

To: ACIS Science Operations Team
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Date: June 6th 2022
Subject: Optimal Parameters for Release B of the TXings Patch (v 1.5)

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1. Introduction

The possibility of using ACIS as a detector of high levels of background radiation that might damage the instrument was first described in the document referenced in §10.a. At that time, the Chandra spacecraft relied on the EPHIN instrument to detect high radiation levels and to signal to the OBC to put the payload into a safe condition, but EPHIN deteriorated and ceased to be reliable after 2014. Its monitoring function was assumed by the anti-coincidence counters of the HRC instrument, and a “TXings” software patch to ACIS, described in §10.b,c,d, was developed as a backup to HRC. After EPHIN was dropped, the OBC monitored signals from both HRC and ACIS. In the period from June 2011 through January 2022, HRC triggered 11 times and ACIS 3 times. The HRC response was more rapid because of its shorter integration period: 1 minute *vs.* 15 minutes.

After HRC experienced anomalies in August 2020 and again in February 2022, the TXings patch became the only autonomous protection for the ACIS CCDs. The original release A patch responded only to monotonically increasing radiation levels, while ignoring high but decreasing levels that might be experienced when Chandra came out of perigee. Front-illuminated (FI) CCDs are more sensitive to particle background events than back-illuminated (BI) CCDs and the original patch was less accurate when averaging the lower BI rates. Also, twice as much archival data was available in 2022 with which to “tune” the TXings algorithms. Efforts have been made (see §10.i) to improve its performance. The current document describes the choice of optimal parameters for the new release B of the patch.

2. The Original TXings Algorithm

Both patch releases replace two small BEP subroutines: `EventExposure::copyExpEnd()` which is called whenever a FEP reports the end of processing an exposure frame, and `Leds::show()` which toggles the “heartbeat” `1STAT0ST` bilevel every 64 seconds.

The replacement for `copyExpEnd()` performed its original functions and then called `TXings::saveTXings()` which added the number of reported threshold crossings from that CCD to an accumulator and the number of row-seconds of exposure to a second accumulator.

The replacement for `show()` toggled `1STAT0ST` and then called `TXings::triggerRadmon()` which computed the average threshold crossing rates for each CCD, then for FI and BI CCDs, and if the rates had

stayed above a predetermined FI or BI level and increased by more than a predetermined amount, signaled the OBC by changing the `1STAT3ST-1STAT0ST` ACIS bilevels to the special value of 1101, referred to in ACIS IP&CL (§10.k) as `LED_BOOT_SPARE1` and in the Chandra telemetry database as `1AHIRADF`.

3. The Improved Patch

Release B of TXings (fully documented in §10.j) makes one change to `saveTXings()`: release A ignored all exposure frames that reported zero threshold crossings. In fact, zero crossings have frequently been reported from small sub-array exposures. Ignoring them can seriously affect the estimation of background rates from these runs. Release B only ignores frames whose `exposureNumber` is less than 3, which is appropriate since the FEPs process their initial exposures without correcting for amplifier drift.

Release B for `triggerRadmon()` is updated in two respects. The average rates are computed in a way that uses the 32-bit integer registers—the BEP has no floating point processor—for minimal roundoff error without integer overflow. The original version was sufficiently accurate for FI rates but suffered truncation errors when calculating the lower rates from BI chips. The other change is to replace the tests of FI and BI CCDs with a set of 6 separate tests, each with its own objectives and set of parameters:

0	Monotonically ascending rates from FI CCDs	1	Monotonically ascending rates from BI CCDs
2	Monotonically descending rates from FI CCDs	3	Monotonically descending rates from BI CCDs
4	Very high rates from FI CCDs	5	Very high rates from BI CCDs

4. TXings Parameters

TXings uses 3 blocks in BEP D-cache to store its parameters, each as `TX` structures defined below. At the start of each science run, the `TXnext` block is copied to `txings` and then the `TXinit` block is copied to `TXnext`. The blocks are known by these names in the BEP load map. A 4th block, `txcount`, contains the rates and accumulators internal to the patch. The blocks are located in regions of BEP D-cache memory which can be updated by `writeBep` commands sent to the spacecraft and directed to the software serial port of the ACIS DPA.

