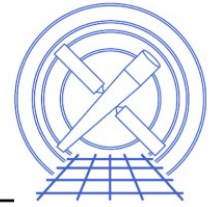


CHANDRA

X-ray Center 60 Garden St., Cambridge Massachusetts 02138 USA



Date: May 25, 2023
From: Gregg Germain
To: Chandra Operations Team
Subject: Chandra Radiation Event and Shutdown April 2023
Cc: MSFC Project Science, CXC Director's Office

1 Abstract

On April 23, 2023 22:37z the APR1723A load was interrupted by a ground-commanded SCS-107 in order to safe ACIS from the ongoing radiation storm. This memo discusses the thought process that the operations team, especially the ACIS operations team, used during the solar storm event. The key decision points leading up to the shutdown are reviewed.

In total, ACIS accumulated an attenuated ACE P3 fluence of 3.3×10^9 from the start of the orbit to the shutdown. The fluence saved because of the shutdown was 8.4×10^8 . Without the shutdown ACIS would have accumulated a total of 4.10×10^9 or more than double the orbital budget. Prior to this storm, ACIS had already accumulated more than half of the yearly 2.0×10^{10} budget.

2 Introduction

Solar activity has increased this year as we approach solar maximum. On April 23, 2023, a ground-commanded SCS-107 was executed to halt the ACIS accumulation of fluence during a solar storm. This is the third shutdown of the year: SCS-107's were commanded late February and mid March due to solar activity. It was noted that the ACE P3 rates were very unsettled and that a peak in the rates had not declared itself. The peak could not be observed because of an ACE P3 web page drop out. The only available autonomous Radiation shutdown mechanism is the ACIS txings monitor. During this storm the txings rates were high but txings did not trigger due to the unsettled rates. ACIS Ops concluded that a telecon should be convened at the start of the 22:25z Comm and if txings had not initiated a shutdown then an SCS-107 would be called for. During the Comm it was determined that txings had not initiated a shutdown and ACIS Ops recommended a shutdown. The shutdown was commanded during this contact with a shutdown time of 2023:113:22:37:31.00.

This memo reviews the space weather activity and describes the events, alerts discussion, decisions and provides a timeline of these events.

3. Detailed Timeline April 21-23, 2023

- 2023:106:23:42 Saturday, April 16 the APR1723A load begins. ACE P3 rates quiescent
- 2023:112:12:00 Comm begins (60 minutes)
- 2023:112:15:16 RADMON ENABLED: orbit begins. ACE P3 rates quiescent.
- 2023:112:10:01 SpaceWeather announces Earth-directed CME. Noted by ACIS Ops.
- 2023:112:21:25 Comm begins (60 minutes) ACIS Ops notices a rise in ACE P3 rates.
- 2023:113:02:30 Comm begins (60 minutes)
- 2023:113:11:05 Comm begins (60 minutes)
- 2023:113:15:24 ACIS Ops begins discussion of the radiation situation via Slack and email
 - Rates have been increasing since the afternoon of the 22nd.
 - ACIS Ops notes that ACE P3 flux is at 20,400.
- 2023:113:17:10 **ACE P3 page data reporting drops out**
- 2023:113:17:25 SpaceWeather alerts announces the CME will arrive at Earth within 20 to 30 minutes.
- 2023:113:17:42 DOSS Monitoring and trends announces ACE P3 2 hour limit violation with an observed value of 3.720×10^8 .
- 2023:113:18:15 ACIS Ops considers it unlikely that txings would have triggered due to HRC proxy values.
- 2023:113:18:19 **ACE P3 Max value of 190,737.28** (from post-storm data analysis)
- 2023:113:18:25 ACIS Ops program acis-P3-fluence.pl sends an email reporting that the estimated ACIS fluence accumulated has exceeded 1.0×10^9 .
- 2023:113:20:16 ACIS Ops sends email to Scott Wolk and Steve O'Dell asking if they can contact the ACE group asking to restore the data.
- 2023:113:20:20 **ACE P3 data reporting resumes**
- 2023:113:21:13 ACIS Ops continues discussion and concludes that, as the orbital limit has already been reached, a recommendation of a shutdown will be made.
 - ACE P3 bouncing between 70,000 and 112,000 over the last 45 minutes.

