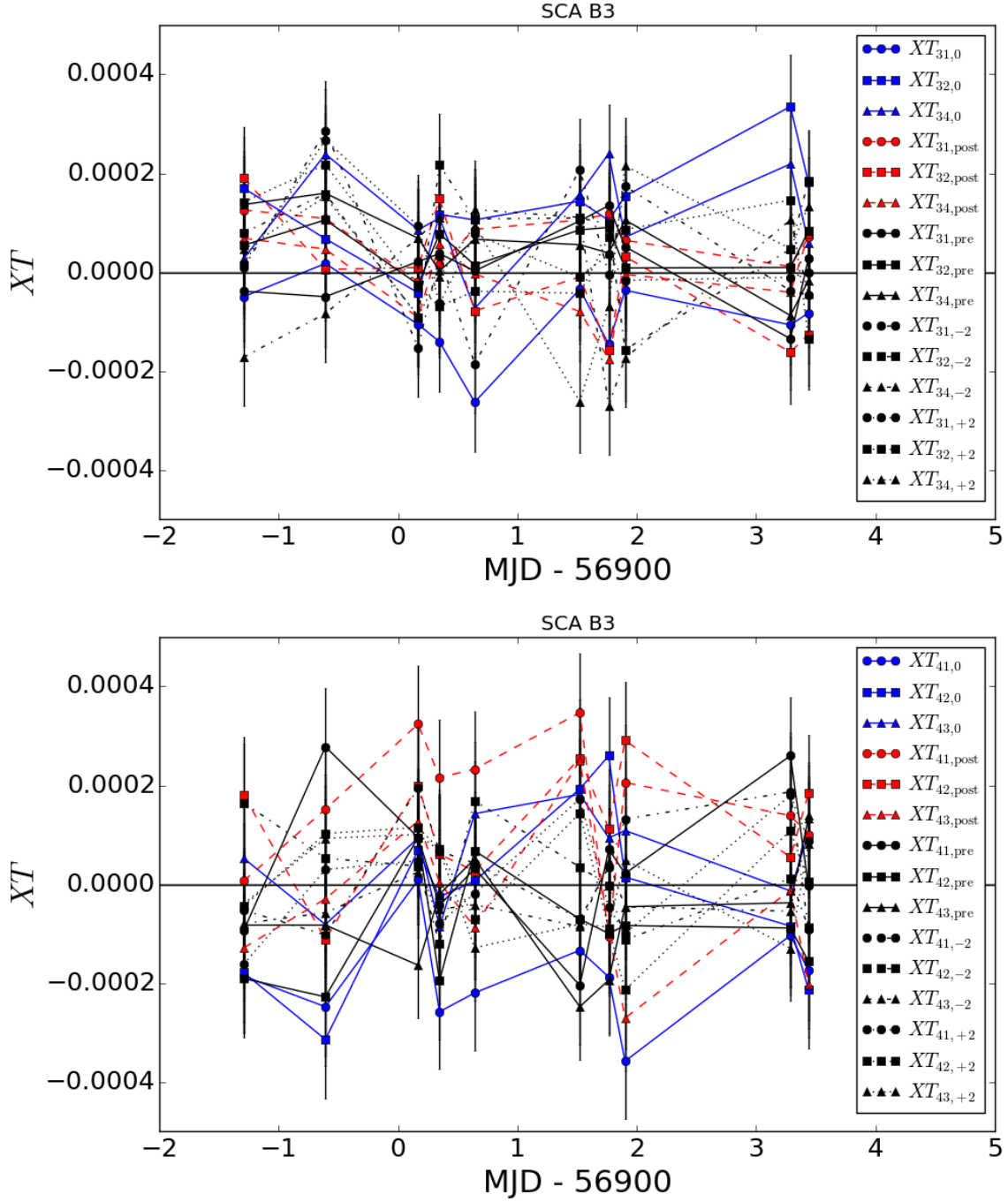


Figure 23 Cross-talk for offending amplifiers 3 and 4 of SCA B3 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