Block Name	TXings Release A		TXings Release B		Contents
	Address	Words	Address	Words	
<code>TXinit</code>	0x8003dc30	8	0x8003dc30	22	Default TXings parameter block
<code>TXnext</code>	0x8003dc50	8	0x8003dc88	22	Parameter block for the next run
<code>txings</code>	0x8003dc70	8	0x8003dce0	22	Parameter block used by the current run
<code>txcount</code>	0x8003dca0	31	0x8003dd38	39	Accumulator block

When triggered, the 39 or 61 words (depending on the patch release) comprising `txings` and `txcount` are written to telemetry in a single `bepReadReply` packet. In C notation, the release B parameters are as follows:

```

struct _TX {
    unsigned MINUTES;           // integration interval x 64 seconds
    unsigned TX_MODE;          // txings mode (flags to ignore CCDs, etc)
    unsigned MAX_TX_PER_ROW;   // max crossings per row
    unsigned CC_TICKS;         // ticks per frame in CC mode
    unsigned TRIGGER_COUNT[6]; // number of integration steps before trigger
    unsigned RATE_LIMIT[6];    // trigger thresholds per 100 rows per sec
    unsigned TX_INCR[6];       // trigger threshold increments/decrements
} TX;

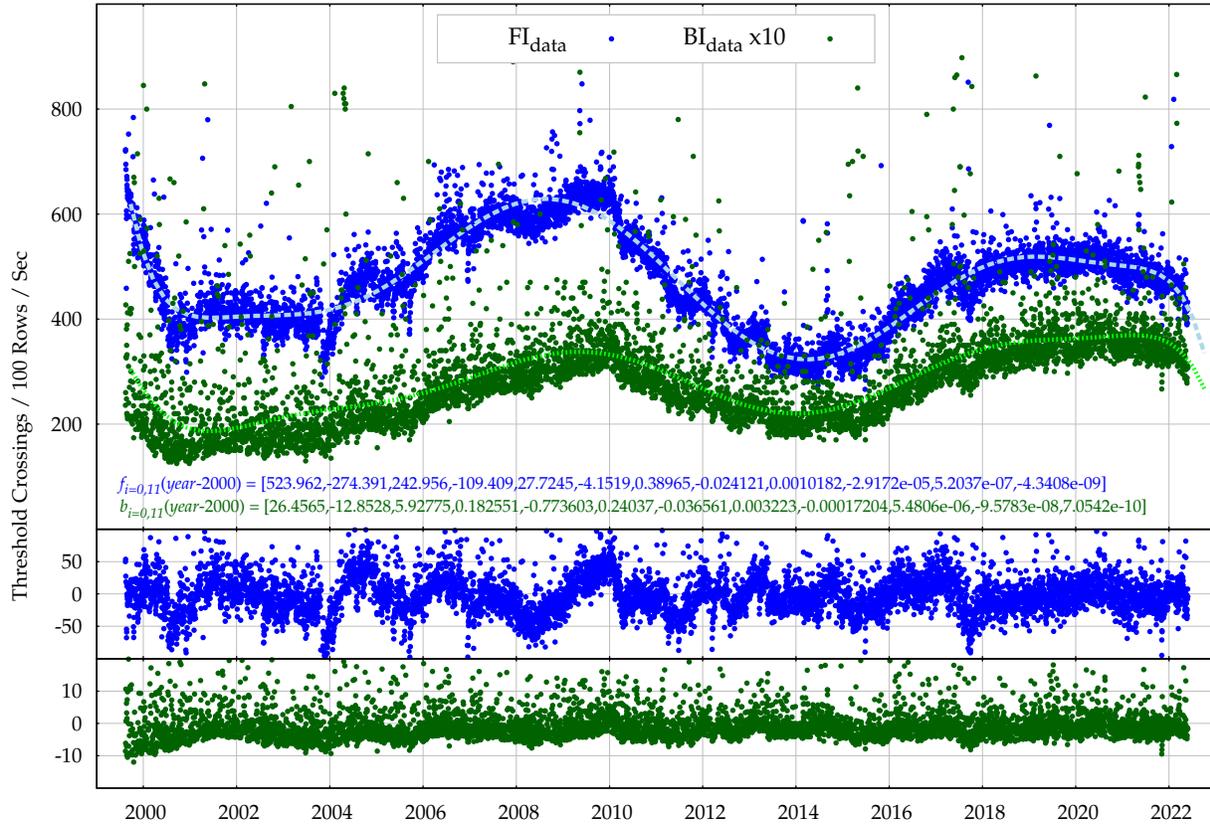
```

