CHANDRA
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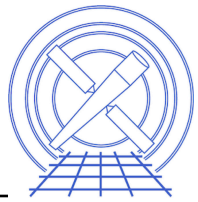

Date: March 6, 2026
From: John ZuHone
To: Chandra Operations Team
Subject: Chandra Radiation Event and Shutdown in November 2025
Cc: MSFC Project Science, CXC Director's Office
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1 Abstract

This memo discusses the thought process that the operations team, especially the ACIS operations team, used during a very high radiation event between November 11-14, 2025. *Chandra* was shut down via an autonomous trigger of SCS-107 via the ACIS *txings* algorithm. The key decision points to resume science operations are reviewed, and the details of the storm are presented.

During this storm, the accumulated attenuated ACE P3 fluence was approximately 4.6×10^8. Thanks to the autonomous shutdown, ACIS avoided accumulating another $\sim 9.4 \times 10^9$ of P3 fluence. The agreed annual budget for this quantity is 2.0×10^{10}.

2 Introduction

During the days of November 11-14, 2025, *Chandra* experienced a radiation storm which resulted in the autonomous shutdown of the spacecraft via an ACIS txings trigger of SCS-107 to protect the ACIS instrument from the damaging soft solar wind protons that increase CTI. Though we were past solar maximum at the time, solar activity was still high.

The ACIS txings rate onboard monitoring software serves as the only available way to trigger autonomous shutdowns due to high radiation levels. In this storm, the txings rates reached their trigger levels right before the peak of the proton rates in nearly all channels, averting a substantial amount of radiation damage to the ACIS CCDs from soft ($\sim$100 keV) proton fluence.

This memo discusses the properties of the storm, the radiation received in terms of the single-orbit and annual budgets, the differences between various radiation measurements, and the response.

All times in this memo are in UTC unless otherwise noted, and may be approximate. The various electron and proton channel fluxes for ACE and GOES are in units of particles s^{-1} cm^{-2} sr^{-1} MeV^{-1}, and assumed throughout when numbers for these fluxes are quoted.

3 November 9-14 2025 Detailed Timeline

- 2025:313 **Sunday November 9, 2025**
- 2025:313:00:00:00 The NOV0825 load is in progress.
- 2025:313:07:35:00 Earth-orbiting satellites detect an X1.7-class solar flare. It is Earth-directed and a CME is associated with it.
- 2025:314 **Monday November 10, 2025**
- 2025:314:09:19:00 Earth-orbiting satellites detect an X1.2-class solar flare. It is Earth-directed and a CME is associated with it. Proton levels are on the rise.
- 2025:315 **Tuesday November 11, 2025**
- 2025:315:03:30:00 **Comm** begins (45 min).
- 2025:315:07:45:00 All ACE proton channels experience significant increases in flux. ACE P3 is at 5000.
- 2025:315:10:04:00 Earth-orbiting satellites detect an X5.1-class solar flare. It is Earth-directed and a CME is associated with it.
- 2025:315:10:09:00 The GOES P7 proton channel, the HRC Proxy, the ACIS txings proxy, and the ACE electron channels begin to rise very sharply.
- 2025:315:10:58:50 SCS-107 runs due to a txings trigger, out of comm.
- 2025:315:16:00:00 ACIS Ops convenes a tagup with the rest of the project to discuss the radiation situation. It is decided at this tagup to manually shutdown the spacecraft at the upcoming comm if it has not already been shut down by a txings trigger.
- 2025:315:16:20:01 **Comm** begins (60 min). The spacecraft comes up with the science loads terminated; ACIS is safe.
- 2025:315:20:00:00 ACE proton channels P1, P3, and P5 begin to sharply rise again. ACE P3 rises from $\sim 1.5\times 10^4$, up to a maximum of $\sim 4\times 10^5$ 3.5 hours later. After this, there is a steep followed by a shallow decline with time for the next ∼14 hours.
- 2025:315:22:33:00 Space weather alerts go out indicating a CME is approaching Earth, which appears to be the combination of the CMEs associated with the X1.7 and X1.2 solar flares on DOYs 313 and 314, respectively. Within the next hour, GOES proton channels, ACE electron channels, and the HRC proxy rates sharply increase.

