CHANDRA
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MEMORANDUM

Date:	April 14, 2015
From:	Richard J. Edgar
To:	Chandra Operations Team
Subject:	Chandra Radiation Events and Shutdowns, December 22-24, 2014
Cc:	MSFC Project Science, CXC Director's Office
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1 Abstract

This memo discusses the thought process that the operations team, especially the ACIS operations team, used during the very high radiation week and events on or about 22 through 24 December, 2014. During this time frame, we experienced two radiation-induced shutdowns. Both of these were by ground command.

The key decision points to continue or suspend science operations are reviewed. During this time frame, a decision for the first manual shutdown resulted in sparing ACIS from a fluence of ACE P3 protons of nearly 1.7×10^9. No high priority, constrained, or coordinated observations were missed. The actual accumulation for this orbit was 2.14×10^9.

2 Introduction

The week prior to Christmas 2014 was challenging for the Chandra radiation environment. There were two M-class flares (M8.7 on Dec 16, and M6.9 on Dec 18) from Active Region 12241, and then an X1.8 flare on Dec 19 from AR 12242. The latter had a clear CME associated, though the LASCO imagery indicated that it was mostly directed to the south. The ENLIL heliospheric model predicted a glancing blow from the M flare activity on Dec 21 in the morning hours, EST.

3 Detailed Timeline

- 2014:351 **Wednesday Dec 17, 2014**
- 2014:351:04:39 – M8.7 solar flare (x-ray flux of 8.7×10^{-5} W m^{-2}) from Active Region (AR) 12241.
- 2014:352 **Thursday Dec 18, 2014**
- 2014:352:22:42 – M6.9 solar flare from AR 12241. There was a possible detection of a halo CME from this flare.
- 2014:354 **Saturday Dec 20, 2014**
- 2014:354:00:28 – X1.8 solar flare from AR 12242. This flare was associated with a visible CME, mostly directed to the south.
- 2014:355 **Sunday Dec 21, 2014**
- 2014:355:08:00 – Predicted arrival of CME from day 352 M6.9 flare. It was delayed by several hours.
- 2014:355:09:14 – Radiation belt entry
- 2014:355:20:30 – ACE P3 rates at 33,500. After exit from the radiation belts, the schedule called for bare ACIS observations until the HETG insertion at 356:16:16.
- 2014:355:22:15 – Radiation belt exit. Fluence integration begins.
- 2014:356 **Monday Dec 22, 2014**
- 2014:356:04:00 – Radiation telecon was called at 11pm local time. ACE P3 flux rates were 40,000–50,000 and noisy.

  The DEC1514B load then executing included the following relevant events. Extrapolated fluence numbers are included, assuming P3 = 45,000 and flat.

  - 356:13:45 – Next comm. Projected fluence 2.1×10^9
  - 356:16:15 – HETG insertion. The HETG attenuates P3 fluxes by a factor of five. Projected fluence 2.5×10^9

  The decision was difficult because the projected rate was close to the budgeted orbital fluence of 2.0×10^9. Discussion included the expectation that rates would decline; in fact they did by a factor 2–3 over the hours that followed. (They then spiked sharply on day 357.) It was suggested that we were under budget for the year to date. SOT Mission Planning was consulted, and none of the upcoming targets were

high priority, constrained, or coordinated with another observatory. The decision was made to shut down after 45 minutes of discussion.

- 2014:356:04:10 – Comm starts – Extended beyond the scheduled one hour window.
- 2014:356:04:52:35 – SCS 107 run by ground command. Execution was nominal. Integrated fluence so far this orbit: 0.66×10^9.
- 2014:356:17:00 – DEC2214A load review (12:00 EST)
- 2014:356:21:30 – Go/no-go telecon for the DEC2214A science resumption loads
- 2014:356:22:25 – DEC2214A load first segment uplinked.
- 2014:356:22:57 – DEC2214A load begins executing, beginning with an HETG insertion.
- 2014:357 **Tuesday Dec 23, 2014**
- 2014:357:09:15 – P3 fluence for the orbit exceeds 1.0×10^9. This was expected, and the P3 flux was still around 35,000.
- 2014:357:10:45 – MTA alert: the P3 two-hour averaged flux exceeded 50,000.
- 2014:357:11:30 – Radiation telecon. The P3 flux was 300,000, which produces a fluence of 1×10^9 in under an hour. The decision is made to shut down. ACIS threshold crossing counts were extremely high, resulting in significant data processing delays on the front-illuminated chips. Subsequent examination of the data suggests ACIS was minutes from triggering an automated shutdown (see figure 6).
- 2014:357:11:36:38 – SCS 107 run by ground command. Execution was nominal. Integrated fluence so far this orbit: 2.14×10^9.
- 2014:357:23:00 – DEC2414A load review (6:00 pm EST)
- 2014:358 **Wednesday Dec 24, 2014**
- 2014:358:18:05 – DEC2414A load first segment uplinked.
- 2014:358:18:30 – DEC2414A load begins executing.

A graphical timeline of key events superimposed on the P3 flux is presented in figure 1.

4 Discussion

As before, the Science-Only Safing (SOSA) paradigm greatly simplified the considerations as to whether a radiation shutdown would be necessary, and what the consequences would be. We were taking data again in 18 hours (Dec 22) and 30.5 hours (Dec 24), which is a testament to the hard work of the mission planning and review teams and flexibility of the SOSA approach.

A discussion of the radiation budget philosophy was started during the telecon the evening of Dec 21. We deferred action on any changes to the procedures and limits to a future radiation working group meeting, to allow time for measured consideration of any proposed changes. At the present time, the radiation budget for a single orbit is 2.0×10^9 and for a year is 20.0×10^9, so up to ten full-budget orbits are allowed in a year (with no other significant radiation).

In this particular case, no high priority or time-critical targets were in the upcoming load, so perhaps there is less need to expend the ACIS radiation budget. In the MAY2213 case, there was a high-priority observation of Sgr A*, and a TOO, which we were able to execute because of careful use of the available comm opportunities and radiation budget.

If we had not shut down at 356:04:52, the P3 fluence would have been 1.6×10^9 by the time of the HETG insertion the following morning, 356:16:15. Extrapolated at the observed rate of 45,000, the expected fluence by that same time would have been 2.51×10^9. This is the number we had at the time the decision was made.

In table 2, we present full-orbit fluences under four scenarios. These are the as-run history, with both shutdowns; a case with the first shutdown (356:04:52) but not the second (357:11:36); a case without the first shutdown (356:04:52) but with the second (357:11:36); and a no-intervention case, in which the DEC1514B loads would run to completion without intervention. This case also assumes ACIS would not have shut down autonomously. These numbers show that the first shutdown saved us 1.05×10^9, while the second saved 1.71×10^9. In the event, this very active orbit came in slightly over the one-orbit budget, saving 2.8×10^9, or an orbit and a half worth of budgeted radiation.

The HRC Anti-coincidence shield rate, and its GOES proxy, were flat throughout this storm. The hard protons to which they are sensitive seemed to be unaffected by this event. Softer GOES proton bands do show a strong shock-like jump at approximately time 2014:357:23:00. However, note that the 10 MeV protons measured by the ACE SIS instrument do show a spike at 357:11:00 or so (see figure 4).