The `TX_MODE`, `MAX_TX_PER_ROW`, and `CC_TICKS` values are used by `saveTXings()` to determine the exposure times and, optionally, exclude particular CCDs from contributing. The remaining sets of parameters are used in `triggerRadmon()` for the 6 independent tests, indexed $i = 0..5$, which proceed as follows:

- Keep accumulating exposure frames for **MINUTES** intervals, *i.e.*, for **64*MINUTES** seconds.
- Compute the average threshold crossing rates for each CCD of the desired type.
- Ignore further processing unless each CCD's average rate exceeds that test's **RATE_LIMIT**[*i*].
- Compute the average rate of all CCDs of the desired type: FI or BI.
- Ignore further processing if this rate exceeds (for ascending tests) or lies below (for descending tests) the prior rate by less than **TX_INCR**[*i*]. This step is skipped for the pair of very high rate tests.
- If any of the 6 tests reaches this point after **TRIGGER_COUNT**[*i*] intervals, ACIS bilevels **1STAT3ST-1STAT0ST** are set to **1101** and no further tests are made until the next observation is started.

Figure 1: Polynomial Fits to the Average Threshold Crossing Rates

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5. Fitting the Average Rates

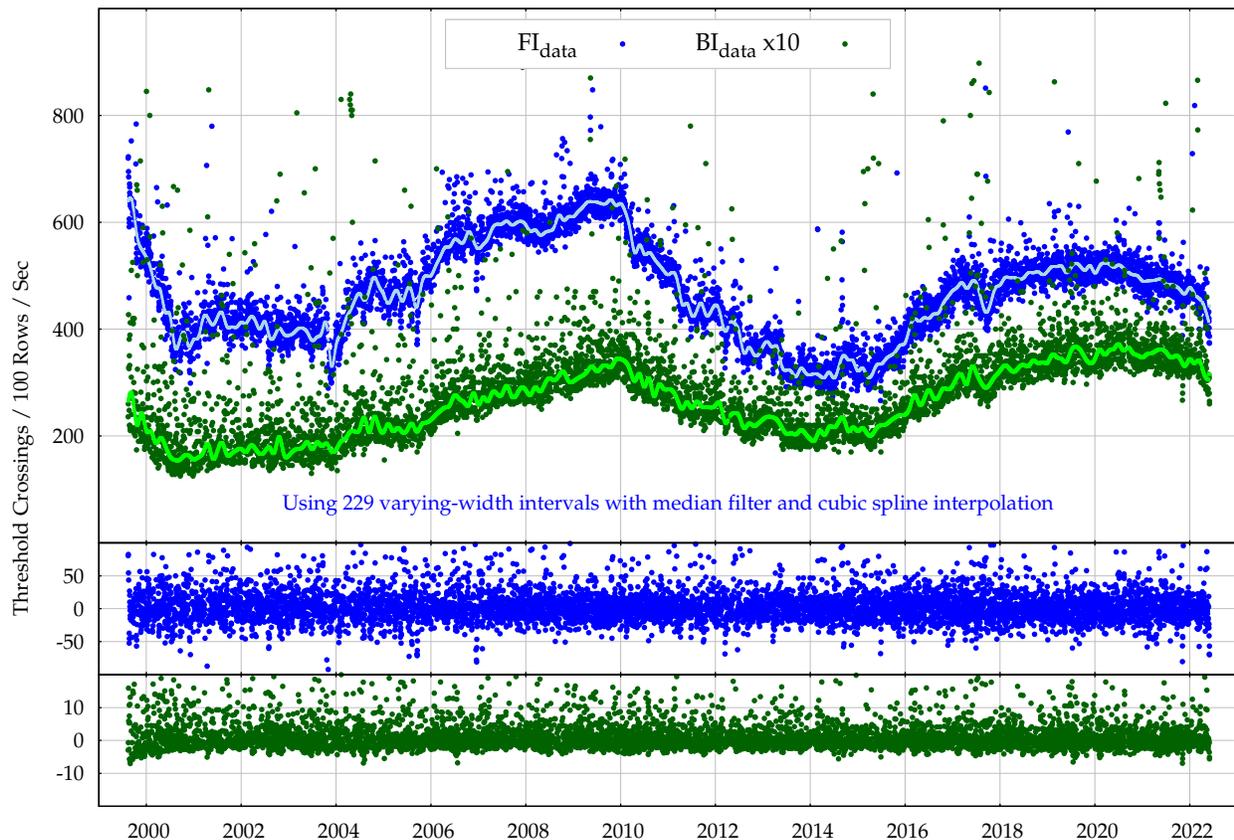
Figure 1 shows the average threshold crossing rates which vary considerably over the 11 year solar cycle. After ignoring observations of high-flux targets and instances of high solar radiation, the remainder have been fitted to polynomials in $f(y)$ and $b(y)$:

$$f(y) = \sum_0^n f_n y^n \quad \text{and} \quad b(y) = \sum_0^n b_n y^n \quad \text{where} \quad y = \text{year} - 2000.0$$

Even with the 11th order polynomials used in Figure 1, $f(y)$ often differs from the average front-illuminated rates by more than 50 counts/100 rows/sec and $b(y)$ is noticeably biased higher than the median in some epochs. An alternative approximation scheme was therefore adopted in which the threshold crossing data were first binned in 36-day intervals. The median rates in each bin were then interpolated using cubic splines. The resulting $f(y)$ and $b(y)$, shown in Figure 2, fitted the average rates with significantly lower residuals. The 2000.0 values were $f(0) = 537.3$ and $b(0) = 22.0$, contrasted with the polynomial values of 524.0 and 26.5.

Figure 2: Spline Fits to the Median Threshold Crossing Rates

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6. Testing

A C++ program named *txings_test* which runs on Linux and Solaris operating systems has been developed to compile with the TXings patch. Preprocessor variables in the source code are used to identify features only used in the flight patch (`mips`) and in 64-bit processors (`LINUX64`). It can set its TXings parameter values from *bepReadReply* packets and pass them to the appropriate TX structures, and it can be used in several different ways depending on its command-line parameters, *viz.*:

1. Extract the threshold crossing rates and limits from downlinked telemetry for inclusion in the Crossing-Rate Library (CRL). The TX parameters are updated from *bepReadReply* packets in the input telemetry, *e.g.*, from `RBTXINGALL` commands in the daily load.
2. Examine the data archive for possible triggers from a specific set of TX parameters, adjusting their `RATE_LIMIT` values by polynomial or spline fits to background rates, as updated periodically from the CRL. The polynomial results are published monthly in §10.1 and the spline results in §10.m.
3. Test the CRL archive for the number of triggers expected from a “default” version of TX to be compiled into the patch and only run until updated with more suitable values.

7. Optimum Parameters

With no opportunity to calibrate the ACIS threshold crossing rates against *in situ* particle flux and energy, the only available data comes from the ACIS telemetry archive itself, augmented by the EPHIN and HRC rates and times of high background radiation reported by ACE, GOES, etc. Since the installation of the original TXings patch in 2012, the following steps have been taken to optimize TX parameter values:

1. The CRL is updated by *txings_test* from daily ACIS processing, augmented by HRC anti-coincidence rates when available. The daily plots are published in §10.n.
2. Every 2 months, at the conclusion of each ACIS processing phase, the average FI and BI background rates are fit to polynomials and splines as described in §5, above.
3. Every month, *txings_test* is run with the current polynomials and telemetry from the current processing phase to identify new observations to include in the Runs-of-Interest (RoI) set on the basis of their crossing rates or other features, *e.g.*, EPHIN or uplink triggers, high HRC rates, etc. The list is published in §10.i. Each RoI is assigned a category: “ascending”, “descending”, or “unassigned”, depending on whether or not the observation shows substantial ascending or descending rates not associated with the behavior of the target(s). RoIs that were triggered by EPHIN or HRC or by ground command are assigned to the “ascending” category, whether or not there is evidence for this in the ACIS data.
4. Before each monthly ACIS Operations Team meeting, the recent average rates in the CRL are inspected. If they have changed substantially, the current **TX.RATE_LIMIT** parameters may need to be adjusted.