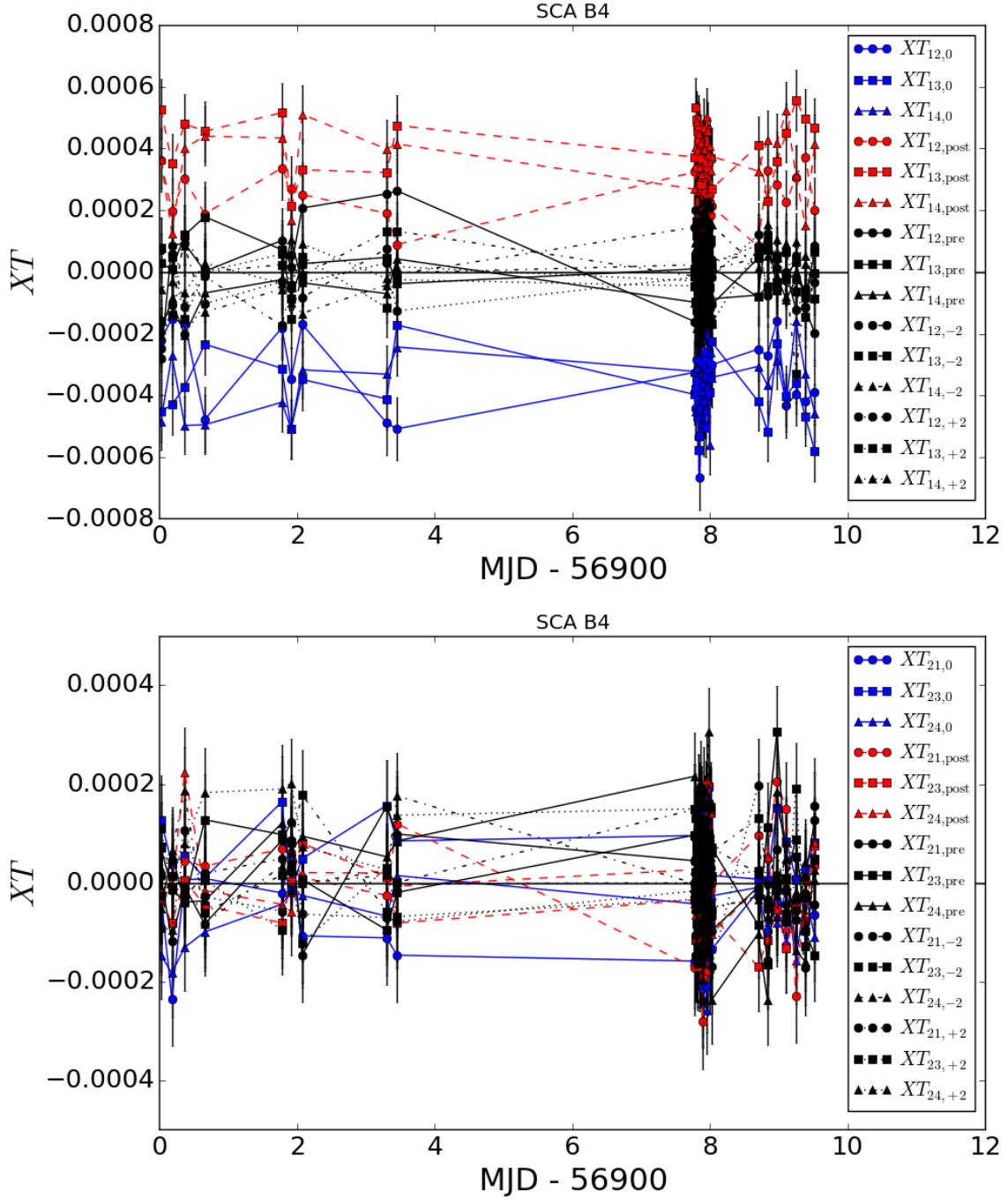


Figure 24 Cross-talk for offending amplifiers 1 and 2 of SCA B4 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

