r e p o r t

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To: ACIS Science Operations Team
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Subject: Improvements to the ACIS high radiation trigger patch (v 1.0)

1. Introduction

With the continuing degradation of the EPHIN detector on board the Chandra X-Ray Observatory, *txings*, the recently developed ACIS patch, becomes increasingly important as a means of protecting the science instruments against damaging levels of background radiation. The patch was installed on the flight instrument on November 2nd 2011 and triggered twice, on January 27th and May 17th 2012, before the necessary patches were installed in t he Chandra OBC in May 2012. In the following 13 months of in-flight operation, a period of relatively low background flux, *txings* has triggered once more, May 22nd 2013, sending the observatory into science saving mode, as intended; during that time, Chandra was put into safe mode on five other occasions, all due to high background flux—three times by ground command based on data from the ACE spacecraft, and once triggered by the anti-coincidence counter in Chandra's HRC instrument and once by EPHIN's E1300 channel.

The *txings* patch must distinguish real high-flux conditions from bright x-ray and optical sources, and from various non-critical hardware and software anomalies. It must also allow for changing background flux during the 11-year solar cycle. For these reasons, *txings* uses a set of parameters that can be altered by ground command: it was originally installed with very conservative parameters which were updated in April 2012 to a set that had been optimized to detect the most number of high-flux periods within the 12-year ACIS data archive, without generating any false triggers. This selection process was documented in the ACIS reports "Selecting optimal parameters for the *txings* patch", Revision 1.1, April 12 2012, and "Using ACIS to detect and report high radiation conditions," Revision 1.3, April 15, 2011, which also serve as tutorials for understanding the design and implementation of the patch code itself.

Time marches on, and improvements to *txings* have been proposed. These are described in the following three sections. Section 5 updates the change in average background rates over the past year, and discusses whether these would necessitate a change in *txings* parameters, even if no changes were made to the algorithm itself. Finally, in Section 6, we describe how the task of searching for optimal parameters has been ported to a computing cluster, and what results have been obtained.

2. Omission of Exposures with no Threshold Crossings

The patch ignores exposures that report no threshold crossings, on the grounds that these are probably due to a hardware or software anomaly. In fact, sub-array readouts of back-illuminated CCDs frequently report no crossings, so to ignore these exposures causes a serious systematic error in estimating the overall crossing rate. The code should therefore be changed to remove the highlighted terms:

```
// ignore zero excessive crossings
if (thresh > 0 && thresh <= tx.ccd_tx_max) {
    thresh += tx.increment; // increment crossings only when testing
    tx.threshold_accum[ccdId] += thresh;
    tx.exposure_accum[ccdId] += tx.ccd_ticks;
}
```

3. Rate Quantization Error

The patch computes average threshold crossing rates from the threshold crossing and exposure time accumulator arrays, `threshold_accum[10]` and `exposure_accum[10]`, by the following statements, where `cc` is the `ccdId` index running from 0 through 9:

```
unsigned exptime = ( tx.exposure_accum[cc] + 500 ) / 1000;
unsigned rate = tx.threshold_accum[cc] / exptime;
rate = ( 10000 * rate ) / tx.ccd_rows;
```

While this is guaranteed not to overflow the 32-bit unsigned values over the course of a maximally long (one Chandra orbit) observation, it severely quantizes the low `rate` values typical of back-illuminated CCDs under average background flux conditions. An improved version, still guaranteed not to overflow, would be:

```
unsigned exptime = ( tx.exposure_accum[cc] + 500 ) / 1000;
unsigned nthresh = ( tx.threshold_accum[cc] + 500 ) / 1000;
unsigned rate = ( (10000000 / tx.ccd_rows) * nthresh) / exptime;
```

4. High but Decreasing Crossing Rates

On April 11th 2013, ACE reported high radiation flux but Chandra was close to perigee passage and the decision was made not to command it to enter science safing mode. ACIS was executing OBSID 15624 with only CCD_S3, a back-illuminated (BI) device, taking data. Fig. 1 shows that the threshold crossing rate never exceeded the BI threshold (the green horizontal line), although a front-illuminated (FI) chip would probably have caused *txings* to trigger because the observation that followed, OBSID 53786, did use FI CCDs and registered a decreasing threshold crossing rate that was clearly above the FI threshold. By then, however, the OBC's RADMON function was disabled prior to perigee passage and a *txings* trigger would not have resulted in a science safing action.

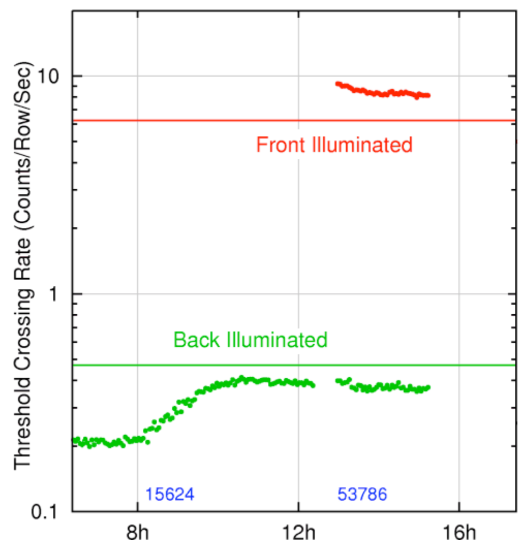

Figure 1. Crossing rates on April 11 2013.

Nevertheless, this example prompted Chandra management to ask the ACIS instrument team to investigate the possibility of developing a trigger in response to "high but decreasing" background flux, *quod fecimus*. This involves changing

```
if (rate > tx.saved_rates[tt] + TX.TX_INCR[tt]) { ... }
```

to

```
if (tx.saved_rates[tt] == 0 || rate < tx.saved_rates[tt] - TX.TX_INCR[tt]) { ... }
```

but there is no guarantee that the same choice of *txings* parameters will prove optimal for triggering on genuinely decreasing rates while not reporting false positives. Two sets of parameters must be employed and, since the parameters also control how the per-exposure rates are summed and averaged, two sets of accumulator arrays must be used. This effectively doubles the size of the patch without making it any harder to test, since the two algorithms run side-by-side without interfering with one another.