The number of adjustable parameters in the **TX** table is large, but the search in parameter space is eased by the following considerations:

1. Most parameters are independent of one another. 4 of the 6 tests depend on only 4 parameters each: **MINUTES**, **TRIGGER_COUNT**, **RATE_LIMIT** and **TX_INCR**. The other pair of tests depend only on 3 parameters: **MINUTES**, **TRIGGER_COUNT**, and **RATE_LIMIT**. Of these parameters, only **RATE_LIMIT** can take on more than a small range of values.
2. Only telemetry from RoIs needs to be examined. Moreover, the event and histogram packets that comprise more than 99% of most observations can be ignored, using the *fpket* program to create a secondary data archive without the events, bias maps, and other packets not needed by *txings_test*.
3. Many tests can be run in parallel on modern multi-core Linux systems, *e.g.*, the *maaxnew* processor recently acquired by the MKI ACIS team.

Table 1: Output files written by *txbatch.sh*

File Name	CCD Type	Test	Triggering Algorithm	RoI Category	Triggers
b1	Back-illuminated	0	Ascending	Unassigned	119027
b11				Ascending	19192
b1-1				Descending	2136
b2		2	Descending	Unassigned	74910
b21				Ascending	6025
b2-1				Descending	2516
b3		4	Very High	Unassigned	339
b31				Ascending	0
b3-1				Descending	0
f1	Front-illuminated	1	Ascending	Unassigned	21352
f11				Ascending	38712
f1-1				Descending	8580
f2		3	Descending	Unassigned	18789
f21				Ascending	12978
f2-1				Descending	17285
f3		5	Very High	Unassigned	0
f31				Ascending	1197
f3-1				Descending	872

The process of deriving optimum parameters for Release A used a compute cluster. It is described in §10.e,f,g and will not be repeated here. Release B uses a single multi-core computer and a global minimization program, *txbatch.sh*, shown in reference §10.j, which steps through 5 values of **MINUTES** and **TRIGGER_COUNT**,

6–9 values of `RATE_LIMIT`, and 7 of `TX_INCR`, a total of 5,900 tests for each of the 960 RoIs, registering each triggered RoI and its parameters in one of the following files according to the three criteria of CCD Type, Triggering Algorithm, and the Category assigned to that RoI.

`txbatch.sh` writes each trigger into one of 18 files according to the type of test and the category of the RoI, as listed in Table 1, above. Each file contains the one-line output of each `txings_test` run that triggered TXings. The large number of triggers in the last column reflects the wide range of parameters included in `txbatch.sh` script, most of which either trigger on almost all RoIs or on almost none of them. Each triplet of files with the same CCD type and algorithm is then combined into one of 6 data streams whose ASCII records contain the following:

File Minutes,Trigger_Count,Rate_Limit,TX_Incr Ascending Unassigned Descending

where the last three fields are the number of triggering RoIs that belong to each category. The final step is to examine the 6 streams and find the parameter set that maximizes the “success” of each algorithm, *i.e.*, the measure of true trigger detections *vs.* false trigger rejections. These metrics are defined as follows:

- For the ascending algorithms: Ascending – Unassigned – Descending
- For the descending algorithms: Descending – Unassigned – Ascending
- For the very high algorithms: Ascending + Descending – Unassigned

Table 2 lists the optimal parameters from polynomial and spline fitting. Where different, the spline parameters are enclosed in parentheses.

Table 2: Optimal TXings parameters with polynomial (spline) interpolation

Algorithm		MINUTES	TRIGGER_COUNT	RATE_LIMIT	TX_INCR	Pro/Con	Metric
Front Illuminated	Ascending	3	4	660 (650)	5	25/4 (25/3)	21 (22)
	Descending	3	5	700 (670)	4	9/1	8
	Very High	3	4	1500	0	9/5	4
Back Illuminated	Ascending	3	6	30	2	10/0	10
	Descending	3	6	55	6	1/1	0
	Very High	3	6	4500	0	5/0	5

All optimal algorithms accumulated for 3 minutes, which allowed us to simplify both the TXings patch itself and its test procedures. The `RATE_LIMIT` values (in units of threshold crossings per 100 rows of CCD per second of exposure) are appropriate for the year 2000.0 and must be adjusted by the polynomial or spline approximations to their average FI and BI background rates $f(y)$ and $b(y)$ introduced in §5, above.