We attach plots of a number of relevant quantities, showing the ACIS threshold crossings beginning to rise toward a possible autonomous shutdown; the GOES proton rates; ACE electron and proton rates; and the ACE solar wind SWEPAM and MAG data on the magnetic field, velocity and density. These show the arrival of several shock disturbances.

On day 357 just prior to the second shutdown, when P3 rates were spiking above 10^5, we observe that the total chip count rate for both the S3 chip and the sum of the FI chips was increasing rapidly, roughly an order of magnitude above what it was prior to

the disturbance. This occurs shortly after the spike in the GOES proton rates. Plots of this for the whole 5-day period, and for just day 357, can be found in figures 7 and 8. The variations in ACIS rates around day 355.9 in this figure are not significant as there were three different observations during the brief execution of command load DEC2214A. Variations in source parameters can cause differences in BI to FI ratios.

5 Obsid 16099, 23 Dec 2014

The last obsid prior to the shutdown on 23 December 2014 suffered greatly from telemetry saturation and increased background effects.

This observation, which started at time 2014:357:08:11:07, observed for roughly 11 ksec without significant incident. At time 2014:357:11:29:35, telemetry staturated, and ACIS began dropping frames. A total of 154 frames occur in the dropped frames list, plus about 12 at the end (after the last good frame received from a given chip). These were all from the four FI chips (I2, I3, S2, and S4), in roughly equal numbers (40–45 frames dropped for each chip). Having many fewer threshold crossings to process, the FEP for the S3 chip was able to keep up and get its results in ahead of the struggling FEPs for the FI chips. Over half the exposures were lost to telemetry saturation during the last few minutes.

109 frames were received with a total of 13k events after this time, during the final 107.5 seconds (55 frames) of the observation, prior to shutdown. Summing over this time interval and all chips, 322 events were dropped for amplitude (roughly at the typical rate) and 2029 for grade (about 3 times normal and rising).

For comparison, a thousand frames earlier, 275 frames were received (all of them), during $2439 \leq \mathrm{EXPNO} \leq 2493$, with 6k events, 420 dropped for amplitude, and 683 for grade.

Among accepted events, g02346, $0.35 \leq \mathrm{Energy} \leq 8.0$ keV, background also began to rise at some 240 seconds prior to telemetry saturation. The total good event rate for the S3 chip rises from about 1.8 counts per frame to over 10 before SCS 107 cuts off the integration. Also of note is that the S4 (an FI chip which exhibits streaks in some cicumstances) rate goes from 17 counts/frame to over 60. The other FI chips are better behaved, with only a factor of about two background increase.

For illustration, we plot a number of quantities vs. time for the last few kiloseconds of this observation. Times in each case have the start time for the observation subtracted, for clarity. The good event histogram is in units of 9.3 seconds, or three frames.

In figure 9 we present plots of the threshold crossings and total events sent vs. time for each of the 5 active chips, color coded for the CCD_ID as marked.

In figure 10 we show the number of events dropped per frame for two reasons, amplitude and grade. On FI chips particularly, charged particle hits can give rise to many flight grade 255 events, which are dropped on board. They can also have very large amplitudes, which would exceed the upper level pulse height limit. Both quantities begin to rise sharply at

Time (UTC)	Event
2014:351	Dec 17, 2014
2014:351:04:39	M8.7 solar flare
2014:352	Dec 18, 2014
2014:352:22:42	M6.9 solar flare
2014:354	Dec 20, 2014
2014:354:00:28	X1.8 solar flare
2014:355	Sunday Dec 21, 2014
2014:355	P3 rates rising through the day
2014:355:22:15	Radmon Enabled
2014:356	Monday Dec 22, 2014
2014:356:04:00	Radiation telecon P3 $4 - 5 \times 10^4$
2014:356:04:52:35	SCS 107 run by ground command
2014:356:21:30	go/no-go telecon
2014:356:22:57	DEC2214A load execution begins
2014:357	Tuesday Dec 23, 2014
2014:357:09:15	P3 fluence exceeds 1.0×10^9
2014:357:10:45	MTA alert (P3 2 hr avg $> 50,000$)
2014:357:11:30	Radiation telecon P3 = 300,000
2014:357:11:36:38	SCS 107 run by ground command
2014:358	Wednesday Dec 24, 2014
2014:358:18:05	DEC2414A load execution begins

Table 1: Abbreviated Timeline

the end of the observation.

And in figures 11 and 12, we show light curves generated from good events. Since chips I2, I3, and S2 are similar, they're plotted together. The rates for S4 (CCD_ID 8) are substantially higher than for the other FI chips, and of course S3 (CCD_ID 7) is a different technology. The same rises in rates are observed, though the magnitude of the effects is different.

6 Notes

ACE fluxes are given in units of particles s^{-1} cm^{-2} MeV^{-1} sr^{-1}, and ACE fluences are in particles cm^{-2} MeV^{-1} sr^{-1}.

Thanks to the Space Weather Prediction Center (swpc.noaa.gov), and the ACE and GOES data centers for solar wind and particle flux data.

Case	Fluence
As-run (both shutdowns)	2.14×10^9
First shutdown, no second	3.89×10^9
Second shutdown, no first	3.23×10^9
As-planned (no shutdowns)	4.94×10^9

Table 2: Full orbit fluences under various scenarios (with and without each SCS 107 shutdown)