- 2025:316 **Wednesday November 12, 2025**
- 2025:316:01:30:00 **Comm** begins (60 min).
- 2025:316:01:52:50 The HRC proxy reaches a maximum value of ∼5000.
- 2025:316:17:45:00 **Comm** begins (90 min).
- 2025:316:19:07:00 Space weather alerts go out indicating a CME is approaching Earth. All ACE proton/electron, GOES proton, and the HRC proxy rates sharply increase. ACE P3 hits a value of $\sim 2 \times 10^5$.
- 2025:317 **Thursday November 13, 2025**
- 2025:317:01:35:00 **Comm** begins (55 min).
- 2025:317:04:14:16.634 Time of RADMON disable from the OCT0724A loads.
- 2025:317:04:15:00 ACE P3 has declined to a value of $\sim 6 \times 10^3$, and with remain close to this level for a couple of days, past the return to science.
- 2025:317:11:15:00 **Comm** begins (60 min).
- 2025:317:12:36:41.542 Time of perigee.
- 2025:317:16:57:37.043 Time of RADMON enable from the OCT0724A loads.
- 2025:318 **Friday November 14, 2025**
- 2025:318:00:50:00 **Comm** begins (60 min).
- 2025:318:00:59:50.923 ACIS Ops begins a 39-hour 4-CCD ECS measurement using CAP 1795.
- 2025:318:00:50:00 **Comm** begins (85 min).
- 2025:315:08:30:00 Earth-orbiting satellites detect an X4-class solar flare. The associated CME is directed away from the Earth.
- 2025:318:20:35:00 **Comm** begins (60 min).
- 2025:318:21:52:00 First command of the NOV1425A return-to-science loads. The long ECS measurement is stopped by the load.

4 Discussion

In the days leading up November 11th, 2025, the sunspot region AR 4274 had been active, producing a number of number of powerful flares. On November 9th, at 07:35, this sunspot produced an X1.79-class solar flare, with which an Earth-directed CME was associated. On November 10th, at 09:18, the same region produced an X1.21-class flare, and a full halo CME was detected. Both of these CMEs were predicted to reach Earth by November 11-12, and it was determined later that the two CMEs would likely into a single larger CME, as the second flare was faster and would catch up to the former.

On November 11th (2025:315) at 07:45, all ACE proton channels experience a sudden increase in flux (see Figure 2). ACE P3 increased from ∼600 to ∼5000 (see Figure 1). At 10:05, an X5.1-class solar flare is detected. This flare produced prompt particle flux increases in the GOES P7 proton channel and the ACE electron channels (see Figures 4 and 3). The HRC Proxy, which is a linear combination of GOES channels, rose in tandem with the GOES P7 protons (see Figure 7). Obsid 30162, an ACIS-S observation, had just begun setting up, and thus the ACIS txings rates would not begin to be monitored until the observation started. At 10:58:50, SCS-107 was autonomously run due to a txings trigger, out of comm. However, the txings proxy for the FI rates showed a sharp increase as well.

During these events, the ACIS Ops team discussed the radiation situation, and it was decided to call for a radiation telecon, that was held at 16:00 UTC (11 am ET), 20 minutes before the start of the next comm. It was decided at this telecon to manually shutdown the spacecraft at the upcoming comm if it had not already been shut down by a txings trigger. During the telecon, the spacecraft came up with the science loads terminated; ACIS was reported safe.

After the txings data was examined on the ground, it was determined that the SCS107 was due to a trigger of the "FI very high test" (see Figures 5 and 6). This is the first time that this test has triggered a shutdown. Up to this point, all txings triggers have been from the increasing rate tests. In this case, ACIS was in science idle between observations and missed seeing the initial rise in particle rates. The "very high" test was added to txings in 2022, to protect against exactly this situation. The parameters of the "FI very high" test require two ∼3 minutes time bins to be over the limit of 8.4 cts/sec/row. The rate seen in ObsID 30162 was 36 cts/sec/row, more than four times the "very high" limit. The ACIS txings proxy, while predicting the sharp jump in rates, had never seen rates this high before, and thus did not correctly predict the level that would be reached.

Event rates in the interrupted ObsID 30162 were extremely high. Since the observation was configured in Very Faint mode, telemetry was badly saturated. Approximately 40% of the CCD frames were dropped onboard. Bias maps were noisy, due to incomplete particle track removal, which, along with the high level of sacrificial charge, would degrade any spectral analysis of the data. The interrupted observation would have been difficult to analyze, and science results would be compromised, if the radiation shutdown had not occurred.