The zero order polynomial coefficients are not used to interpret the `RATE_LIMIT`s but indicate by how much these limits exceed the average rates, *e.g.*, ~ 135 for ascending FI rates and ~ 3.5 for ascending BI ones, showing how sensitive the latter is to matching the parameters to the current average rates. When `txings_test` applies these parameters and polynomials to the RoIs, it finds 41 triggers (see §10.o), all of which are either categorized as ascending or descending, with zero false positives, which is a considerable improvement on the best results from the original algorithm (see §10.e,f,g). These results are summarized in an online table with links to the observation catalog and the daily plots at §10.i. In the rightmost “code” column, Chandra triggers are colored red, descending RoIs are green, and RoIs with high background that didn’t result in an OBC safing action are in blue.

When the RoIs were processed using spline interpolation and $f(0)$ and $b(0)$ values, the resulting optimal parameters were nearly identical to those from polynomial fitting (see Table 2). Running `txings_test` with the RoIs, only 40 triggers were reported and these were the *same* RoIs as from the polynomial fits. The missing RoI was OBSID 16014, which was a marginal case in the HIRAD class, an example of a substantial rise in background radiation but not severe enough to have damaged the ACIS CCDs. With little to choose between the fitting methods, the polynomial approach is simpler to describe and, as we shall see in §9.2, simpler to use in extrapolating the rate limits to adapt to the solar cycle.

8. Installing the Patch

Before the level G-I-J patches with TXings release B run on the flight unit, the following steps must be taken:

1. Commands `WBTX_QUIET` and `RBTXINGALL` should be eliminated from the daily loads since they access addresses in BEP D-cache that have been reassigned in TXings release B.
2. The following command should be scheduled at the end of each perigee passage, before the first ACIS run, to dump the parameter and accumulator blocks, which will allow daily processing to report the correct rate limits in the daily plots.

```
read # 0x8003dc30 105
```

3. The default TXings parameters, which are intended as a fail-safe and will likely cause frequent false triggers, must be replaced with values appropriate to the epoch, $y = year-2000$. The following command should be prepared for uplink immediately after the BEP is warm booted with the new patch load, where $\Delta f = f(y)-f(0)$ and $\Delta b = b(y)-b(0)$.

```
write # 0x8003dc30 {
  3 0 512 291840
  4 6 5 6 4 6
  660+Δf 30+Δb 700+Δf 55+Δb 1500+Δf 4500+Δb
  5 2 4 6 0 0
  3 0 512 291840
  4 6 5 6 4 6
  660+Δf 30+Δb 700+Δf 55+Δb 1500+Δf 4500+Δb
  5 2 4 6 0 0
}
```