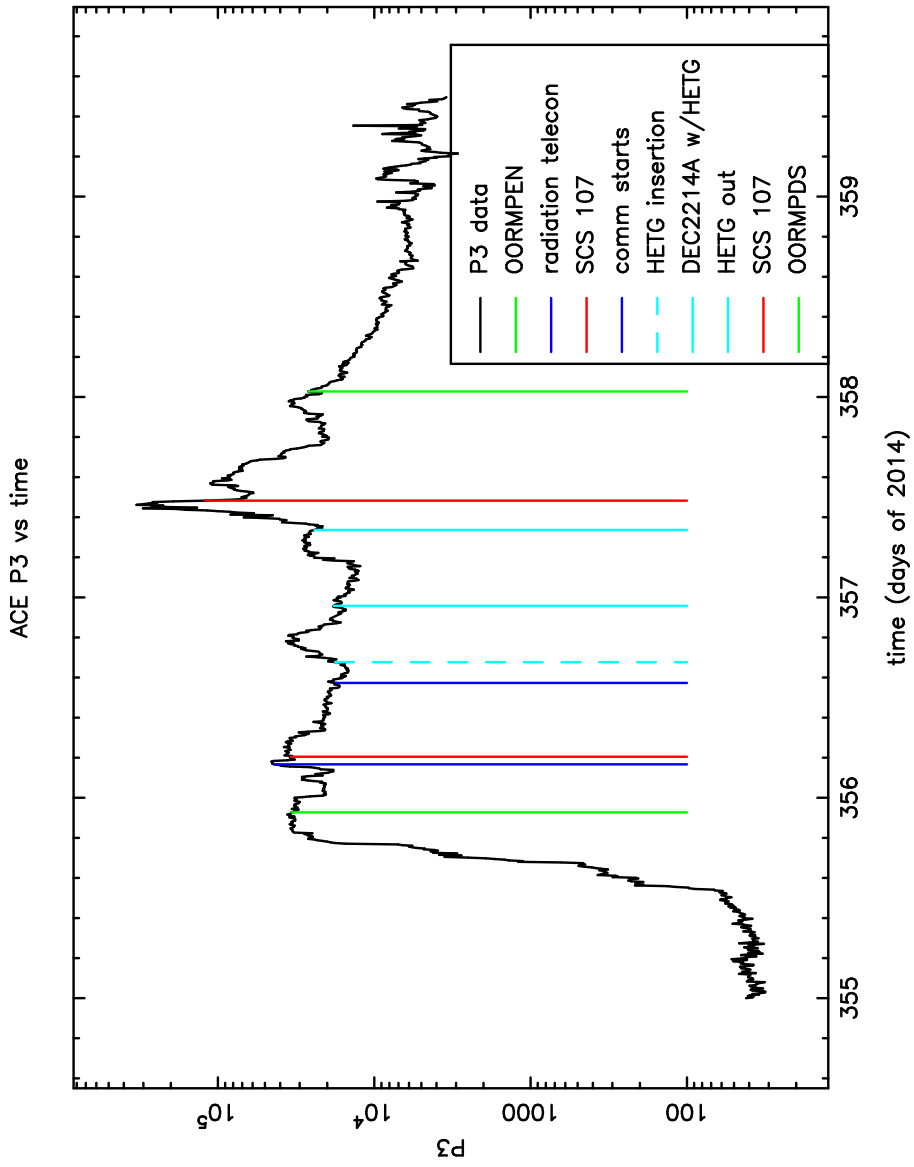


Figure 1: Graphical timeline on the ACE P3 data. Radmon events are in green, SCS 107 in red, HETG (planned and actual) in cyan.