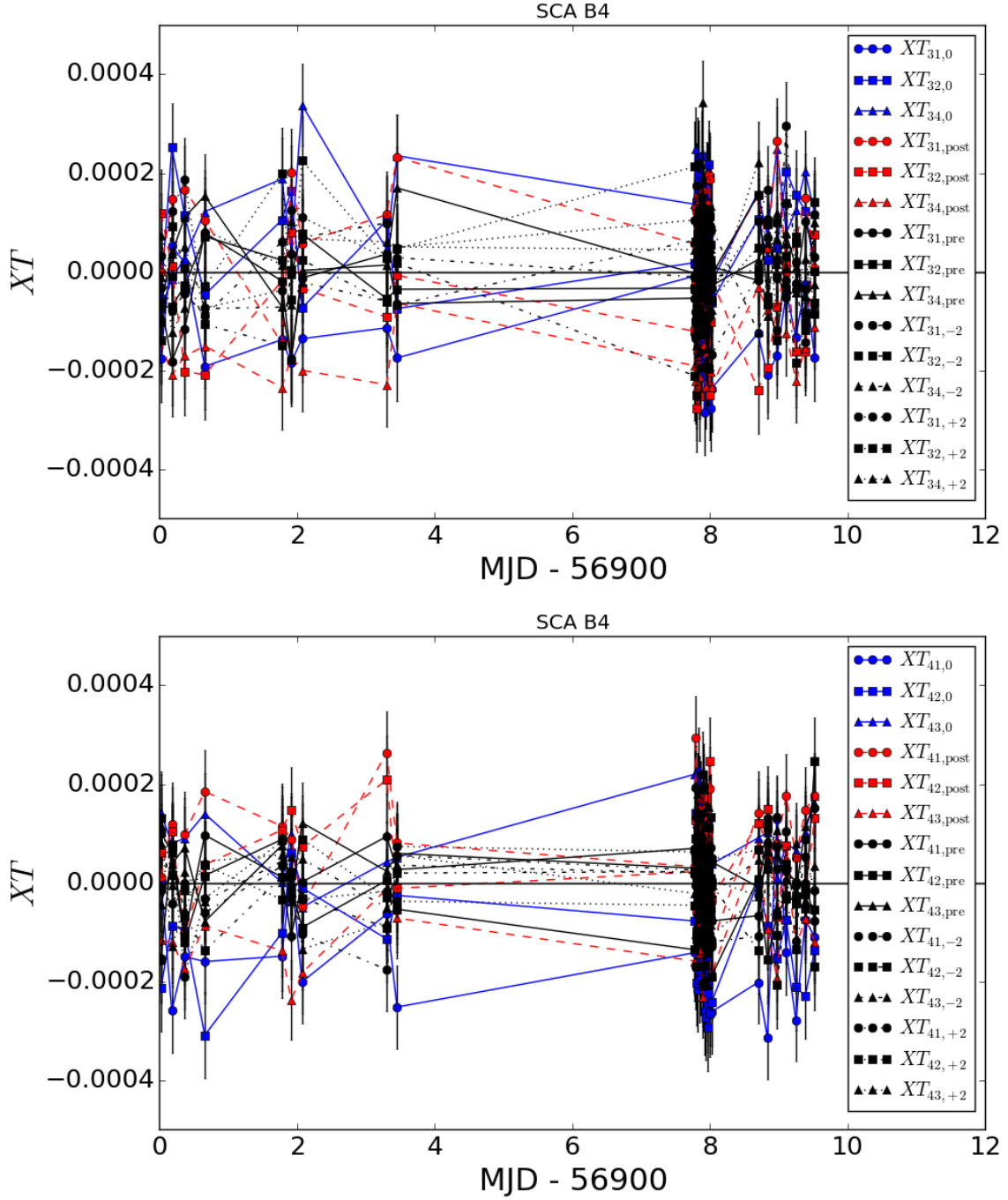


Figure 25 Cross-talk for offending amplifiers 3 and 4 of SCA B4 are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