5. Background Rate Trending

The behavior of the average threshold crossing rates over the mission lifetime is shown in Fig. 2. Note the nearly constant values over the past 12 months, which suggest that there is no strong reason to change the existing *txings* parameters unless the patch itself is changed.

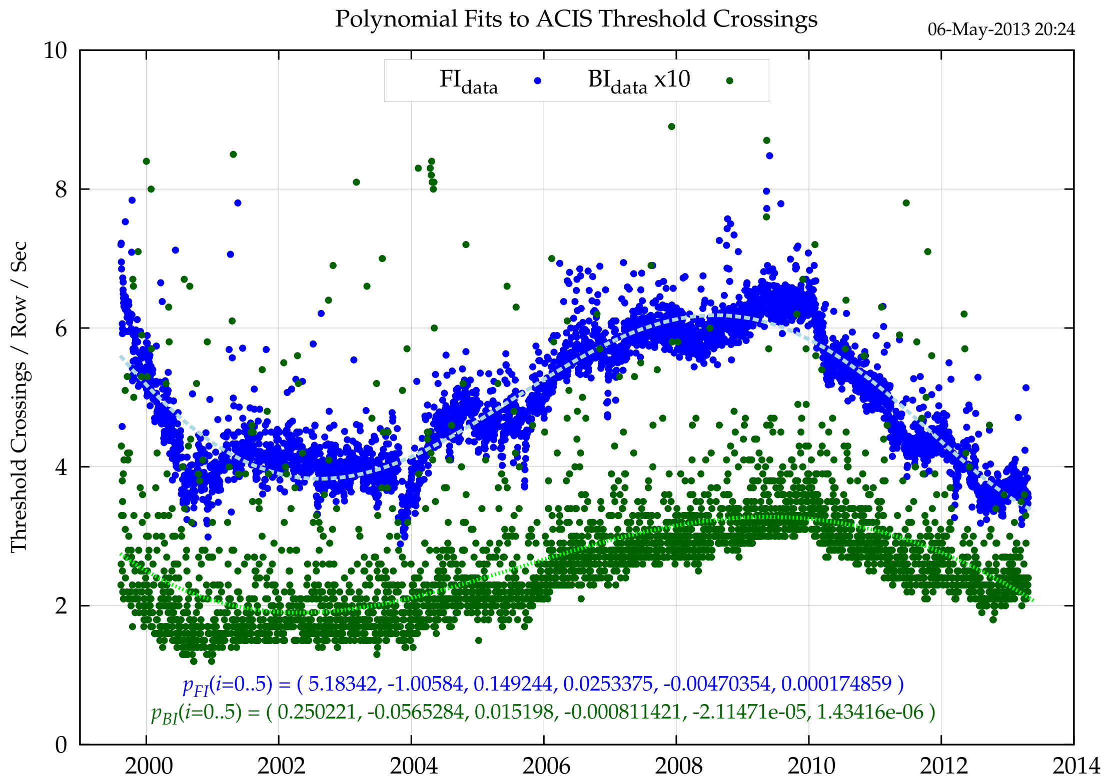

Figure 2. Average threshold crossing rates from ACIS front-illuminated (FI) and back-illuminated (BI) CCDs, excluding bright sources, hardware and software anomalies, and periods of high background radiation flux.

6. Sensitivity to CCD Clocking Parameters

The *txings* algorithm, and the effort to choose the optimal set of parameters, assumes that the threshold crossing rates are independent of the manner in which the CCDs are clocked, *i.e.*, that the probability that a "pixel" contains more than threshold charge varies linearly with the time it spends in the CCD's image store. To see whether this is indeed the case, the archived rates were averaged over each science run, sorted by CC/TE mode and, among TE runs by subarray size, and normalized by the "best fit" polynomial appropriate for that date (see Fig. 2).

The results are displayed in the following pair of tables, Table 1a from faint and very faint mode observations, and Table 1b that includes rates from graded mode runs. In both cases, CTI calibrations, optically bright targets and runs made during periods of high background or anomalous instrument behavior were excluded. The columns contain the following information:

Rows number of rows read from each CCD in one exposure frame (in TE mode).

Nobs the number of runs that contributed threshold crossing rate data of this type.

Rate the average across all runs of the ratio between the threshold crossing rate for CCDs of this type (threshold crossings per CCD row per second) and the polynomial fit for that run's epoch.

Norm the ratio between this Rate and that of TE runs with 961-1024 rows, *i.e.*, full-frame readout.

Evts The average event rate (events per CCD per second) for CCDs of this type.

Table 1a. Threshold-crossing and event rates – excluding graded mode observations.

Rows	Front-Illuminated CCDs				Back-Illuminated CCDs			
	Nobs	Rate	Norm	Evts	Nobs	Rate	Norm	Evts
961-1024	8015	0.995	1.000	8.34	6057	0.875	1.000	11.58
833-960	–	–	–	–	–	–	–	–
769-832	265	0.967	0.972	6.91	265	0.806	0.922	9.11
705-768	13	0.961	0.965	5.73	12	0.823	0.941	7.17
641-704	2	0.991	0.996	5.15	2	0.767	0.876	6.61
577-640	18	0.950	0.955	6.01	22	0.840	0.960	8.28
513-576	19	0.938	0.943	7.99	19	0.884	1.011	10.78
449-512	261	0.968	0.973	4.85	313	0.881	1.007	6.14
385-448	33	0.962	0.967	7.94	33	0.987	1.128	10.88
321-384	6	0.918	0.922	19.57	6	1.405	1.606	27.05
257-320	1	1.016	1.021	2.55	1	0.840	0.960	3.02
193-256	279	0.995	1.000	3.08	390	0.936	1.070	3.22
129-192	16	0.948	0.952	3.85	16	1.079	1.233	5.34
65-128	198	0.997	1.002	2.11	843	1.113	1.272	3.32
CC mode	158	1.139	1.144	3.68	198	1.151	1.316	8.73

Note that the threshold crossing rates listed in Table 1a are systematically higher in continuous clocking mode than in timed exposure mode, by about 14% for front-illuminated and 32% for back-illuminated CCDs. Among timed exposure runs, FI rates are essentially insensitive to the number of rows clocked, while the BI rates appear to increase significantly when clocking 192 rows or less.