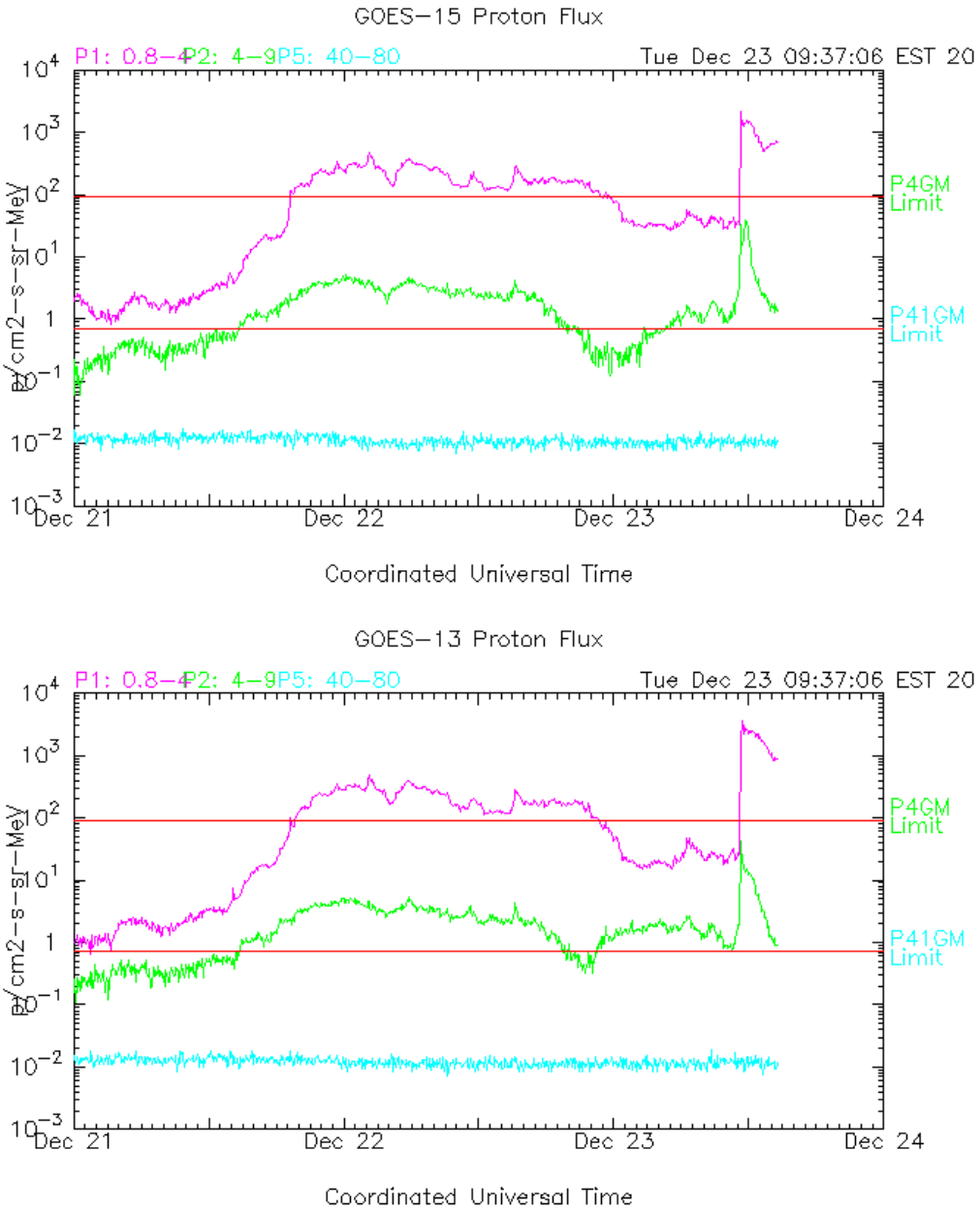


Figure 2: GOES proton data

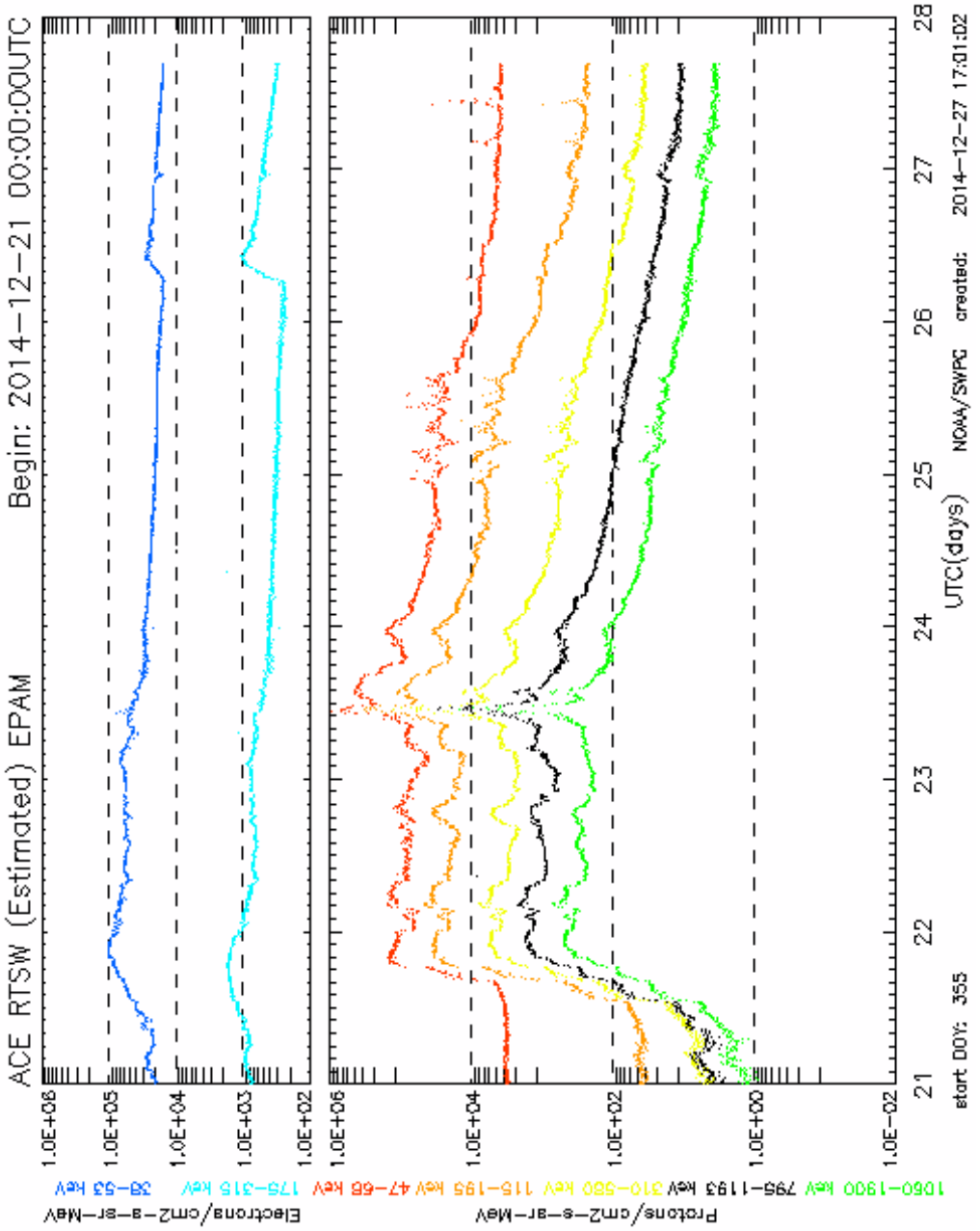


Figure 3: ACE electron and proton rates

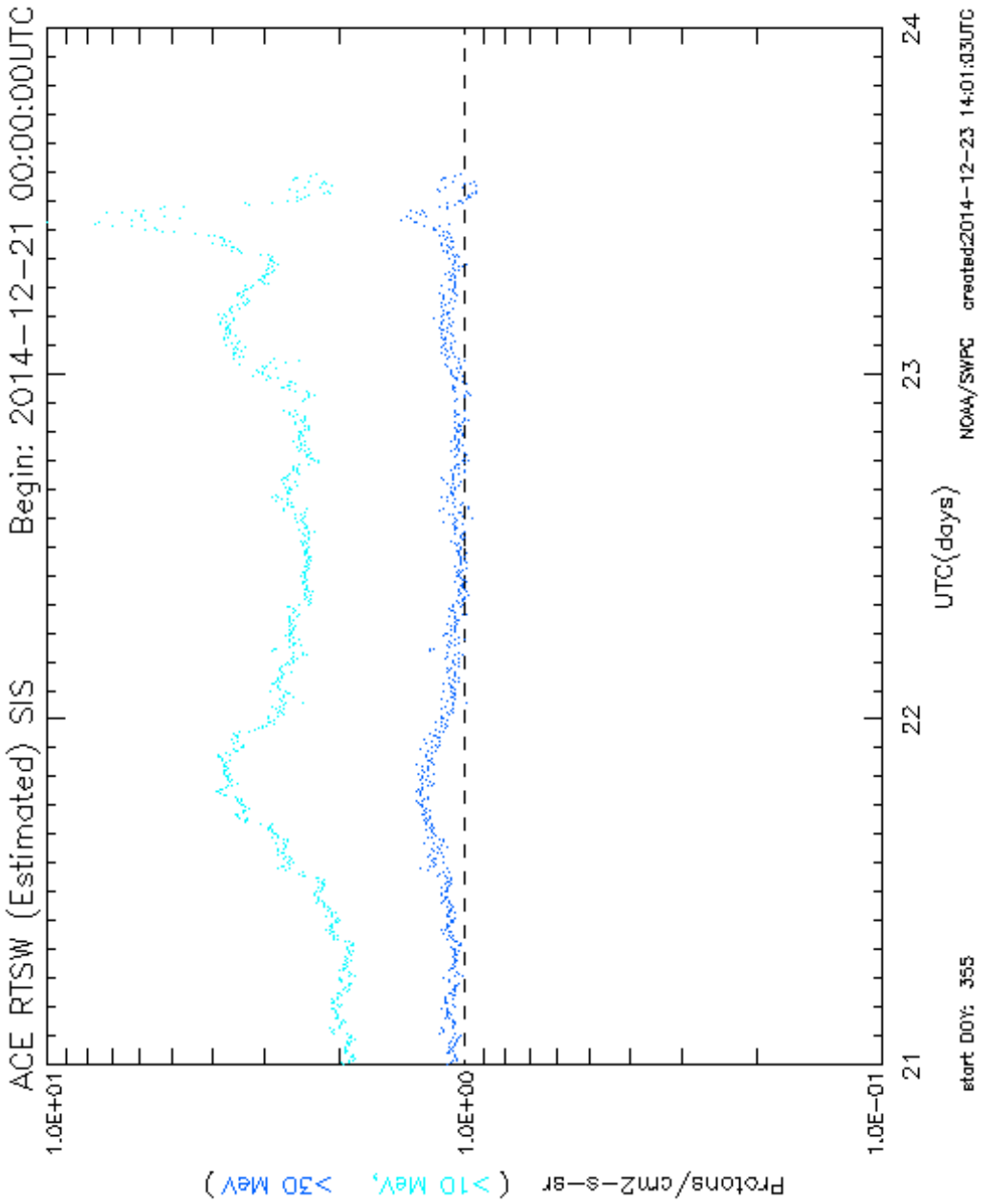


Figure 4: ACE high energy proton rates. Note the spike in the 10 MeV rates on Dec 23