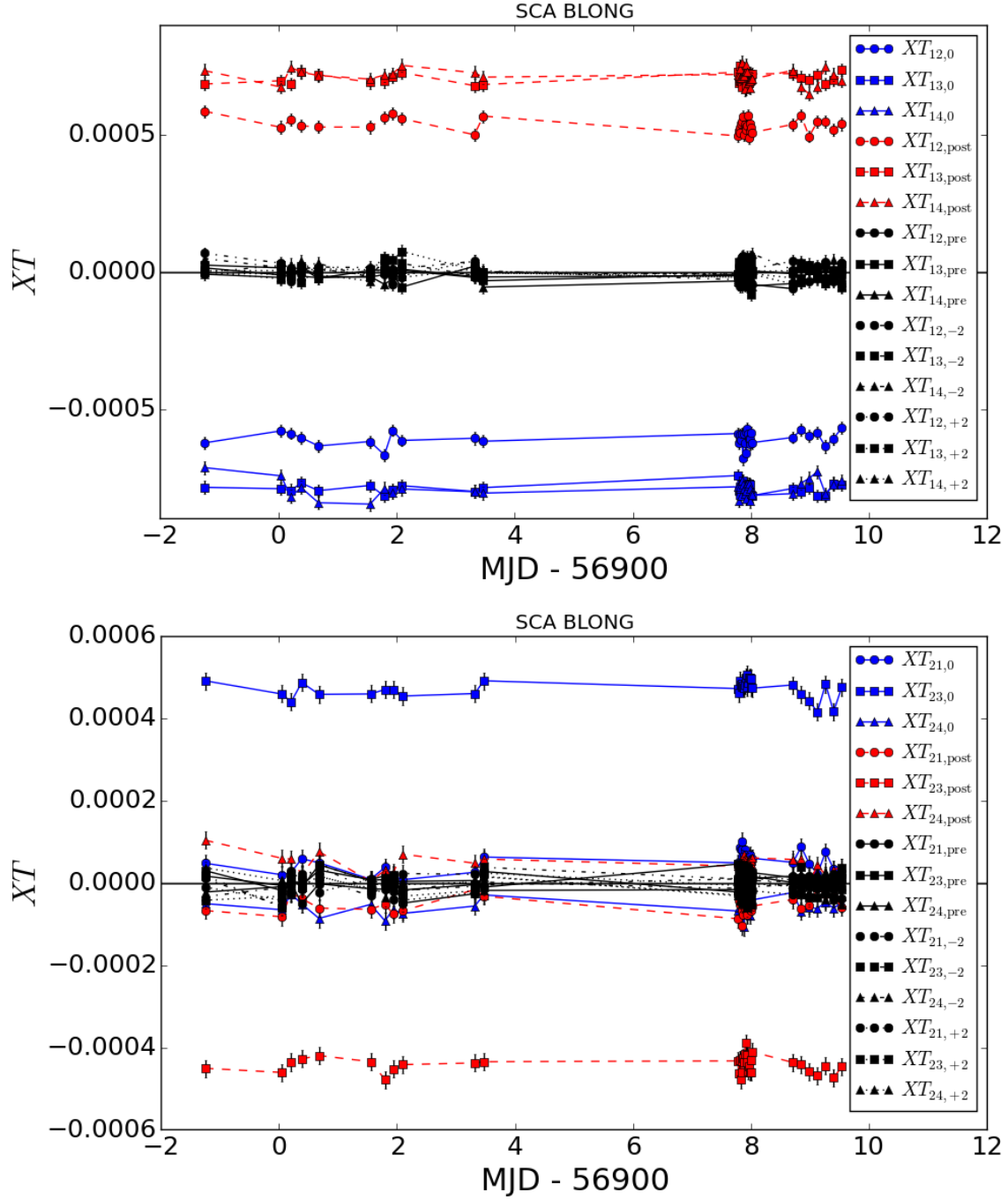


Figure 26 Cross-talk for offending amplifiers 1 and 2 of SCA BLONG are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.