It was decided that given the likelihood of further increases in radiation levels, due to the incoming CMEs, the project would wait to reconvene until the next daily 9 am ET tagup on November 12th to assess the evolution of the radiation environment and the development of a return to science plan. This caution was warranted. In the hours after the txings trigger, ACE channels P1, P3, and P5 rose rapidly, with P3 reaching a maximum of $\sim 4 \times 10^5$ roughly 6 hours later. After this, there was a steep followed by a shallow decline with time for the next ∼14 hours. Late in the evening (UTC) of November 11th, space weather alerts indicated that a CME was approaching Earth, which appeared to be the combination of the CMEs associated with the X1.7 and X1.2 solar flares. This was associated with a steep rise in the GOES proton, ACE electron, and HRC proxy rates.

For the majority of November 12th (2025:316), radiation rates remained elevated but either flat or declining with time. At approximately 19:07 UTC, another space weather alert indicated that a CME was approaching Earth. This was associated with another steep rise in particle rates. ACE P3 hit a value of $\sim 2 \times 10^5$. On November 13th (2025:317), at 04:15 UTC, all ACE channels steeply decline. ACE P3 decreases to a value of $\sim 6 \times 10^3$, and will remain at this level for days, past the return to science.

On November 14th (2025:318), ACIS Operations ran a 39-hour 4-CCD ECS measurement starting at 2025:318:00:59:50, using CAP 1795. Particle rates were sufficiently low that it was decided to proceed with the measurement. At 08:30 UTC, an X4-class solar flare was detected, but the associated CME was directed away from the Earth. The long ECS measurement was stopped at 21:52 UTC by the NOV1425A return-to-science loads, with a run time of just under 21 hours.

The storm spanned portions of two science orbits. In the end, the total accumulated attenuated ACE P3 fluence for the two orbits was 4.6×10^8. The total ACE P3 attenuated fluence that would have been accumulated during these two science orbits had ACIS not been safed is 9.4×10^9. The txings trigger, along with prudent monitoring of space weather and decision-making by the project, prevented the accumulation of this enormous fluence.

5 Data plots for the November 2025 storm

In Figure 1, we have plotted the 5-minute averaged ACE P3 flux rate, in the usual units, which are protons s^{-1} cm^{-2} sr^{-1} MeV^{-1}, throughout the November 11-14 storm. Also marked are radiation belt passages, the time of autonomous SCS-107 execution, comm times, and the start and stop times of a long ECS measurement that was run during the storm (the same times are marked in the rest of the radiation vs. time plots).

Figure 2 shows the flux from four ACE proton channels (P1, P3, P5, and P7) during the storm. Though only P3 is our proxy for damage to the ACIS CCDs, the other channels can serve as informative diagnostics.

Figure 3 shows the flux from two ACE electron channels (DE1 and DE4) during the storm. These electron channels more often then not tend to rise and fall rapidly when the