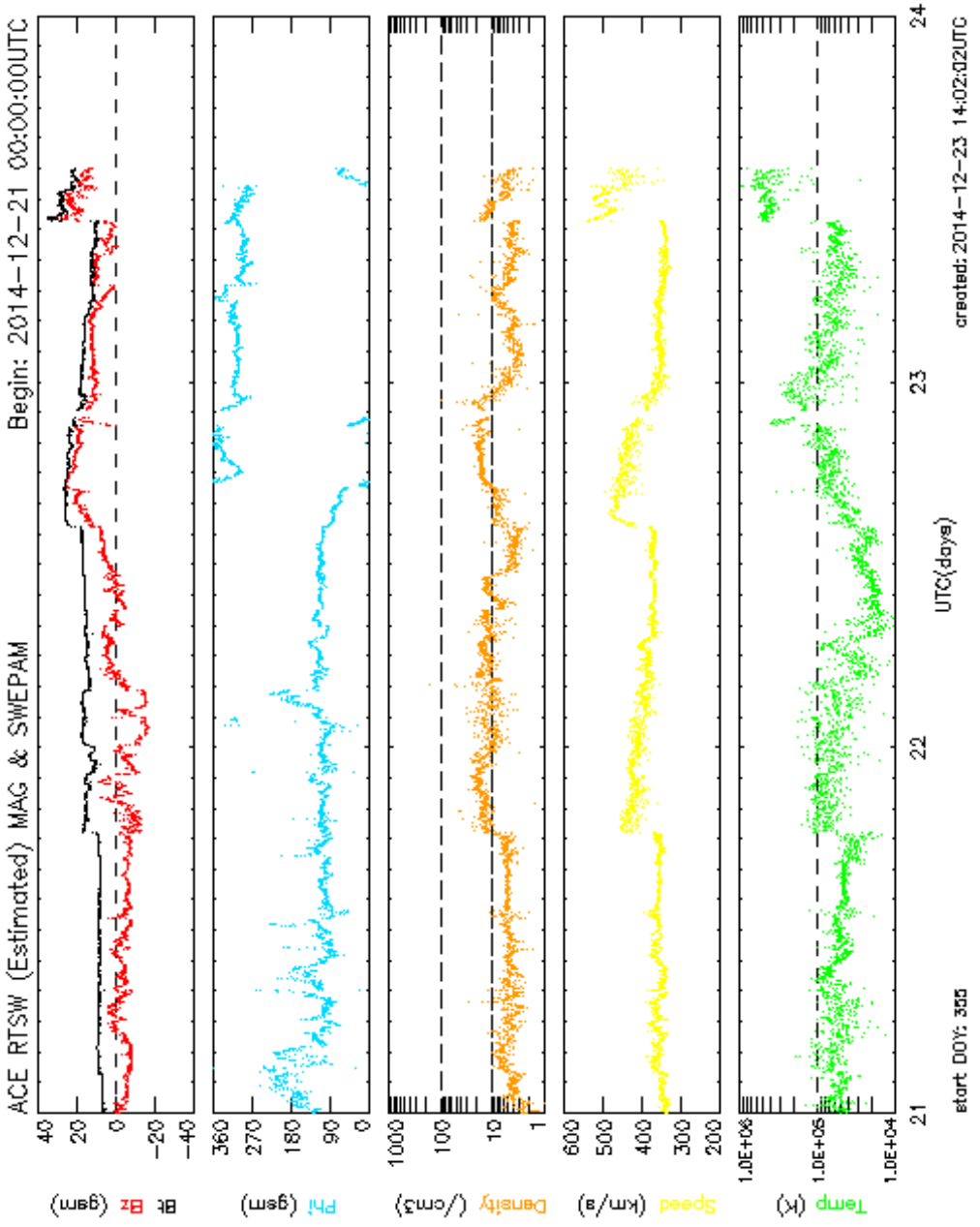


Figure 5: ACE MAG and SWEPAM solar wind magnetic and gas data

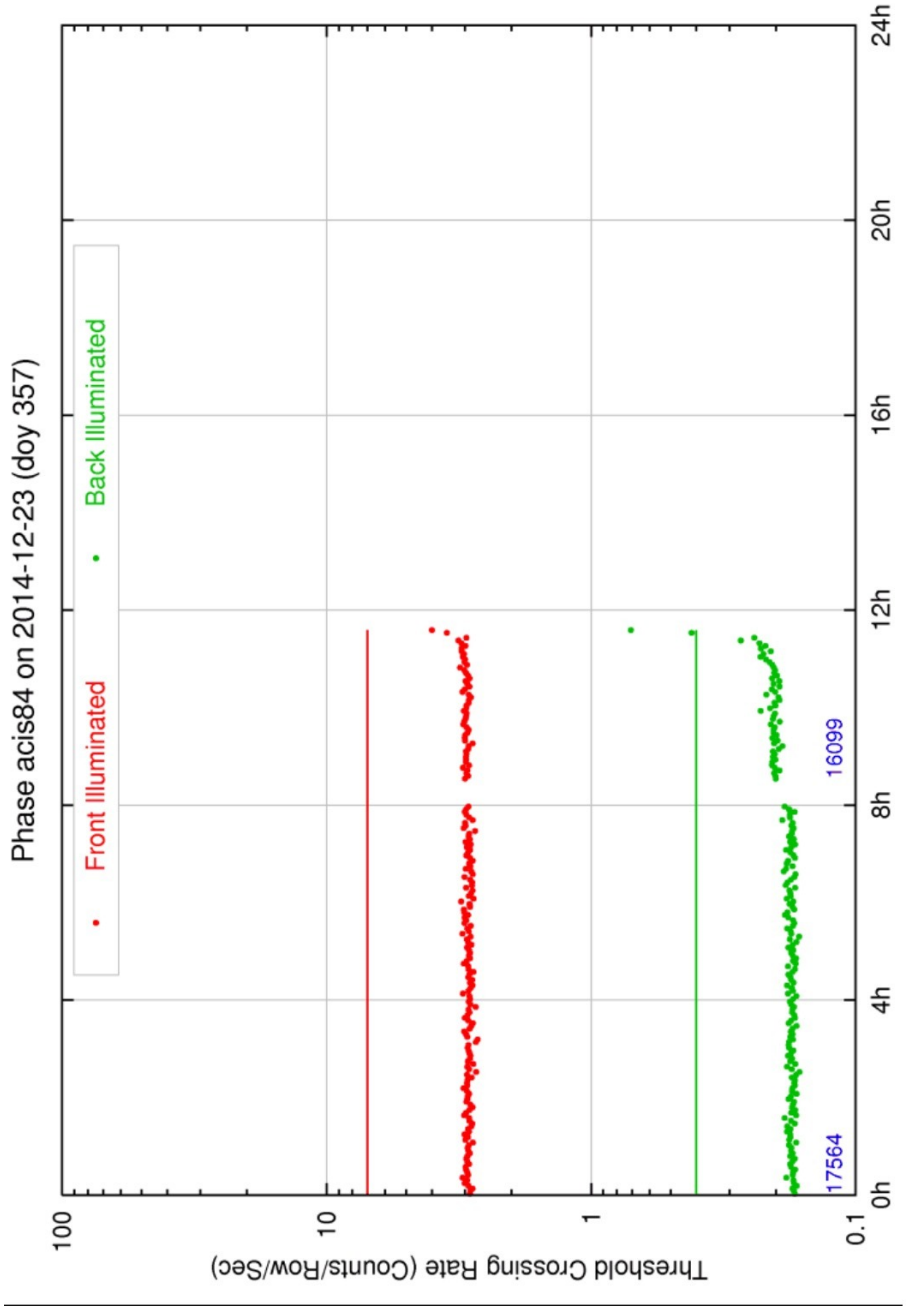


Figure 6: ACIS threshold crossings, and their cutoff limits, for Dec 23, 2014.