Some of the high BI threshold crossing rates may be artifacts of small statistics and X-ray events from bright sources, but the event rates for the 65-192 row range are lower than full-frame. Comparing Table 1a with Table 1b below, which includes graded mode runs — used when faint mode would saturate telemetry — the event rates for sub-array readout are significantly higher in graded mode, as are the threshold crossing rates.

Table 1b. Threshold-crossing and event rates – including graded mode observations.

Rows	Front-Illuminated CCDs				Back-Illuminated CCDs			
	Nobs	Rate	Norm	Evts	Nobs	Rate	Norm	Evts
961-1024	8027	0.996	1.000	8.41	6089	0.885	1.000	12.74
833-960	–	–	–	–	–	–	–	–
769-832	265	0.967	0.971	6.91	265	0.806	0.911	9.11
705-768	13	0.961	0.964	5.73	12	0.823	0.930	7.17
641-704	2	0.991	0.995	5.15	2	0.767	0.866	6.61
577-640	18	0.950	0.954	6.01	22	0.840	0.949	8.28
513-576	29	1.359	1.364	38.97	29	1.923	2.173	48.26
449-512	276	0.970	0.973	7.10	328	0.939	1.061	8.71
385-448	41	1.018	1.022	17.20	41	1.403	1.585	23.40
321-384	11	0.961	0.965	33.58	11	2.122	2.398	48.87
257-320	2	0.966	0.969	11.06	2	1.514	1.711	23.41
193-256	280	0.995	0.999	3.08	391	0.944	1.067	3.33
129-192	16	0.948	0.952	3.85	16	1.079	1.219	5.34
65-128	199	0.997	1.001	2.14	846	1.115	1.260	3.35
CC mode	247	1.140	1.144	8.23	298	1.389	1.569	14.23

7. Selecting Optimal Parameters

The procedure is described in Section 4, "Patch Tests" of the report "Selecting optimal parameters for the *txings* patch". A main program, *txings_test.C*, acts as a "wrapper", reading archived ACIS telemetry files and calling methods of the *txings* class defined in *txings.C*, the patch source itself. To test the changes described in Sections 2–4, the same *txings_test.C* was compiled and linked with three separate versions of the patch:

Table 2. Versions of the *txings* patch.

Binary executable	Patch source	Description
txings_test	*txings.C*	The original patch
txings2_test	*txings2.C*	The original patch with the changes described in Sections 2 and 3 applied, *i.e.*, exposures that report no crossings are accepted, and the average rate calculation keeps more significant digits.
txings3_test	*txings3.C*	As *txings2.C* but further edited so that, after triggering, the patch continues to accumulate and calculate threshold crossing rates. The executable isn't used for parameter selection. It is invoked by the scripts that create the daily plots of crossing rates accessible from the "*http://acis.mit.edu/asc/txgif*" URL.
txings4_test	*txings4.C*	As *txings2.C* but uses the Decreasing Rate algorithm described in Section 4. Note that the executable doesn't simultaneously apply the Ascending Rate algorithm. To test both, *txings2_test* and *txings4_test* must both be run.

Testing for optimal parameters is performed on the *antares* cluster which currently comprises 256 computation cores in 32 nodes. Each node accesses a shared file system that contains an up-to-date archive of ACIS telemetry packets, sorted by processing phase and science run number. The procedure uses three vectored scripts, *txmake*, *txbatch*, and *txmax*, and is organized as follows:

1. The ACIS archive is updated from the online repository — a RAID storage system accessed through the *maax.mit.edu* server.
2. The archive is searched for new science runs — *i.e.*, newer than *txings_test*, *txings2_test*, and *txings4_test* — which are processed by these three binaries using a parameter set with a very low trigger threshold (see the first line in Table 3, below). This task is assigned to three compute cores running *txmake* in parallel. The results are merged into three data files, each containing the result of processing all archived science runs through the corresponding *txings* algorithm.
3. The database files are searched and a file *txdata.txt* is created that lists every archived science run that either triggered one of the three *txings*_test* binaries or is contained in the list of "interesting" runs in *txings_parms.h* (see Appendix).
4. Comparing the updated *txdata.txt* with the prior version shows which observations are to be processed by the three binaries with a wide range of parameter values. This is done by running a separate copy of *txbatch* for each such observation. The results are saved on the cluster's common data server.
5. The results of applying each set of parameters to all observations listed in *txdata.txt* are sorted to determine which parameter sets resulted in the maximum number of true triggers and the minimum number of false ones. This is done with six *txmax* jobs, where each of the three algorithms is evaluated twice according to whether or not instances of increasing or decreasing crossing rates are counted as true or false triggers.
6. A *txprint.pl* script arranges the 6 outputs from the previous step in a format suitable for printing.

The following table shows the number of sets of parameter values ("Param count") that caused the maximum number of "Good triggers" with zero false triggers. The "Desc good?" column denotes whether periods known to have "high but descending" rates were considered good triggers or not.

Table 3. Range of parameters tested by various versions of *txings*.

	Type	Algorithm	Desc good?	Good triggers	Param count	Parameters					
						Tavg mins	Counts	Rate threshold FI	Rate threshold BI	Increments FI	Increments BI
Initial search parameters (see step 2, above)						3	3	600	30	0	0
1	Old	Ascending	no	17	240	3-4	5	670-700	30-55	1-4	1-4
2	Old	Ascending	yes	21	10	4	4	710-720	30	0	1-4
3	New	Ascending	no	18	27	2-4	5-6	680-700	30-40	0-3	2-4
4	New	Ascending	yes	19	6	4	5	660-670	30-40	3	4
5	New	Descending	no	12	5	3-4	6	660-720	50-55	4	1-4
6	New	Descending	yes	12	5	5-6	6	710-720	55	0-3	1-4
Range of parameter values tested						2-6	2-6	660-720	30-55	0-4	0-4

The following tables show the largest set of observations that were triggered by any set of parameters. The codes in the "alert" column have the following meaning:

SCS107	science safe mode commanded from the ground
EPHIN	science safe mode commanded onboard (by EPHIN, HRC, or ACIS)
HIRAD	high background rates, but run was not stopped
DSCRAD	high background rates, but descending
†	commanding error caused science run to continue during belt entry
*	RADMON was not enabled

Table 4a. On-board algorithm (*txings_test*), treating observations with descending rates as "bad". 210 parameter combinations triggered on OBSID 61839; 30 triggered on OBSID 56867; none triggered on both.

nr	obsid	phase	run	date	targetname	ccds	mode		rows	exp	alert
1	61996	acis4	102	07/14/00	Faint_Mode_S	S6	Te3x3	F	1024	3.2	SCS107
2	2344	acis6	41	11/24/00	HDF_NORTH	I5	Te3x3	F	1024	3.1	HIRAD
17a	**61839**	**acis6**	**45**	11/26/00	**Faint_Mode_S**	**S6**	**Te3x3**	**F**	**1024**	**3.2**	**EPHIN**
3	1578	acis8	104	04/03/01	NGC4111	I6	Te3x3	F	512	1.8	EPHIN
4	1890	acis10	79	09/24/01	HD_93497	S6	Te3x3	F	1024	3.2	EPHIN
5	3389	acis11	29	11/21/01	HDF-N	I4	Te5x5	F	1024	3.1	EPHIN
6	2010	acis12	190	11/04/01	PSR0628-28	I6	Te3x3	F	256	1.1	EPHIN
7	61227	acis13	40	04/21/02	Faint_Mode_I	I6	Te3x3	F	1024	3.2	EPHIN
8	4365	acis14	210	08/21/02	Groth-Westphal	I6	Te3x3	F	1024	3.2	HIRAD
9	2783	acis15	187	08/23/02	SNR_N157B	S1	Te5x5	F	256	0.8	EPHIN
10	5760	acis31	107	09/07/05	cl0216-1747	I5	Te5x5	F	1024	3.1	EPHIN
11	58650	acis38	163	12/13/06	Faint_Mode_S	S6	Te3x3	F	1024	3.2	HIRAD*
17b	**56867**	**acis56**	**38**	08/28/09	**Faint_Mode_I**	**I6**	**Te3x3**	**F**	**1024**	**3.2**	**HIRAD†**
12	12613	acis68	56	08/04/11	SWIFT_J1822.3-1	I6	Cc3x3	F	512	1.4	EPHIN
13	13822	acis70	209	01/20/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
14	13819	acis70	213	01/25/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
15	13846	acis72	68	05/16/12	Sgr_A*	S5	Te3x3	F	1024	3.1	EPHIN
16	15234	acis77	74	05/22/13	COSMOS_Legacy	I4	Te5x5	F	1024	3.1	EPHIN

Table 4b. On-board algorithm (*txings_test*), treating observations with descending rates as "good".

nr	obsid	phase	run	date	targetname	ccds	mode		rows	exp	alert
1	61996	acis4	102	07/14/00	Faint_Mode_S	S6	Te3x3	F	1024	3.2	SCS107
2	2344	acis6	41	11/24/00	HDF_NORTH	I5	Te3x3	F	1024	3.1	HIRAD
3	2014	acis8	14	04/17/01	NGC2403	S6	Te3x3	F	1024	3.2	DSCRAD
4	1560	acis8	18	04/18/01	NGC4696	S6	Te3x3	F	1024	3.2	DSCRAD
5	2042	acis8	39	04/28/01	ARP_270	I6	Te3x3	F	1024	3.2	SCS107
6	1578	acis8	104	04/03/01	NGC4111	I6	Te3x3	F	512	1.8	EPHIN
7	1890	acis10	79	09/24/01	HD_93497	S6	Te3x3	F	1024	3.2	EPHIN
8	3389	acis11	29	11/21/01	HDF-N	I4	Te5x5	F	1024	3.1	EPHIN
9	2010	acis12	190	11/04/01	PSR0628-28	I6	Te3x3	F	256	1.1	EPHIN
10	61227	acis13	40	04/21/02	Faint_Mode_I	I6	Te3x3	F	1024	3.2	EPHIN
11	4365	acis14	210	08/21/02	Groth-Westphal	I6	Te3x3	F	1024	3.2	HIRAD
12	2783	acis15	187	08/23/02	SNR_N157B	S1	Te5x5	F	256	0.8	EPHIN
13	60492	acis21	11	11/02/03	Faint_Mode_S	S6	Te3x3	F	1024	3.2	DSCRAD*
14	5760	acis31	107	09/07/05	cl0216-1747	I5	Te5x5	F	1024	3.1	EPHIN
15	58650	acis38	163	12/13/06	Faint_Mode_S	S6	Te3x3	F	1024	3.2	HIRAD*
16	12613	acis68	56	08/04/11	SWIFT_J1822.3-1	I6	Cc3x3	F	512	1.4	EPHIN
17	13822	acis70	209	01/20/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
18	13819	acis70	213	01/25/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
19	13846	acis72	68	05/16/12	Sgr_A*	S5	Te3x3	F	1024	3.1	EPHIN
20	53787	acis76	200	04/11/13	Faint_Mode_I	I6	Te3x3	F	1024	3.2	DSCRAD*
21	15234	acis77	74	05/22/13	COSMOS_Legacy	I4	Te5x5	F	1024	3.1	EPHIN

Table 4c. Updated ascending algorithm (*txings2_test*), treating observations with descending rates as "bad". 12 parameter combinations triggered on OBSID 61839; 15 triggered on OBSID 56867; none triggered on both.