- 2023:113:22:02 ACIS Ops sends email to sot red alert announcing an urgent radiation telecon at the start of the 22:25z Comm to discuss the situation.
- 2023:113:22:25 Comm begins (60 minutes). Txings had not initiated an SCS-107.
 - Telecon Held. ACIS Ops recommends shutdown as the orbital fluence budget has been exceeded, there are 21.8 hours left in the orbit with minimal HRC and no Gratings time and the ACE P3 rates are unsettled.
 - Opinions expressed that once peaked, the rates should decline rapidly.
 - Rapid agreement by all parties that an SCS-107 should be commanded
- **2023:113:22:37:31.00 SCS-107 by ground command interrupts Obsid 27810**

Had there been no shutdown:

- 2023:114:10:43 HRC-S would have been placed in the Focal Plane
- 2023:114:11:00 Comm begins (60 minutes)
- 2023:114:15:29 ACIS placed in the focal plane after the HRC observation
- 2023:114:20:28 Orbit ends

4. Discussion

Solar activity has increased this year as we approach solar maximum (Figure 1). This is the third shutdown of the year: SCS-107's were commanded late February and mid March due to solar activity. Prior to this storm, the yearly accumulated fluence so far already exceeded 50% of the yearly budget.

On April 22nd, a morning SpaceWeather email to ACIS Ops described a "...large magnetic filament snaking across the sun's southern hemisphere exploded, hurling a CME straight toward our planet. Estimated time of arrival: April 24th." At this time, the APR1723A load was executing. On the morning of the 22nd ACIS Ops noted that the rates were in the 10's; then above 1000 in the afternoon and then on the morning of the 23rd it was noted to be above 19,000.

Discussions within ACIS Ops began the late morning of the 23rd. It was noted that the next perigee passage would occur at 2023:114:20:28, and that there was only one HRC observation before the next perigee passage and no ACIS observations used either of the gratings which would mitigate the fluence collected. At approximately 17:10z, the ACE P3 reporting stopped (Figure 2). The orbital fluence at that point was 7.0×10^8 . At 17:42z An ACE P3 alert was received from DOSS-Monitoring and Trends Analysis announcing a violation of the two hour fluence limit (3.6×10^8) with an observed fluence of 3.7×10^8 . Looking at the HRC proxy, ACIS Ops thought it unlikely that txings triggered an SCS-107.

The WSA-ENLIL Solar Wind Prediction pinwheel plot (Figure 3) indicated that this storm consisted of an initial solar outburst followed by a second, faster outburst which overtook the first close to earth impact. In the past, this has resulted in a very high flux, short, sharp impact.

At 18:25z the ACIS Ops ACE P3 alert system estimated that the ACIS fluence accumulated has exceeded 1.0×10^9 . This estimate was arrived at by using the last known value of flux before the drop out. Analysis after the storm indicates that the ACE P3 flux reached a maximum of 190,737.28 at 2023:113:18:19 while the ACE P3 page was not reporting data. Analysis after the storm shows that the fluence exceeded 2.0×10^9 at 2023:113:19:54:59.634. The flux values were highly unsettled: 45 minutes before the dropout the ACE P3 flux value was 26018.69. The last three 5 minute flux values before the ACE data dropout were 60294.92, 87748.01 and 109757.02.

At 20:16z, ACIS Ops sent emails to Scott Wolk and Steve O'Dell reporting that the ACE page was not updating and requested that an email be set to alert the ACE people. Reporting on the ACE data web page resumed at approximately 2023:113:20:20. The flux at the resumption was similar to the value at the start of the ACE P3 web page drop out. By 22:13z it was clear to the ACIS Ops team that the 2.0×10^9 limit would be exceeded before the 22:25z Comm. During the orbit there was only one HRC observation, where ACIS would not be in the focal plane for 17ksec, and none of the ACIS observations required the gratings to be in.