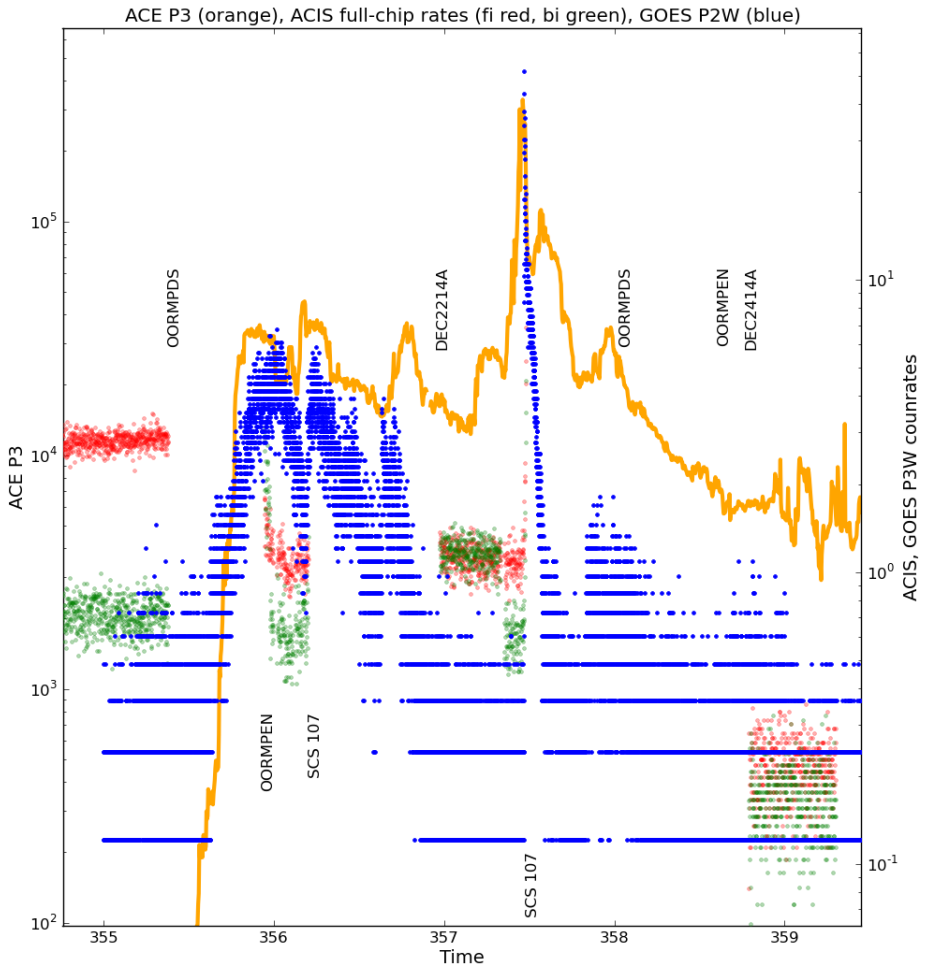


Figure 7: ACIS full-chip count rates for S3 and all active FI chips, with the ACE P3 and GOES-13 P2W rates. Note the order of magnitude spike in the ACIS rates just prior to shutdown. On day 355.9, there was a short observation just after resumption of science, so the apparent change in rates and BI/FI ratio at that time reflects the different target fluxes and spectra.

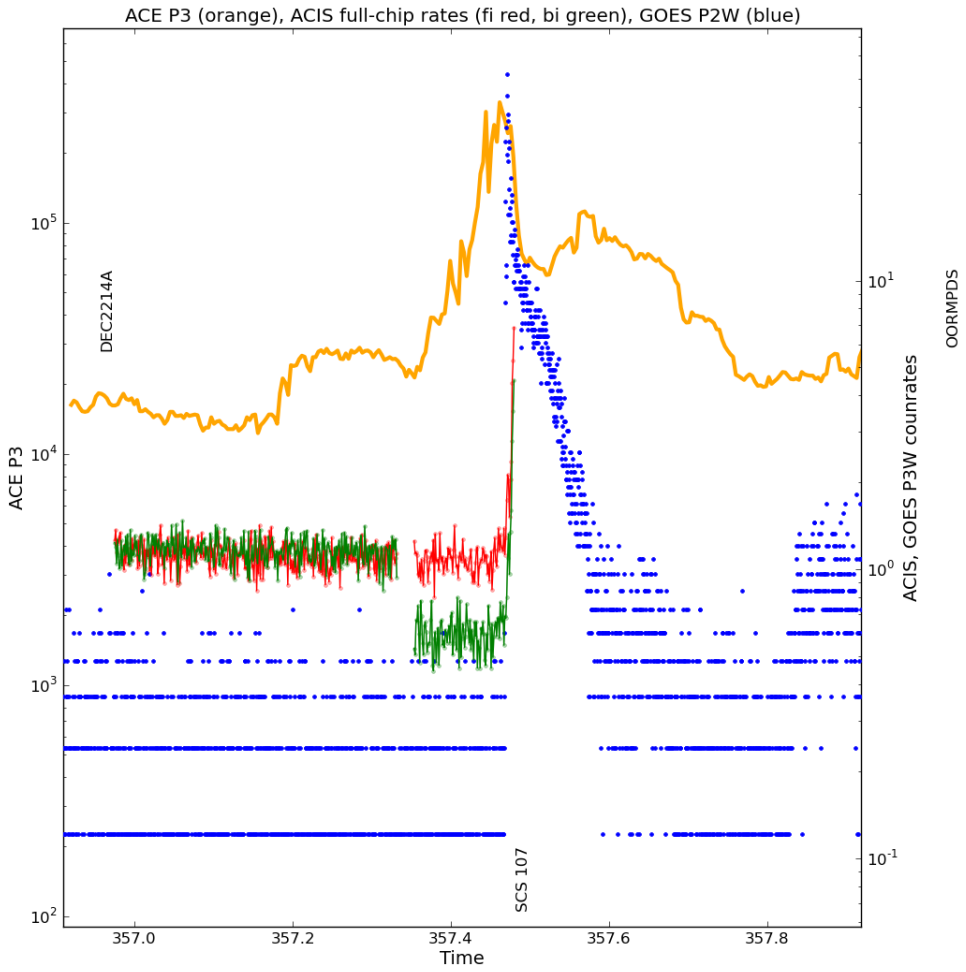


Figure 8: A magnified version of 7 showing the events of day 357. Note the large spikes in the ACIS full-chip count rates and the GOES P2W rate at the time of the ACE P3 spike. Other GOES P2 and P3 channels also show such a spike at this time.