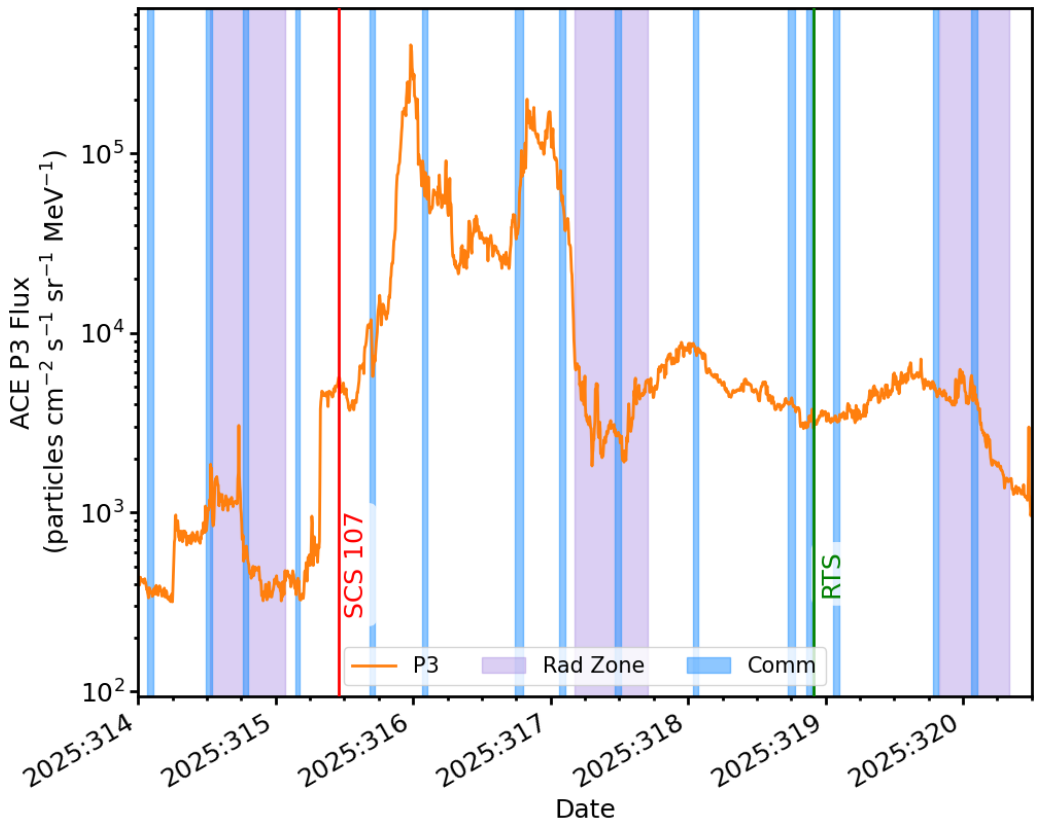

Figure 1: A plot of the ACE P3 flux during the November 2025 storm. Purple shaded regions indicate the radzone passages. Fluence is integrated when ACIS is in focus, and is counted from radzone exit. Blue shaded regions mark scheduled DSN communications.

higher-energy GOES protons are doing the same.

Figure 4 shows the flux from four GOES proton channels (P1, P3, P5, and P7) during the storm. These higher-energy protons are more representative of the radiation that triggers ACIS txings. GOES P5 and P7 have a steep increase in flux at the time of the txings trigger.

In Figure 5, we present the ACIS threshold crossings as a function of time for the days of the storm. Both the FI and BI rates passed their trip thresholds, but the FI rate triggered first. Figure 6 shows a close-up of the txings rates on DOY 315.

Finally, Figure 7 shows the HRC Shield Proxy during the storm. The HRC Anti-Coincidence Shield rates are no longer available for radiation monitoring, but had they been, they would have triggered SCS-107 at around the same time as the txings trigger.