nr	obsid	phase	run	date	targetname	ccds	mode		rows	exp	alert
1	61996	acis4	102	07/14/00	Faint_Mode_S	S6	Te3x3	F	1024	3.2	SCS107
2	2344	acis6	41	11/24/00	HDF_NORTH	I5	Te3x3	F	1024	3.1	HIRAD
18a	**61839**	**acis6**	**45**	11/26/00	**Faint_Mode_S**	**S6**	**Te3x3**	**F**	**1024**	**3.2**	**EPHIN***
3	1578	acis8	104	04/03/01	NGC4111	I6	Te3x3	F	512	1.8	EPHIN
4	1890	acis10	79	09/24/01	HD_93497	S6	Te3x3	F	1024	3.2	EPHIN
5	3389	acis11	29	11/21/01	HDF-N	I4	Te5x5	F	1024	3.1	EPHIN
6	3463	acis12	175	03/18/02	RX_J170930.2-26	I6	Cc3x3	F	512	1.4	SCS107
7	2010	acis12	190	11/04/01	PSR0628-28	I6	Te3x3	F	256	1.1	EPHIN
8	61227	acis13	40	04/21/02	Faint_Mode_I	I6	Te3x3	F	1024	3.2	EPHIN*
9	4365	acis14	210	08/21/02	Groth-Westphal	I6	Te3x3	F	1024	3.2	HIRAD
10	2783	acis15	187	08/23/02	SNR_N157B	S1	Te5x5	F	256	0.8	EPHIN
11	5760	acis31	107	09/07/05	cl0216-1747	I5	Te5x5	F	1024	3.1	EPHIN
12	58650	acis38	163	12/13/06	Faint_Mode_S	S6	Te3x3	F	1024	3.2	HIRAD*
18b	**56867**	**acis56**	**38**	08/28/09	**Faint_Mode_I**	**I6**	**Te3x3**	**F**	**1024**	**3.2**	**HIRAD†**
13	12613	acis68	56	08/04/11	SWIFT_J1822.3-1	I6	Cc3x3	F	512	1.4	EPHIN
14	13822	acis70	209	01/20/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
15	13819	acis70	213	01/25/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
16	13846	acis72	68	05/16/12	Sgr_A*	S5	Te3x3	F	1024	3.1	EPHIN
17	15234	acis77	74	05/22/13	COSMOS_Legacy	I4	Te5x5	F	1024	3.1	EPHIN

Table 4d. Updated ascending algorithm (*txings2_test*), treating observations with descending rates as "good".

nr	obsid	phase	run	date	targetname	ccds	mode		rows	exp	alert
1	61996	acis4	102	07/14/00	Faint_Mode_S	S6	Te3x3	F	1024	3.2	SCS107
2	2344	acis6	41	11/24/00	HDF_NORTH	I5	Te3x3	F	1024	3.1	HIRAD
3	61625	acis8	87	05/20/01	Faint_Mode_S	S6	Te3x3	F	1024	3.2	DSCRAD*
4	1578	acis8	104	04/03/01	NGC4111	I6	Te3x3	F	512	1.8	EPHIN
5	1890	acis10	79	09/24/01	HD_93497	S6	Te3x3	F	1024	3.2	EPHIN
6	3389	acis11	29	11/21/01	HDF-N	I4	Te5x5	F	1024	3.1	EPHIN
7	3463	acis12	175	03/18/02	RX_J170930.2-26	I6	Cc3x3	F	512	1.4	SCS107
8	2010	acis12	190	11/04/01	PSR0628-28	I6	Te3x3	F	256	1.1	EPHIN
9	61227	acis13	40	04/21/02	Faint_Mode_I	I6	Te3x3	F	1024	3.2	EPHIN
10	4365	acis14	210	08/21/02	Groth-Westphal	I6	Te3x3	F	1024	3.2	HIRAD
11	2783	acis15	187	08/23/02	SNR_N157B	S1	Te5x5	F	256	0.8	EPHIN
12	5760	acis31	107	09/07/05	cl0216-1747	I5	Te5x5	F	1024	3.1	EPHIN
13	58650	acis38	163	12/13/06	Faint_Mode_S	S6	Te3x3	F	1024	3.2	HIRAD*
14	56867	acis56	38	08/28/09	Faint_Mode_I	I6	Te3x3	F	1024	3.2	HIRAD†
15	12613	acis68	56	08/04/11	SWIFT_J1822.3-1	I6	Cc3x3	F	512	1.4	EPHIN
16	13822	acis70	209	01/20/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
17	13819	acis70	213	01/25/12	NGC3115	I5	Te5x5	F	1024	3.1	EPHIN
18	13846	acis72	68	05/16/12	Sgr_A*	S5	Te3x3	F	1024	3.1	EPHIN
19	15234	acis77	74	05/22/13	COSMOS_Legacy	I4	Te5x5	F	1024	3.1	EPHIN

Table 4e. New descending algorithm (*txings4_test*). The following observations triggered on 5 parameter combinations. The four "HIRAD" observations that triggered possess periods in which the rates were both ascending and descending; "HIRAD" observations without descending periods did not trigger the algorithm. ¶ denotes observations made with RADMON disabled, after which either EPHIN or HRC triggered an automatic shutdown as soon as RADMON was enabled again.

nr	obsid	phase	run	date	targetname	ccds	mode		rows	exp	alert
1	2344	acis6	41	11/24/00	HDF_NORTH	I5	Te3x3	F	1024	3.1	HIRAD
2	2014	acis8	14	04/17/01	NGC2403	S6	Te3x3	F	1024	3.2	DSCRAD
3	61663	acis8	17	04/18/01	Faint_Mode_I	I6	Te3x3	F	1024	3.2	DSCRAD*
4	1560	acis8	18	04/18/01	NGC4696	S6	Te3x3	F	1024	3.2	DSCRAD
5	4365	acis14	210	08/21/02	Groth-Westphal	I6	Te3x3	F	1024	3.2	HIRAD
6	60492	acis21	11	11/02/03	Faint_Mode_S	S6	Te3x3	F	1024	3.2	DSCRAD ¶
7	59611	acis30	84	06/17/05	Faint_Mode_I	I6	Te3x3	F	1024	3.2	DSCRAD*
8	58650	acis38	163	12/13/06	Faint_Mode_S	S6	Te3x3	F	1024	3.2	HIRAD*
9	58648	acis39	1	12/13/06	Faint_Mode_I	I6	Te3x3	F	1024	3.2	DSCRAD ¶
10	12338	acis68	60	08/09/11	Gl_124	S6	Te5x5	F	256	1.1	DSCRAD
11	54787	acis71	100	03/13/12	Faint_Mode_S	S6	Te3x3	F	1024	3.2	HIRAD ¶
12	53787	acis76	200	04/11/13	Faint_Mode_I	I6	Te3x3	F	1024	3.2	DSCRAD*