At 22:22z ACIS Ops concluded to recommend a ground commanded SCS-107 shutdown at the next available Comm given that:

- We have already exceeded the 2.0×10^9 orbital limit,
- The last 3 ACE P3 readings were over 100,000 at the time the decision was taken.
- That the rates are still unsettled with no clear declaration of a peak and turnover,
- That at the present rates we would get a full orbital dose roughly every 4.6 hours,
- That the orbit still has approximately 22 hours to go until RADMON DISABLE.
- Prior to this storm, the yearly accumulated fluence already at 1.1×10^{10} : half the yearly budget obtained in the first quarter of the year.
- The next Comm was 12 hours later. If the rates remained at the present level then ACIS would absorb another 4.3×10^9 fluence.

A telecon was called at the start of the 2023:113:22:25 Comm. Telemetry showed that txings had not initiated an SCS-107 shutdown. ACIS presented the case for the shutdown. Some opinions were that this would be a short storm with a rapid flux reduction. But given the present situation and the flight rules, all agreed that a ground commanded SCS-107 should be initiated at 2023:113:22:37:31.00.

5 Post Storm Analysis

After the storm the ACE data became available for the entire extent of the storm. Figure 4 displays the full history of the storm utilizing this ACE data, showing the extent of the full orbit containing the storm, the location of the ACE data dropout with respect to the ACE rates, the Comm schedules and HRC observation, and the location of the ground commanded SCS-107. The plot shows that the P3 rates at the end of the data dropout were in the same vicinity as the rates just before the drop out. Given that, it was not possible to conclude that the rates have turned over and started a decline. The plot also shows the highly unsettled rates after the end of the data dropout.

In total, ACIS accumulated an attenuated ACE P3 fluence of 3.3×10^9 from the start of the orbit to the shutdown. The fluence saved because of the shutdown was 8.4×10^8 . Without the shutdown ACIS would have accumulated a total of 4.1×10^9 or more than double the orbital budget.

Figure 5 shows the ACIS txing plot for DOY 113. The front side illuminated readings never exceeded the threshold. The backside readings did exceed the limit, but the values were not monotonically increasing due to the unsettled P3 rates. Therefore ACIS Txings did not initiate an SCS-107.

Given the ACE data dropout, the ACIS fluence integrator value is an estimate of the true fluence ACIS had accumulated. During the period of the dropout the value used, by the integrator, is the last value reported. The actual fluence during the ACE P3 dropout was 1.73×10^9 . The fluence estimated by the integrator was approximately 1.25×10^9 which is low by 27.7%.