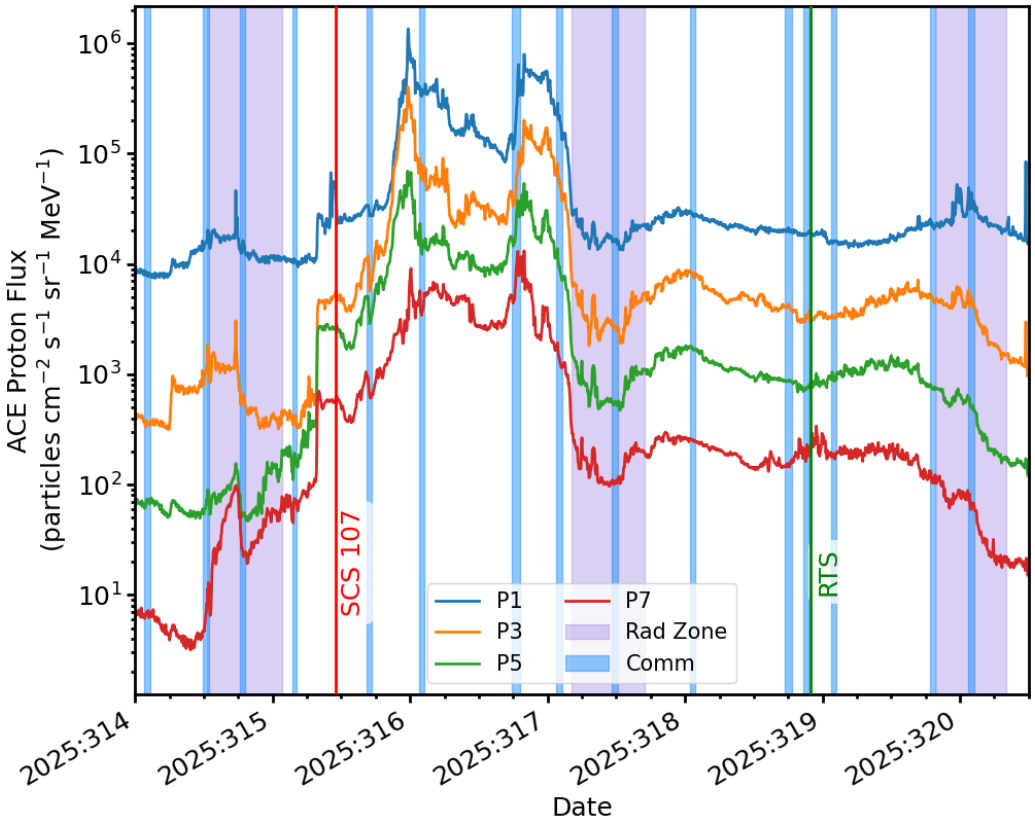

Figure 2: A plot of the flux from four ACE channels P1, P3, P5, and P7 during the November 2025 storm. Shaded regions and vertical lines have the same meaning as in Figure 1.

6 Lessons Learned

- The txings trigger shut down the spacecraft early in the storm, but the potentially damaging ACE P3 fluence did not occur until ∼12 hours later. Prudent monitoring of space weather and decision-making by the project prevented the accumulation of a large amount of radiation damage to the ACIS CCDs, which could have occurred had the RTS been rushed in light of ACE-P3 rates initially being low.
- When attempting a long ECS measurement, it is important to discuss and consider the radiation levels at the time of the measurement. In this case, the hard proton rates were declining and near the HRC Proxy trigger level, so it was safe to proceed with the measurement, but in other storms this may not be the case.
- The ACIS txings proxy correctly predicted that there would be a large increase in

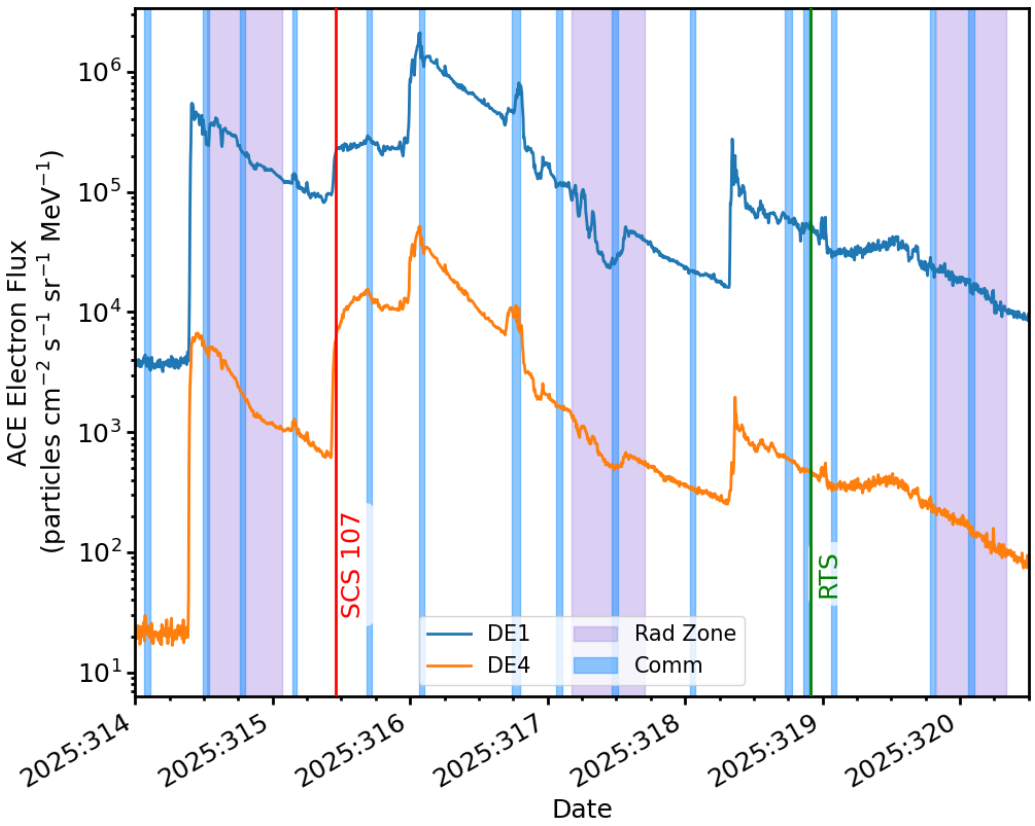

Figure 3: A plot of the flux from the ACE electron channels DE1 and DE4 during the November 2025 storm. Shaded regions and vertical lines have the same meaning as in Figure 1.

the txings rates at the time of the shutdown, but did not correctly predict the level that would be reached. The proxy had never seen rates this high before in training, and thus it was not surprising that it missed the mark. The proxy has seen been re-trained on the data including this storm in order to better predict future storms.