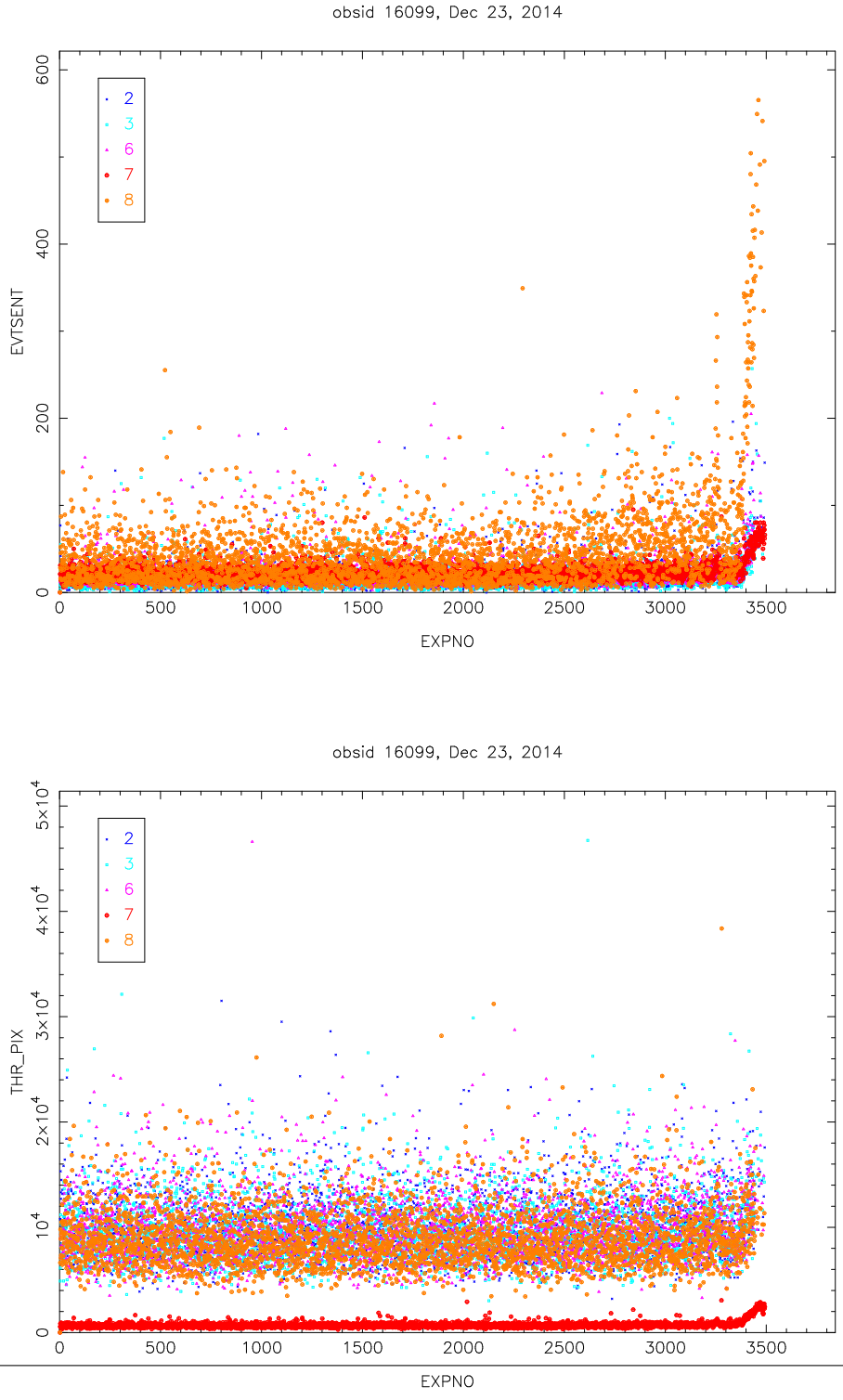
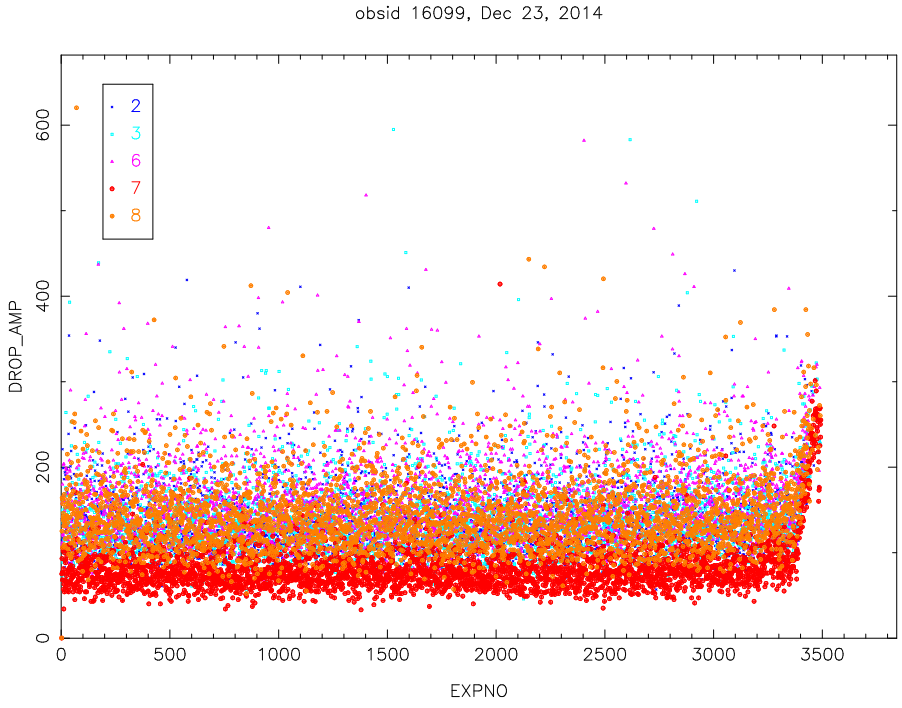


Figure 9: Total events sent (EVTSENT) and Threshold crossing rates vs. frame number for obsid 16099 on 23 Dec 2014. Color encodes the CCD_ID.



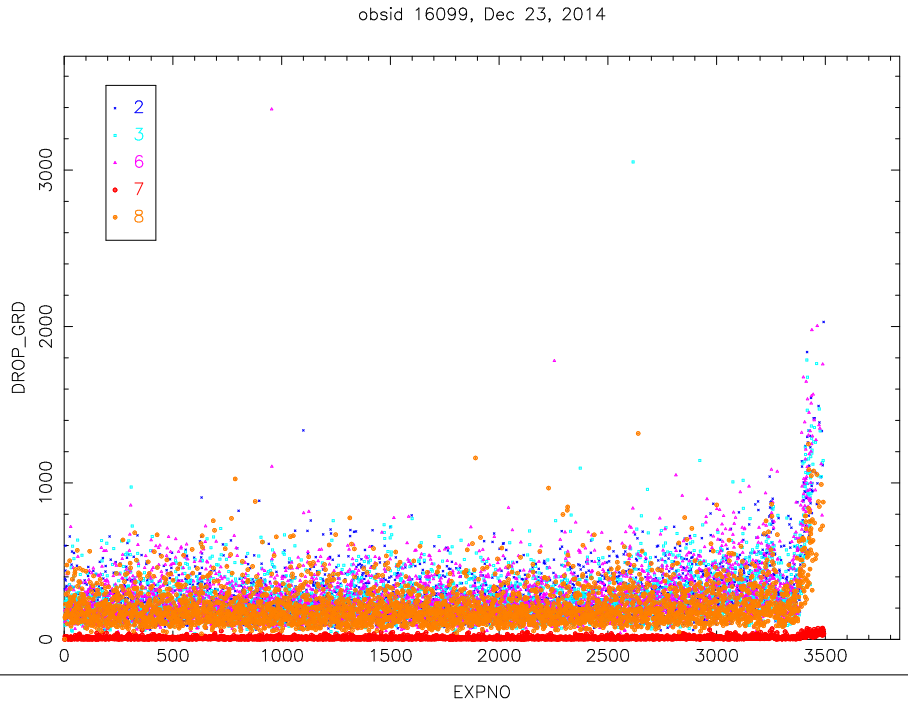


Figure 10: Events per frame which were rejected for amplitude (energies too high to be x-rays) and for grade (surrounding pixels also have charge, which indicates probable charged-particle hits), as a function of the frame number for obsid 16099 on 23 Dec, 2014.