6 Plots and Images

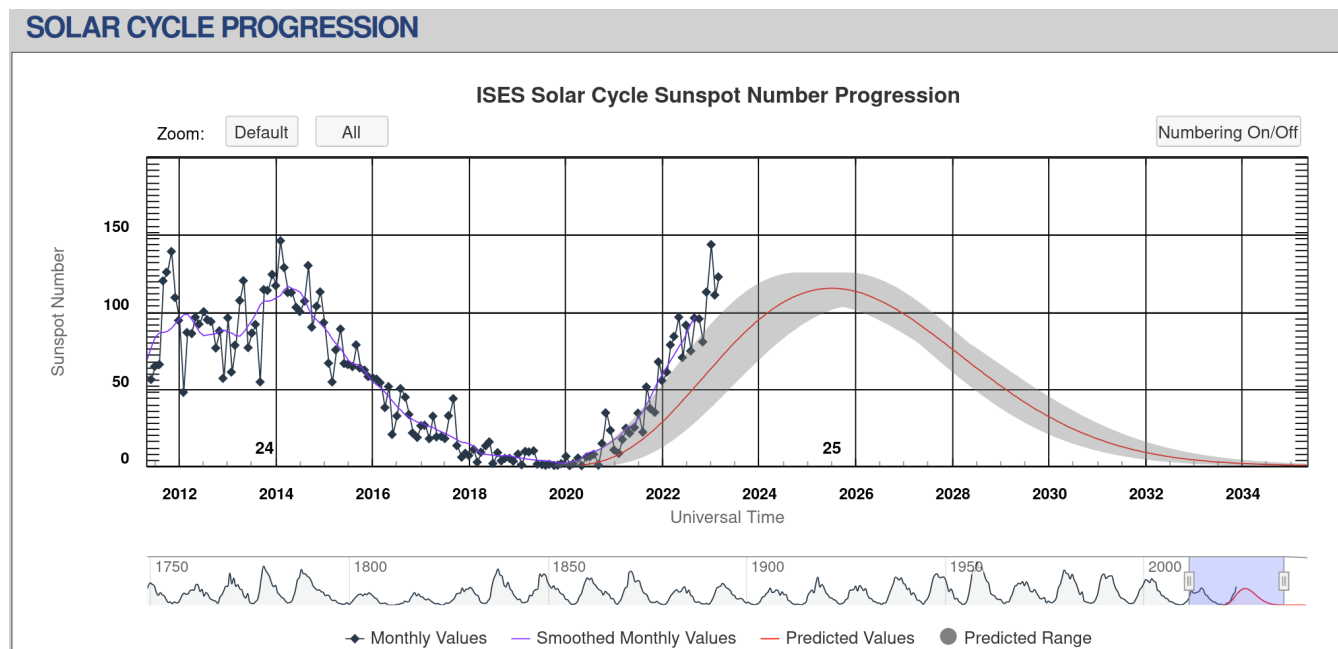


Figure 1: Solar Cycle Sunspot Progression - The number of sunspots are exceeding the predictions