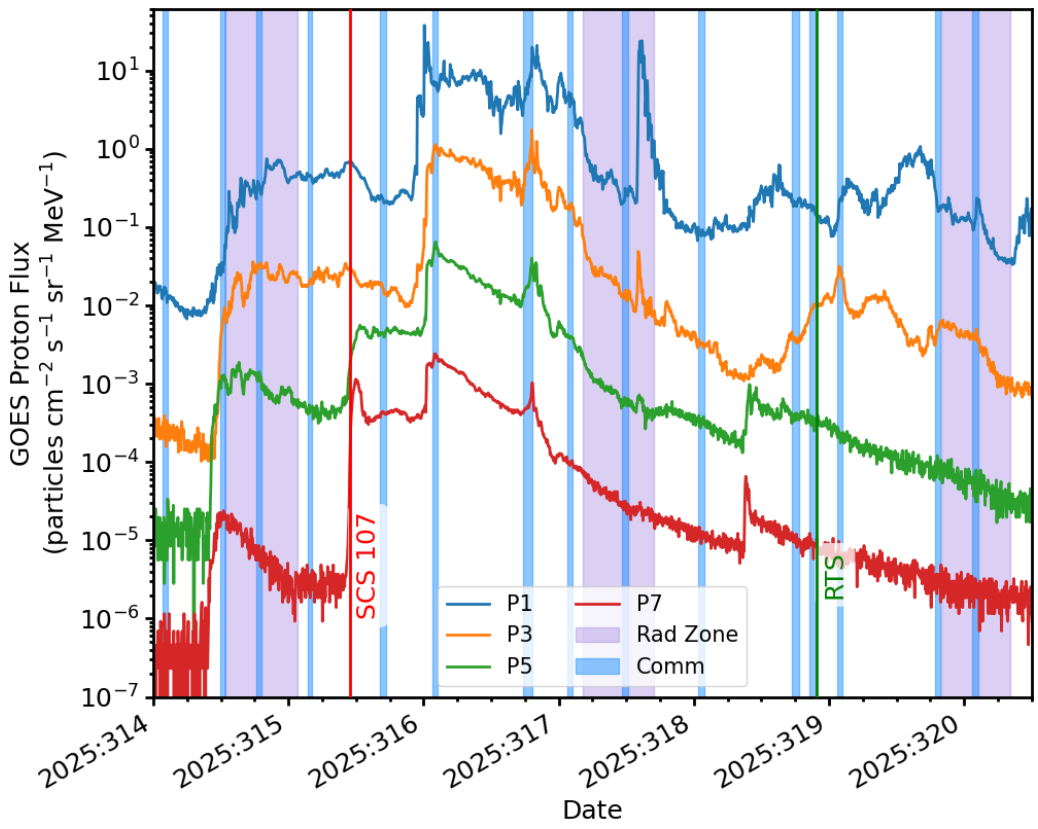

Figure 4: A plot of the flux from four GOES channels P1, P3, P5, and P7 during the November 2025 storm. Shaded regions and vertical lines have the same meaning as in Figure 1.