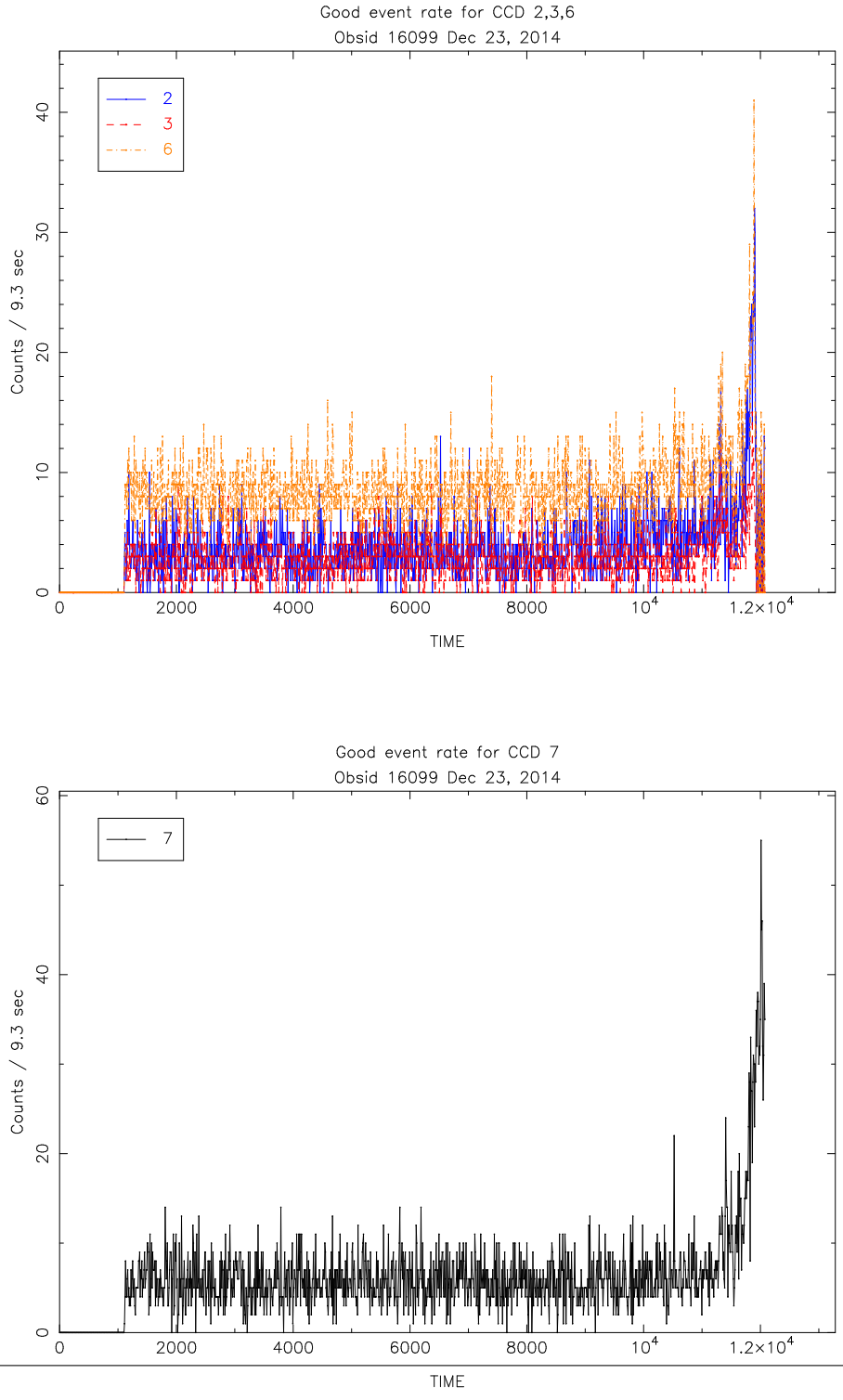


Figure 11: Light curves of good events (g02346, $0.35 - 8$ keV) vs time since the beginning of the observation, for I2, I3, S4 (top plot), and S3 (bottom plot). Note the sharp increases at the end of the observation, which indicate high and rapidly increasing background rates.

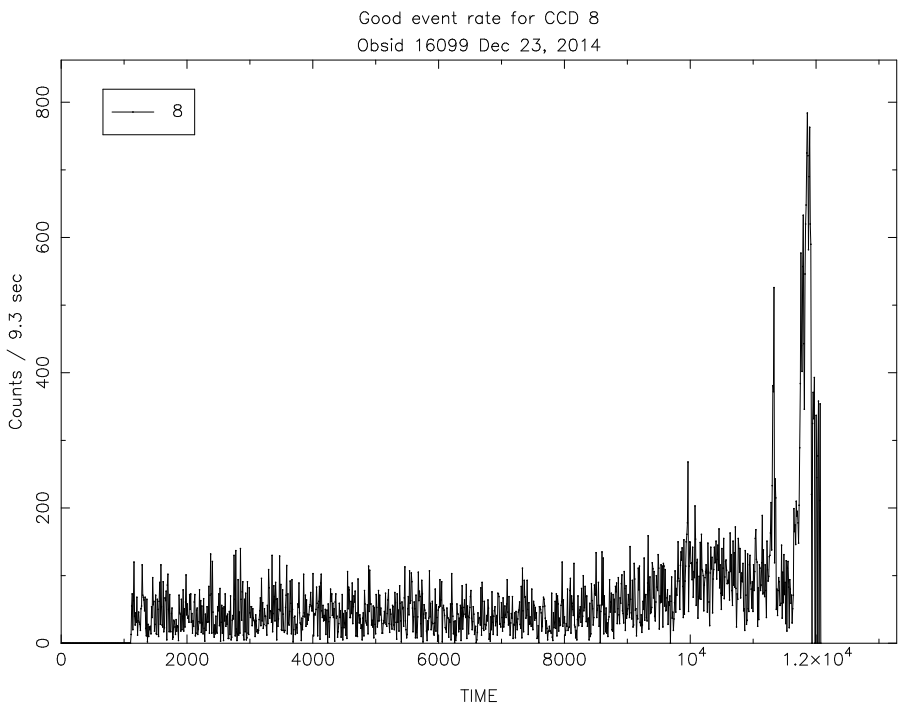


Figure 12: Light curves of good events (g02346, $0.35 - 8$ keV) vs time since the beginning of the observation, for S4. Note the sharp increases at the end of the observation, which indicate high and rapidly increasing background rates. Note also the rates on S4 are much larger than for the other chips.