ACE REAL-TIME SOLAR WIND

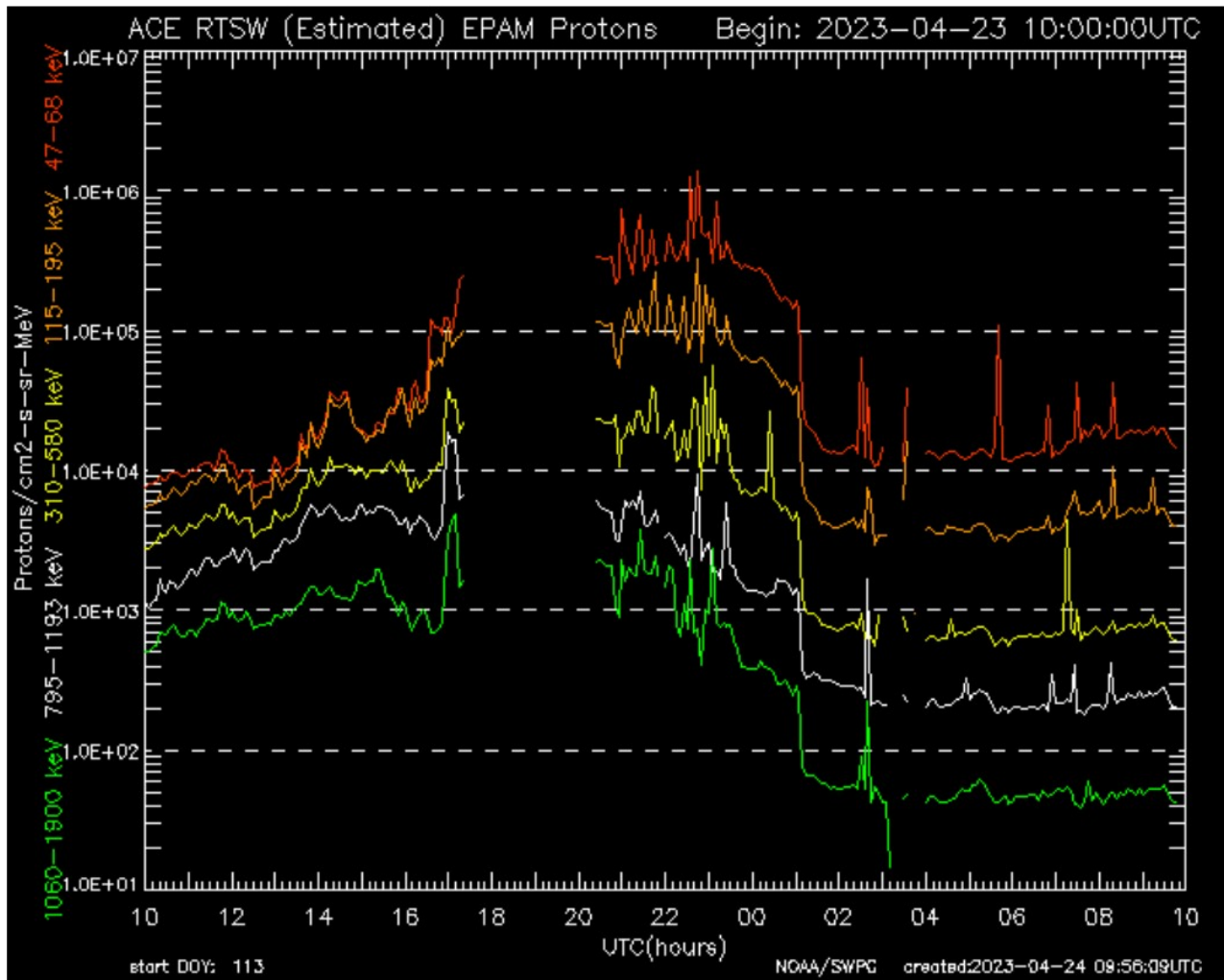


Figure 2: ACE Real Time Solar Wind: Indicating the start and stop of the Chandra ACE page data dropout