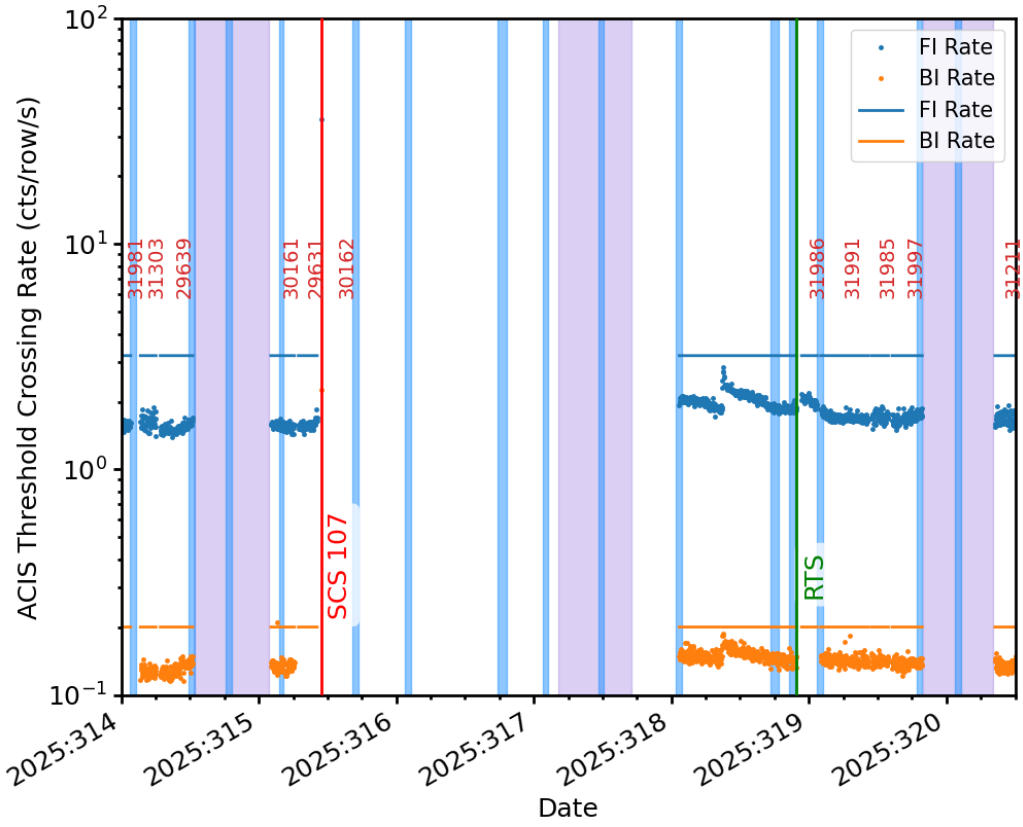

Figure 5: A plot of the txings data during the November 2025 storm. Blue is for FI chips, orange is for BI. The horizontal lines are the increasing values trip thresholds for each type of chip. Shaded regions and vertical lines have the same meaning as in Figure 1.

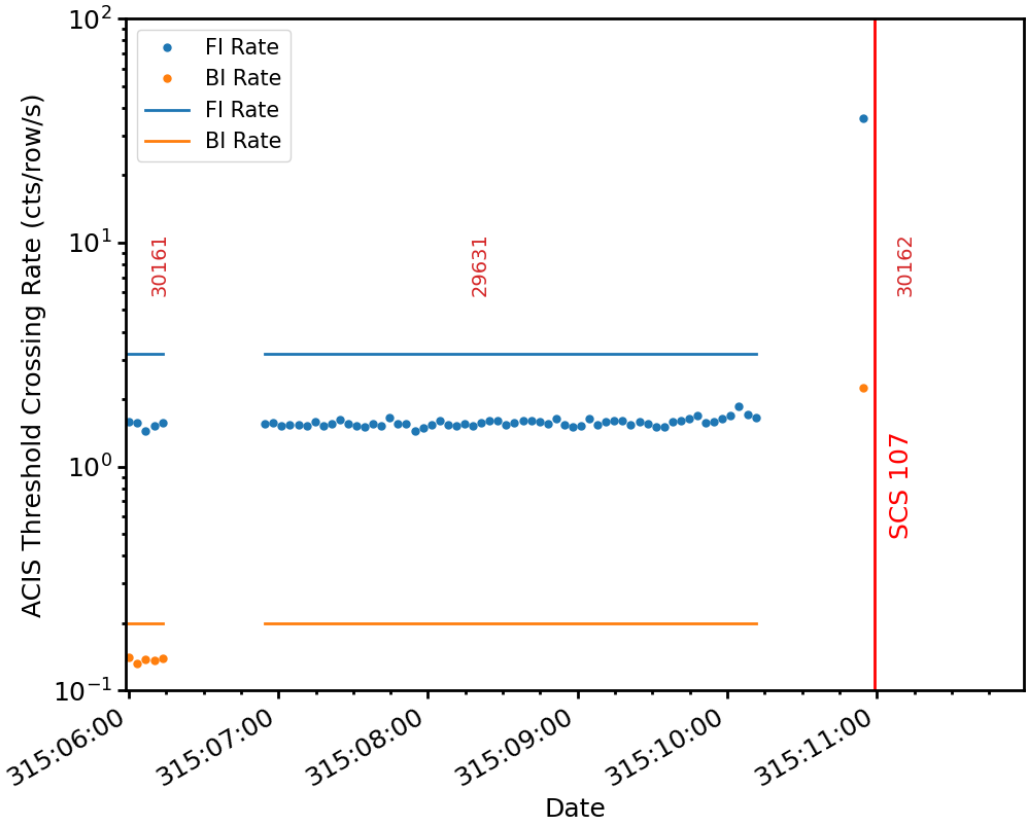

Figure 6: A plot of the txings data during the November 2025 storm, near the time of the txings trigger on DOY 315. All lines, labels, and shaded regions have the same meaning as in Figure 5.