9. Subsequent Operations

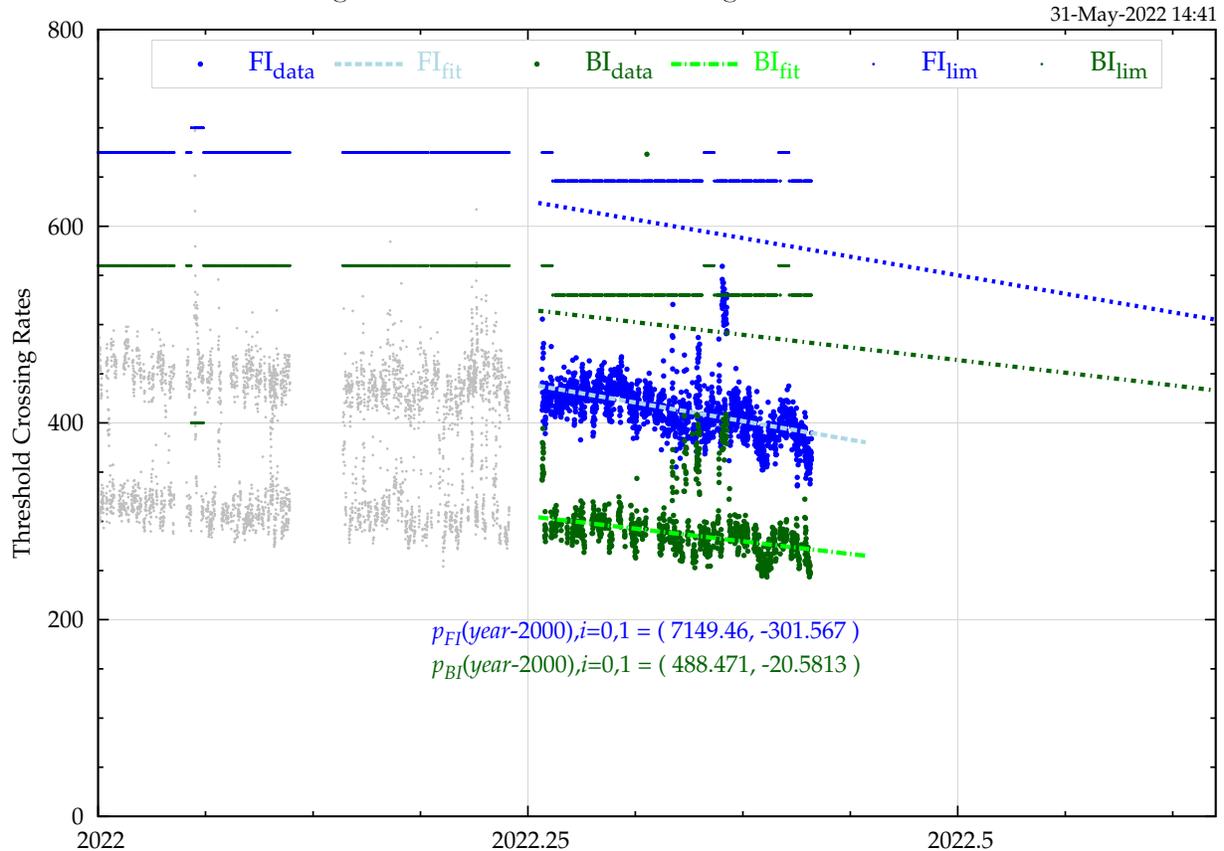
To maintain optimal TXings parameters over the future course of the Chandra mission, we advocate the following steps:

1. The CRL will continue to be updated during the daily ACIS telemetry processing at MIT. At least once a day, up to 2 weeks of downlink data will be processed through `txings_test` to store the FI and BI rates averaged over 3 minute intervals, along with the current rate limits.
2. Each month, the latest 4-6 months of CRL data will be linearly fitted to extrapolate the 6 optimal `RATE_LIMIT` values to a time approximately one month in the future. Fig. 1 shows a recent plot used to adjust the parameters of the release A patch. The horizontal blue and green lines show the current `RATE_LIMIT` values; the lower dotted lines are the linear fits through the current data (the colored dots) as polynomials $f(y)$ and $b(y)$ for FI and BI CCDs, respectively; the upper dashed lines are the optimal values for the rate limits, based on the linear fit and the analyses in §10.e,f, which placed the optimum FI rate at 186 units above the current mean and the optimum BI rate at 21 units above the mean.

A similar analysis for the limits in TXings release B will also use the CRL archive to estimate the optimum rate limits. For instance, if the current average FI background rate is $f(y)$ and the optimum FI ascending rate limit in 2000.0 was $f_a(0)$, the ascending rate limit at epoch y will be $f_a(y) = f_a(0) + f(y) - f(0)$ and similarly for the descending and very high limits f_d and f_{vb} , and the BI limits, b_a , b_d , and b_{vb} . In short, the rate limits at y are their values in 2000, adjusted by the change in the average FI or BI background rate since 2000.

Figure 3 illustrates a linear fit to data from April 2 through May 30, 2022. (Ignore the upper horizontal and dashed lines which refer to the limits used in release A of TXings.) Using the values of $f(0)$ and $b(0)$ from Figure 1, the extrapolated rates on July 1, 2022 will be $7149.46 - 301.567 * 22.496 = 365.41$ and $488.471 - 20.5813 * 22.496 = 25.47$, so the optimal ascending `RATE_LIMITS` values are $660 - 524.0 + 365.41 \approx 501$ and $30 - 26.5 + 25.47 \approx 29$, and so on for the other 4 rate limits, all rounded to nearest integers.