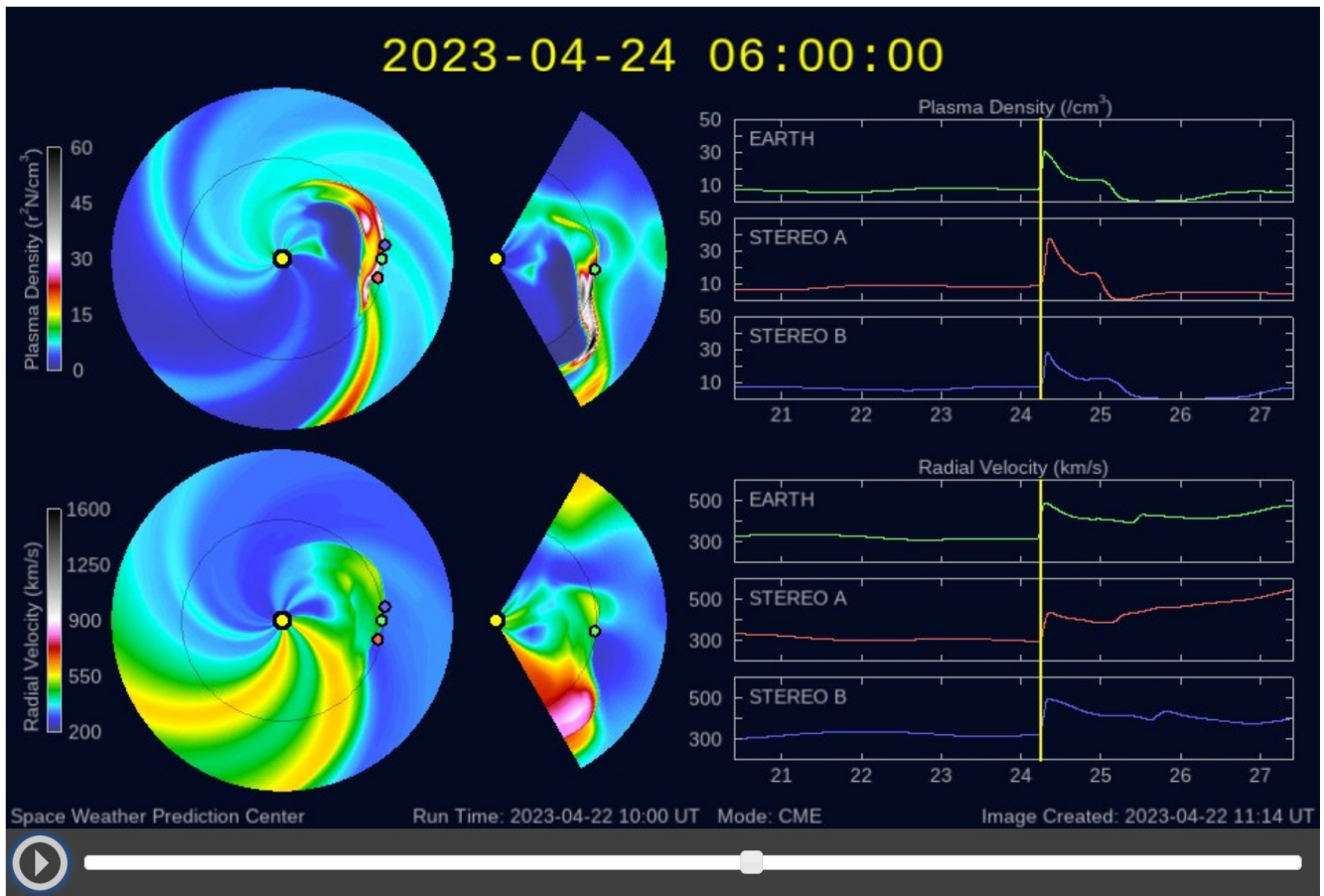


Figure 3: WSA-ENLIL Solar Wind Prediction Pinwheel Plot

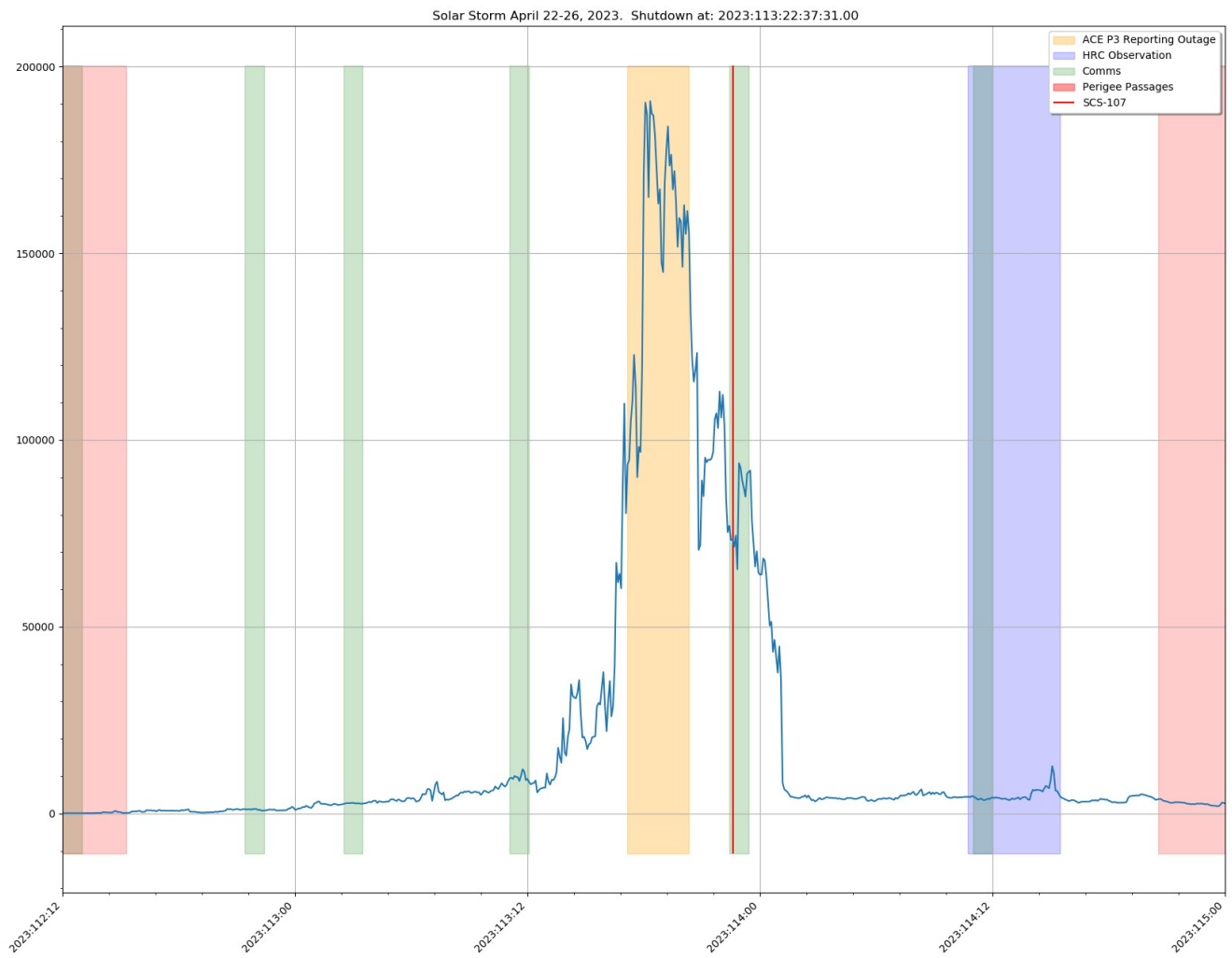


Figure 4: ACE P3 History during the April 23, 2023 Solar Storm.