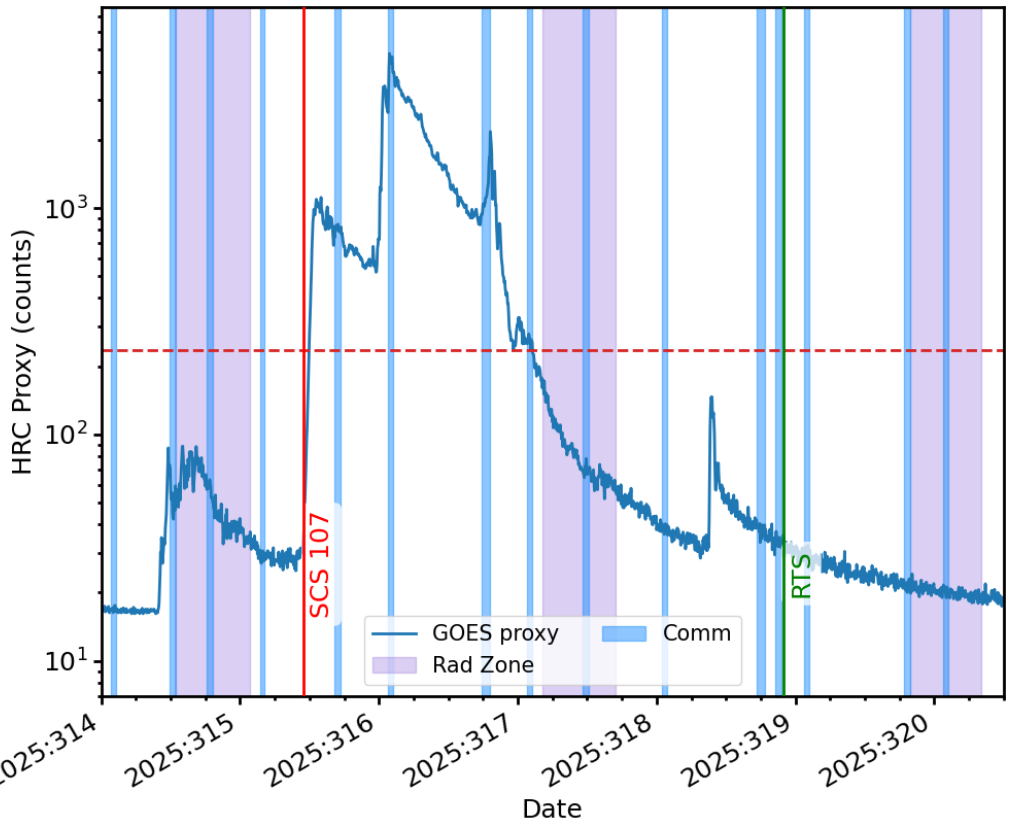

Figure 7: The HRC Shield proxy during the November 2025 storm. Shaded regions and vertical lines have the same meaning as in Figure 1. The HRC proxy exceeded its trigger value at around the same time as the txings trigger, and remained at a very high level for the next 48 hours.

7 Resources

The research required for this memo, as well as the real-time response, would not have been possible without the valiant efforts of `solarham.com` to provide timely and accurate space weather information.

The archive of ACE data stored in ASCII tables at `https://sohoftp.nascom.nasa.gov/sdb/goes/ace/daily/` has gaps that are not back-filled; the full dataset can however be found in the "ACE Browse" archive:

`ftp://mussel.srl.caltech.edu/pub/ace/browse/`

The data are in HDF4 format, which can be converted to HDF5 data by use of a program `h4toh5` which I downloaded from `https://www.hdfeos.org/software/h4toh5.php`. A Python script, `get_ace.py`, which downloads the data and uses `h4toh5` to convert it is available on the HEAD LAN in `/data/acis/ace`. Instructions for downloading the data using this script and extracting the ACE proton channels are given in `/data/acis/ace/README_browse.md`.

The HRC Shield Proxy and GOES proton data are stored in HDF5 format here:
`/proj/sot/ska/data/arc/hrc_shield.h5`.

Thanks to Peter Ford for providing the ACIS txings data.