8. Conclusions

Regarding the variation of count rate with clocking parameters described in Section 6, there appears to be no hard evidence that the rates depend on the number of CCD output rows. This accords with simple arithmetic: for minimum frame time without pre-flushing, and ignoring parallel transfer times, each row of pixels spends on average twice as long in the CCD image store as in its frame-store, irrespective the number of rows. This is not, however, the case in continuous clocking mode, where each row spends the same time in each store. It is therefore to be expected that the threshold crossing rates should be higher in continuous clocking mode than in timed exposure mode, and the increase (see Table 1a, bottom row) for back-illuminated CCDs (31.6%) might exceed than for front-illuminated ones (14.4%) due to the effects of frame-store shielding. However, the difference could also be attributed to the more frequent use of CCD_S3 to observe very bright sources in continuous clocking mode.

Consult rows 1 and 3 of Table 3 to compare the effectiveness of the "old" (*txings*) and "new" (*txings2*) algorithms at triggering on ascending threshold-crossing rates. The new algorithm finds one additional instance in the archive, but the "volume" of parameter space — the number of parameter combinations that triggered on this many observations — is smaller: 15 *vs*. 210 for *txings*, reflecting the greater sensitivity of *txings2*'s less quantized rate estimation. The number of parameter sets that trigger *txings2* in as many runs as *txings* did (17) is 80. We expect that *txings2* should be superior for back-illuminated CCDs, but there have been few instances of triggers when only those CCDs were taking data (indicated by "S1" in the "ccds" column of Tables 4a-e.) Also, it is not known at this time which of the changes—the inclusion of zero-rate exposures or the improvement in rate quantization—is most responsible for the changed behavior from *txings* to *txings2*.

The triggers from *txings* and *txings2* (Tables 4b and 4d) share 16 observations in common, with five additional triggers only in *txings* and three only in *txings2*. This might lead us to conclude that the new version is *less* effective than the old, but most of the difference can be traced to the "best fit" parameter values: the optimal *txings* results came from higher rate thresholds and lower rate increments than those from *txings2* — compare Table 3, rows 2 and 4 — so the *txings2* triggers were less sensitive to the *rate* of crossing rate increase, $\partial^2 r/\partial t^2$. Of the five observations that triggered *txings* but did not trigger *txings2*, four possessed high but decreasing rates. With an optimal FI increment of zero, *txings* was more likely than *txings2* (whose FI increment was 3) to trigger on brief moments when the rates were ascending. The crossing rates for the fifth observation (OBSID 2042) only rose above threshold for a short interval before the observatory was commanded into safe mode, so *txings2*, with its longer integration times, had insufficient time to trigger. Of the three observations that triggered *txings2* but not *txings*, OBSID 3463 was a real radiation event in CC mode, with higher BI rates than FI, and hence more likely to trigger *txings2* with its improved sensitivity to BI rates. The other two triggers occurred during CTI runs with RADMON disabled: OBSID 61625 was an outbound run whose crossing rates fell below the trigger thresholds before the end of the observation and OBSID 56867 was still running (due to a commanding error) when Chandra entered the radiation belts, and was subsequently halted by ground command.

Table 4e, which shows the results from running the new descending algorithm (*txings4*) lists twelve radiation triggers. Three of these overlap with those shown in Table 4d, so are not unique to the descending algorithm. Of the remaining nine, six came from CTI observations when RADMON was disabled and could not have triggered a spacecraft shutdown. As it happens however, four of the outbound CTI observations had threshold crossing rates that were still well above the triggering threshold at their conclusion, so it is likely that the following science observations would also have triggered. For example, OBSID 1560 follows after OBSID 61663 and both are listed as *txings4* triggers. The three science observations made with RADMON enabled only triggered *txings4*, the descending algorithm: (1) OBSID 1560 immediately followed OBSID 61663, an outbound CTI observation, which also triggered *txings4* (see Table 4e); (2) OBSID 2014 had very high and decreasing rates and immediately followed a radiation shutdown; while other radiation measures may have seemed acceptable for a restart, its threshold crossing rates were clearly still too high; the earlier shutdown would have needed to be extended for a much longer time (~2 days) to avoid risking an ACIS trigger; (3) OBSID 12338 had threshold crossing rates that only stayed high for a few hours.

In summary, the optimal parameters for the new ascending-rate algorithm (*txings2*) buy us one new trigger (OBSID 3463) but miss one (OBSID 2042) that would most probably have triggered if Chandra had not been shut down by ground command. The new algorithm is also rather more sensitive to its parameters, reflecting less quantization of BI rates. The descending-rate algorithm (*txings4*) triggered mostly while RADMON was disabled, produced no false-positives, and caught three science observations with high-but-descending rates, two of which (OBSIDs 1560 and 2014) might have warranted a shut-down, while the third (OBSID 12338) did not.

9. References

"Using ACIS on the Chandra X-ray Observatory as a particle radiation monitor," C. E. Grant, B. LaMarr, M. W. Bautz and S. L. O'Dell, SPIE, June 2010.

"DPA Hardware Specification and System Description," MIT 36-02104, Rev. C, April 15, 1997.

"ACIS Software User's Guide," MIT 36-54003, Rev. A, (NAS8-37716/DR/SDM05) July 21, 1999.

"ACIS Software Detailed Design Specification (As-Built)," MIT 36-53200, Rev. A, (NAS8-37716/DR/SDM03) February 3, 2000.

"Using ACIS to detect and report high radiation conditions," Rev. 1.3, MIT report, April 15, 2011.

"Selecting optimal parameters for the *txings* patch," Rev. 1.1, MIT report, April 12, 2012.