Figure 3: Linear Fit to Threshold Crossings – 2022.25 - 2022.42



- If the new FI rate limits change since the last update by more than 10 units, or if the new BI rate limits change by more than 5, the new values should be uplinked by a `writeBep` command and associated SAR. We choose these values based on (a) the variation in $f(0)$ and $b(0)$ between polynomial and spline fits, and (b) the variation in the number of triggers from RoIs when the `RATE_LIMITS` were varied in `txbatch.sb`. In the following example, the FI and BI rate limits in `TXinit` for year y will be set as follows:

```
write n 0x8003dc58 {
  fa(y) ba(y) fd(y) bd(y) fvb(y) bvb(y)
}
```

This will not affect any currently-executing run, nor the next run after that, but only subsequent runs. To affect only the next science run, execute the following command:

```
write n 0x8003dcb0 {
  fa(y) ba(y) fd(y) bd(y) fvb(y) bvb(y)
}
```

and execute both commands to ensure that the change applies to all subsequent runs, or rewrite the entire contents of `TXinit` and `TXnext` in a single command, as in step 3 of §8, above.

- At the end of each ACIS downlink processing phase, typically every 2 months, the long-term CRL rates will be updated and the rate polynomials recalculated. If there are triggers or other runs with high background in that phase, the RoI tables will be updated and the optimal parameters updated as described in §7.

10. References

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- b. [“Using ACIS on the Chandra X-ray Observatory as a particle radiation monitor II,”](#) C. E. Grant, P. G. Ford, M. W. Bautz and S. L. O’Dell, arXiv:1207.3329, July 2012.
- c. [“Using the Chandra ACIS x-ray imager as a background particle flux detector,”](#) P. G. Ford and C. E. Grant, SPIE, October 2012.
- d. [Using ACIS to detect and report high radiation conditions,](#) MIT Software Report, Rev 1.3, April 15, 2011.
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- g. [Further Adjustments to the TXings Patch Parameters,](#) MIT Software Report, Rev 1.0, January 1, 2022.
- h. [Part 36-58030.33, MIT Engineering Change Order 36-1044,](#) Revision A, March 2, 2011.
- i. [ACIS Runs of Interest \(RoIs\),](#) MIT web page, June 4, 2022.
- j. [“Flight S/W patch to report high background radiation levels, Revision B,”](#) MIT ECO-1058, April 20, 2022.
- k. [“ACIS Software IP&CL Structure Definition Notes,”](#) MIT 36-53204.0204, Revision N, March 15, 2001.
- l. [“Polynomial Fits to ACIS Crossing Rates,”](#) ACIS web page, June 1, 2022.
- m. [“Cubic Spline Fits to ACIS Crossing Rates,”](#) ACIS web page, June 1, 2022.
- n. [“ACIS Threshold Crossing Rates,”](#) ACIS web page, June 4, 2022.
- o. [“Optimum ACIS TXings Triggers,”](#) ACIS web page, June 4, 2022.

11. Glossary

1STAT#S	The telemetry mnemonics for the 8 ACIS bilevel fields ($n = 0..7$).
Back-Illuminated (BI)	A CCD that detects x-rays incident on the face opposite to that of its junctions.
BEP	ACIS Back End Processor—the unit that interfaces between FEPs and RCTU.
Bi-Level	A one-bit data channel from BEP to RCTU.
CCD	Charge-Coupled Device—the type of x-ray detectors used by ACIS.
CRL	Crossing-Rate Library—archive of ACIS threshold crossing rates.
D-cache	The radiation-hard data cache memory used in BEPs and FEPs.
EPHIN	Electron, Proton and Helium Instrument—flown on Chandra and SOHO.
FEP	ACIS Front End Processor—extracts event candidates from a pixel stream.
Front-Illuminated (FI)	A CCD that detects x-rays incident on the same face as its junctions.
readBep	External command to ACIS to dump specified contents of BEP memory.
RCTU	Remote Command and Telemetry Unit—interface between spacecraft system.
RoI.....	Run of Interest—an ACIS observation that may contain high background.
TX	An array in BEP memory that contains TXings parameters.
writeBep	External command to ACIS to update specified contents of BEP memory.