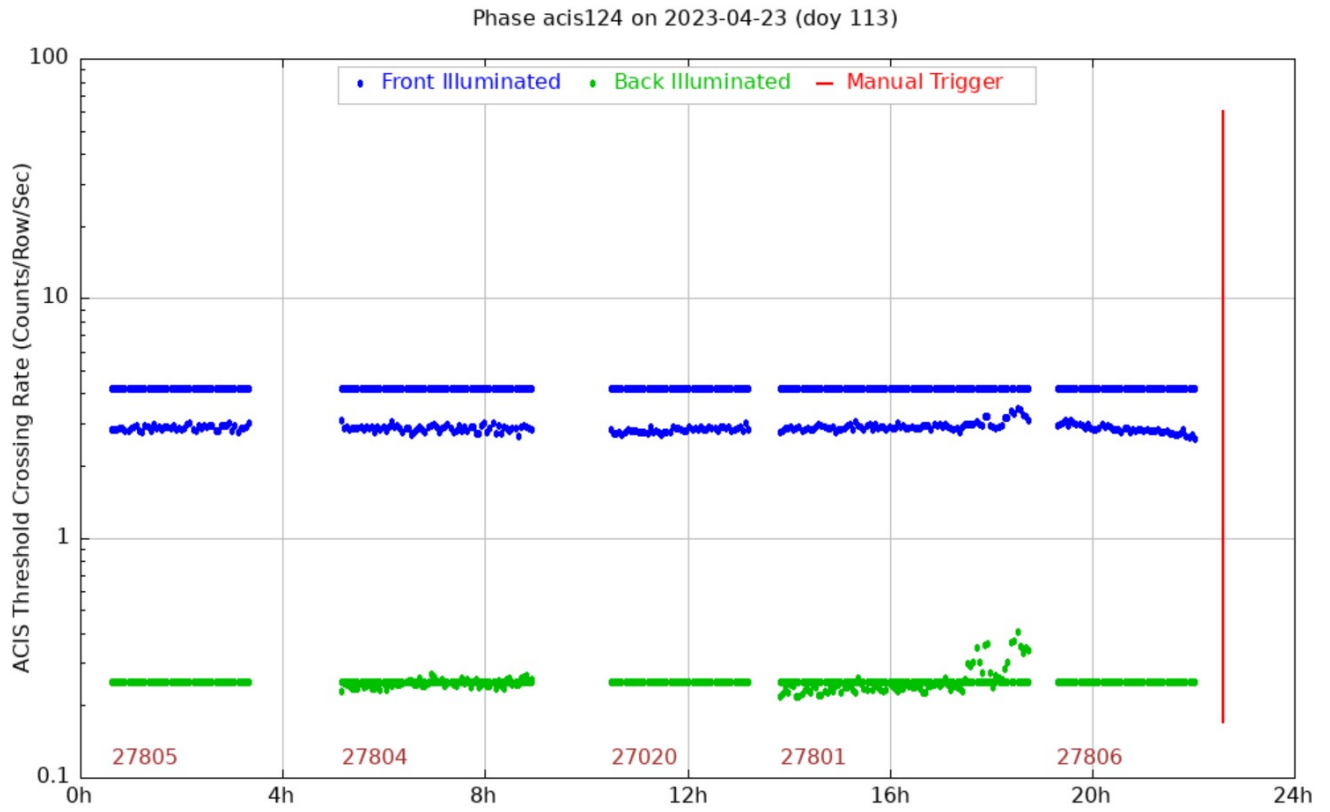


Figure 5: ACIS Front Side and Back Side Txings during DOY 113

7 Resources and Notes

Peter Ford of MIT provided the Txings plot for DOY113

ACE data was obtained from <ftp://mussel.srl.caltech.edu/pub/ace/browse/>

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