10. Glossary

Back-Illuminated .... 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 RCTU and FEPs.
BI .... An abbreviation for Back-Illuminated. (*q.v.*)
CC .... An abbreviation for Continuous Clocking (*q.v.*)
CCD .... Charge-Coupled Device — the x-ray detectors used by ACIS.
ccdId .... The index of a particular ACIS CCD (0..3 = I0..I3, 4..9 = S0..S5).
CXC .... Chandra X-Ray Observatory Science Center.
EPHIN .... Electron, Proton and Helium Instrument — flown on Chandra and SOHO.
EU .... ACIS Engineering Unit — duplicate DEA+DPA+PSMC in an MIT laboratory.
FI .... An abbreviation for Front-Illuminated. (*q.v.*)
Front-Illuminated .... A CCD that detects x-rays incident on the same face as its junctions.
OBC .... On-Board Computer — the Chandra spacecraft's central controller.
OBSID .... Observation Identifier — a unique number assigned by the CXC to a science run.
RADMON .... Excessive radiation alert signal from EPHIN or ground to OBS and/or ACIS.
SCS107 .... Command to OBC from EPHIN or ground to safe the science instruments.
TE .... An abbreviation for Timed Exposure (*q.v.*)
Threshold .... Value by which a pixel exceeds its corresponding bias value to become interesting.
TX .... The sub-array in *txings* containing parameters for the current science run.
tx .... The sub-array in *txings* containing accumulators for the current science run.

Appendix A – the *txings* parameter file

The most recent version of *txings_parms.h*, which is included in all *txings* wrapper routines and in the scripts that were used to generate Fig. 2, reads as follows:

```
/* Special observations May 6 2013 */

/* OBSIDs in which EPHIN/HRC triggers occurred */
int radmon[] = {
    433, 648, 1578, 1890, 1900, 2010, 2077, 2080, 2547, 2783, 2943, 2986,
    3057, 3389, 3577, 3713, 3764, 3871, 3896, 3997, 4063, 4591, 4642, 4690,
    4757, 4912, 4996, 5060, 5475, 5760, 5814, 5934, 6390, 6432, 6438, 6904,
    7410, 12613, 12902, 13753, 13822, 13819, 13846, 14401, 14461, 14465,
    15234, 60117, 60497, 61116, 61227, 61452, 61665, 61839,
};

/* OBSIDs in which SCS107 was commanded from the ground */
int scs107[] = {
    642, 2042, 2135, 2365, 2751, 2953, 3130, 3182, 3363, 3463, 3732, 4016,
    4175, 4408, 4756, 5296, 5954, 6152, 13393, 13780, 13853, 14361, 14687,
    14993, 61427, 61996,
};

/* OBSIDs with other high-radiation conditions */
int hirad[] = {
    2344, 4365, 10113, 54786, 54787, 56866, 56867, 57597, 58650,
};

/* OBSIDs with high but descending radiation conditions */
int descrad[] = {
    111, 1560, 2014, 12314, 12338, 53786, 55370, 58648, 59611, 60492,
    61625, 61663,
};

/* Crab and Titan/Crab observations */
int crab[] = {
    168, 169, 170, 769, 770, 771, 772, 773, 1994, 1995, 1996, 1997, 1998,
    1999, 2000, 2001, 2798, 3727, 4412, 4413, 4607, 4621, 4622, 4623,
    4624, 5284, 5285, 5550, 5551, 5552, 5553, 5554, 5555, 5556, 5557,
    5558, 6140, 6141, 6142, 6143, 7587, 13139, 13146, 13147, 13150,
    13151, 13152, 13153, 13154, 13204, 13205, 13206, 13207, 13208, 13209,
    13210, 13750, 13751, 13752, 13753, 13754, 13755, 13756, 13757, 13759,
    13760, 13761, 13762, 14416, 14458, 14679, 14680, 14681, 14685,
};

/* Jupiter observations */
int jupiter[] = {
    1, 960, 1463, 1464, 1465, 1482, 1862, 2398, 2399, 2400, 2401, 2407,
    2408, 2519, 3726, 4418, 7405, 8216, 8217, 8218, 8219, 8220, 12315,
    12316,
};

/* Hardware anomalies */
int fep0_latchup[] = {
    18, 333, 510, 965, 1383, 62327, 62333, 62338, 62340, 62353, 62363,
    62502,
};
```

```
int tplane_latchup[] = {
    371, 2010, 3403, 5560, 6730,
};

/* FI threshold polynomial May 6 2013 */
double FIparm[] = {
    5.18342, -1.00584, 0.149244, 0.0253375, -0.00470354, 0.000174859
};

/* BI threshold polynomial May 6 2013 */
double BIparm[] = {
    0.250221, -0.0565284, 0.015198, -0.000811421, -2.11471e-05, 1.43416e-06
};

/* Addresses of patch blocks  */
unsigned *txinit_addr = (unsigned *)0x8003dc30; /* address of TXinit */
unsigned *txnext_addr = (unsigned *)0x8003dc50; /* address of TXnext */
unsigned *txings_addr = (unsigned *)0x8003dc70; /* address of txings */
unsigned txversion    = 50;                     /* patch version number */
const char *txloadblock = "WBTXING002";         /* name of pblock */

/* "Optimum" txings parameters */
unsigned txopts[8] = { 3, 5, 512, 291840, 626, 47, 1, 1 };
```

Appendix B – vector computation scripts

The Torque batch controller of the *antares* cluster is commanded to start multiple copies of an executable on separate compute cores through its `qsub` command:

```
qsub -t nnn name.pbs
```

which starts one or more copies of **.pbs* on compute cores according to *nnn*, which can specify a comma-delimited list of indices or range of indices, *e.g.*, “`2,5,11-16,21`”. Each **.pbs* is passed its particular index through its `$PBS_ARRAYID` environment variable and gets to tell Torque its memory and CPU requirements via `#PBS` meta-comments. The following example shows *txbatch.pbs*:

```
#!/bin/sh
#
# Run txings commands on multiple ACIS packet streams.
# This script should be invoked with "qsub -t 1-nnn"
# where "nnn" is the number of input # streams to be
# read by "txbatch.sh".
#
#PBS -N tx_batch
#PBS -l nodes=1:ppn=1
#PBS -l mem=50mb
#
# Get number of processors and nodes
NPROCS=`wc -l < $PBS_NODEFILE`
NNODES=`uniq $PBS_NODEFILE | wc -l`
#
# execute in qsub launch directory
cd $PBS_O_WORKDIR
#
# write message to stdout
```

```
echo "Starting tx_batch #$PBS_ARRAYID on `hostname` on `date`"
echo "Using ${NPROCS} processors across ${NNODES} nodes"
#
# process a single packet stream
sh txbatch.sh $PBS_ARRAYID
#
# List resource usage on stdout
qstat -f $PBS_JOBID | grep -i resource
#
# write ending message
echo "Ending tx_batch on `date`"
#
exit 0
```