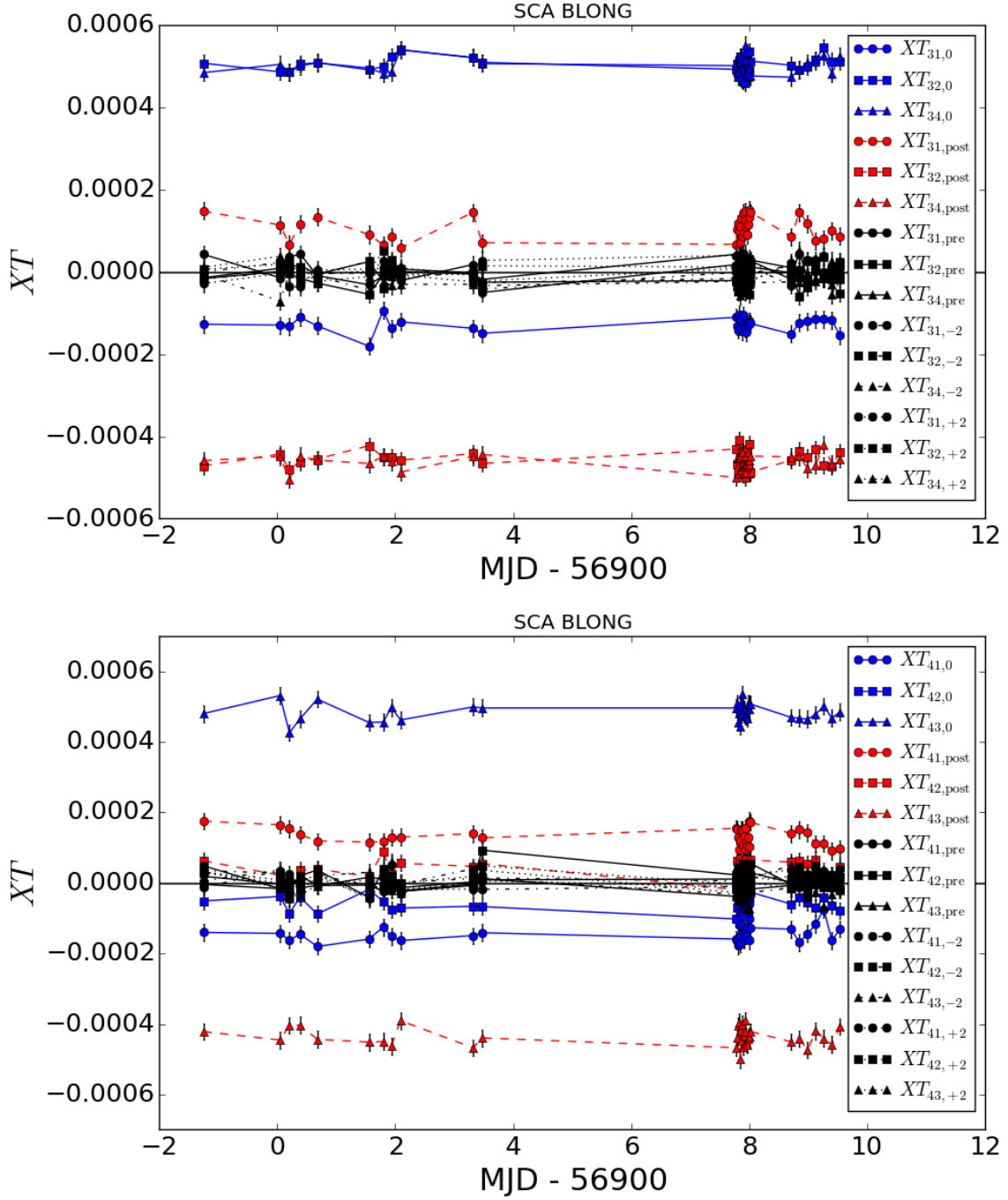


Figure 27 Cross-talk for offending amplifiers 3 and 4 of SCA BLONG are shown in the upper and lower panels, respectively.

Check with the JWST SOCCER Database at: <https://soccer.stsci.edu>
To verify that this is the current version.