The others, *txmake.pbs* and *txmax.pbs*, merely exchange "batch" for "make" and "max", throughout, except that txmake.pbs also passes the *txings* parameter set to *txmake.sh* in positional parameters. They invoke shell scripts, *txmake.sh*, *txbatch.sh*, and *txmax.sh* to do the work. Each script is passed its index as a positional parameter, and accesses the data archive at "*/corscorpii/d1/pgf/*".

```
#! /bin/sh
#
# txmake: run versions of txings to create baseline files
#
# Syntax: "sh txmake.sh n p1 ... p6" where n = 1,2,4
#
NP=$1
PARM="$2 $3 512 291840 $4 $5 $6 $7"
NAME="run.$2.$3.$4.$5.$6.$7.txt"
#
# User data files
DATA=/corscorpii/d1/pgf
#
case $NP in
  1) id= ;;
  2) id=2 ;;
  4) id=4 ;;
  *) echo $0: bad arg: $NP ; exit 1 ;;
esac
#
# Determine binary and output file. Initialize year,doy
proc=bin/txings${id}_test
out=$DATA/dat/txings$id.$NAME
new=$DATA/dat/txings$id.$NAME.ext
tmp=/tmp/txdoy$$
rm -f $new $tmp
echo year=1999 doy0=0 > $tmp
#
# Loop over packet directories
for log in `ls $DATA/pkts/r?/[de]*/acis*/acis*.log | sort -t/ -k 8.5n`
do
  dir=`dirname $log`/pkts
  phase=`expr $log : '.*/acis\([0-9]*\)\.log$'`
  case $log in *a/acis*.log)
    eval `awk '$2==p {print "year="$3,"doy0=0"}' p=$phase phases.txt`
  esac
  cat $log |\
  while read run arg
```

```
    do
      [ "$run" = '#' ] && continue
      doy=`echo "$arg" | awk '{print substr($8,1,3)}'`
      eval `cat $tmp`
      [ $doy -lt $doy0 ] && year=`expr $year + 1`
      echo year=$year doy0=$doy > $tmp
      dat=$dir/run-$run.pkts.gz
      [ $run -lt 1 -o $out -nt $dat ] && continue
      gunzip -cf $dat | $proc -D $phase $run $year $PARM >> $new
    done
  done
  #
  # remove date file
  rm -f $tmp
  #
  exit 0
```

```
  #! /bin/sh
  #
  # txbatch: run txings with varying parameters on a single ACIS packet stream
  #
  # Syntax: "sh txbatch.sh n" where 1 <= n <= nnn (the number of lines in txdata.txt)
  #
  NP=$1
  #
  # User data path
  DATA=/corscorpii/d1/pgf
  #
  # Read line $NP: "phase run year sw1 sw2 sw4"
  eval `awk 'NR==n {print "p="$1,"r="$2,"y="$3,"s1="$4,"s2="$5,"s4="$6}' n=$NP  txdata.txt`
  #
  # If s{1,2,4} are non-zero, and no output file exists, run txings{,2,4}_test
  [ "$s1" -ne 0 ] && out1=$DATA/out/acis$p.$r.1.dat && [ -f $out1 ] && out1=
  [ "$s2" -ne 0 ] && out2=$DATA/out/acis$p.$r.2.dat && [ -f $out2 ] && out2=
  [ "$s4" -ne 0 ] && out4=$DATA/out/acis$p.$r.4.dat && [ -f $out4 ] && out4=
  #
  # Exit if nothing to do
  [ ! "$out1" -a ! "$out2" -a ! "$out4" ] && echo "$NP: acis.$p.$r.*.dat: nothing new" && exit 0
  #
  # Decompress the ACIS packet stream into $in
  in=/tmp/acis$p.$r.$NP.pkts
  gunzip -cf $DATA/pkts/r?/[de]?/acis${p}?/pkts/run-$r.pkts.gz > $in
  #
  # Now step through the parameters
  for min in 6 5 4 3 2 ; do
    for cnt in 6 5 4 3 2 ; do
      for lFI in 660 670 680 690 700 710 720 ; do
        for lBI in 30 35 40 45 50 55 ; do
          for fth in 0 1 2 3 4 ; do
            for bth in 0 1 2 3 4 ; do
              # construct the full parameter string
              parm="$p $r $y $min $cnt 512 291840 $lFI $lBI $fth $bth"
              if [ "$out1" ] ; then  # run txings_test
                ./bin/txings_test -D -P $parm < $in >> $out1
              fi
              if [ "$out2" ] ; then  # run txings2_test
                ./bin/txings2_test -D -P $parm < $in >> $out2
              fi
```

```
              if [ "$out4" ] ; then  # run txings4_test
                ./bin/txings4_test -D -P $parm < $in >> $out4
              fi
            done
          done
        done
      done
    done
done
#
# We are done with $in
/bin/rm $in
#
exit 0
```

```
#! /bin/sh
#
# txmax: create parameter maximization files
#
# Syntax: "sh txmax.sh n" where n = 1,2,4
#
NP=$1
# User data files
DATA=/corscorpii/d1/pgf/dat
OUT=/corscorpii/d1/pgf/out
#
case $NP in
  1) in=1 out=1  opt="-a -n0" ;;
  2) in=1 out=1a opt="-a -d -n0" ;;
  3) in=2 out=2  opt="-a -n2" ;;
  4) in=2 out=2a opt="-a -d -n2" ;;
  5) in=4 out=4  opt="-d -n2" ;;
  6) in=4 out=4a opt="-a -d -n2" ;;
  *) echo $0: bad arg: $NP ; exit 1 ;;
esac
#
txlist_test.pl -s $opt $OUT/acis*.*.$in.dat > $DATA/maximize$out.txt
#
exit 0
```