ACIS Operations Plan for Science Observations without the HRC anti-Co Shield

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Summary:

Operating ACIS without the HRC anti-Co shield increases the risk to the ACIS instrument. The HRC anti-Co shield is the primary radiation monitor on-board Chandra. EPHIN had been the primary radiation monitor. If the HRC anti-Co shield is unavailable, we are left with the tertiary radiation monitor, the ACIS flight SW process known as "*txings*". *txings* is a less effective radiation monitor than the HRC anti-Co shield, which is less effective than EPHIN.

Two Main Concerns:

1. Unprotected Radiation Belt Passage damages the CCDs & the video boards in the Detector Electronics Assembly (DEA)
2. Lack of effective autonomous safing during Solar radiation events significantly increases the damage to the CCDs

Response:

Short term plan: recommendations that may be implemented quickly that mitigate some of the risks
Long term plan: items that will require additional work to implement and other items that will be investigated that may result in more robust operations and further risk mitigation

Concern #1: Unprotected Radiation Belt Passage

- Unprotected radiation belt transits in 1999 substantially degraded ACIS FI CCD performance (8 passages with ACIS at the focal position with no grating, 2 passages with ACIS at the focal position with the HETG inserted)
- 2007 study looked at initial radiation damage, evolving orbit, radiation belt models (Grant, MIT ACIS Memo #207)
  * Predicted radiation damage for unprotected belt transits through the end of 2026
  * Amount of damage varies as the orbit evolves. Radiation damage in 2020 from one unprotected belt passage is equivalent to ~1.5 yr of current CTI increase, requiring a major calibration effort.
  * *However,* the effects of the radiation damage are worse for warmer focal plane temperatures and a higher percentage of observations are executed at warmer temperatures now.
  * BI CCD CTI increase is a few percent or less of FI CCD CTI increase.
  * No CTI damage was measured when the HETG was inserted with a 3-sigma upper limit of 44% of the predicted damage without the HETG. (LETG does not provide the same protection as HETG.)

Operational Response for Radiation Belt Passages

1. SIM is translated to the HRC-S every perigee passage
2. video boards are powered off for the belt transit

- multiple checks are performed to ensure that the commanding in the weekly loads is correct and every load to date has contained the correct commanding for the radiation belt transits
- the sequence of commanding in the load for entering the belts is:
  1. translate the SIM to HRC-S
  2. disable the RADMON process
  3. execute the ECS measurement, power down the video boards
  4. enter the belts
- the sequence of commanding in the load for exiting the belts is:
  1. exit the belts
  2. power up the video boards, execute the ECS measurement
  3. enable the RADMON process
  4. translate the SIM to ACIS-I or ACIS-S

- this sequence of commanding ensures that the SIs are safe for belt transits as the onboard radiation monitor should trigger SCS-107 as the satellite enters or exits the belts if the predicted time of belt entries is inaccurate or the load stops executing before the entry

Radiation Belt Passage Scenarios that Pose a Risk to ACIS

1. **SIM Mechanism Failure**

- requires ground response to address
- two rapid response SOPs which OC/CC and LSE can execute as soon as the anomaly is discovered, Phase 1 and Phase 2 Unsafe ACIS SOPs
- mitigation strategies are 1) scheduling COMs after the scheduled SIM translation but before the radiation belt entry, 2) inserting the HETG for perigee passages

2. **Load Stops Executing or Load Built Incorrectly**

- no occurrences of an incorrectly built load for the radiation belt passages
- two occurrences of a stopped load in the mission
- could potentially leave ACIS at the focal position during a radiation belt transit, this has not occurred because the stopped loads were recognized in time
- the HRC anti-Co shield functioning as the onboard radiation monitor should safe the SIs once the rates exceed threshold and therefore protects against a stopped or incorrect load
- the loss of the HRC anti-Co shield leaves only the ACIS *txings* process to protect against a stopped or incorrect load
- mitigation strategies include 1) scheduling COMs after the scheduled SIM translation but before the radiation belt entry 2) modifications to the *txings* algorithm & RADMON process

Concern #2: Lack of Effective Autonomous Safing during Solar Events

- Chandra science operations are interrupted by autonomous and manual (ground commanded) actions that safe the SIs.
- There have been 57 autonomous (45.5 EPHIN, 9.5 HRC and 2 ACIS) and 32 manual shutdowns.
- The HRC anti-Co shield is now the primary radiation monitor and *txings* the secondary radiation monitor that would produce an autonomous shutdown.
- Solar radiation events require the Ops team to evaluate the space weather environment using data from ACE, GOES, SOHO, STEREO, etc.
- Manual shutdowns require the team to make an assessment of the probability of a potentially damaging radiation environment before the next COM and then to decide to shutdown or continue operations.
- There have been radiation storms during which the decision was made to continue operations and the environment deteriorated enough before the next COM such that one of the onboard triggers safed the instruments.
- We had the luxury of accepting more risk by not shutting down, knowing that the onboard monitors were functioning and would safe the instruments. With only one radiation monitor left, we need to be more conservative in our decisions.
- The mitigation strategy will be to decide to shutdown for a lower probability of a major storm.

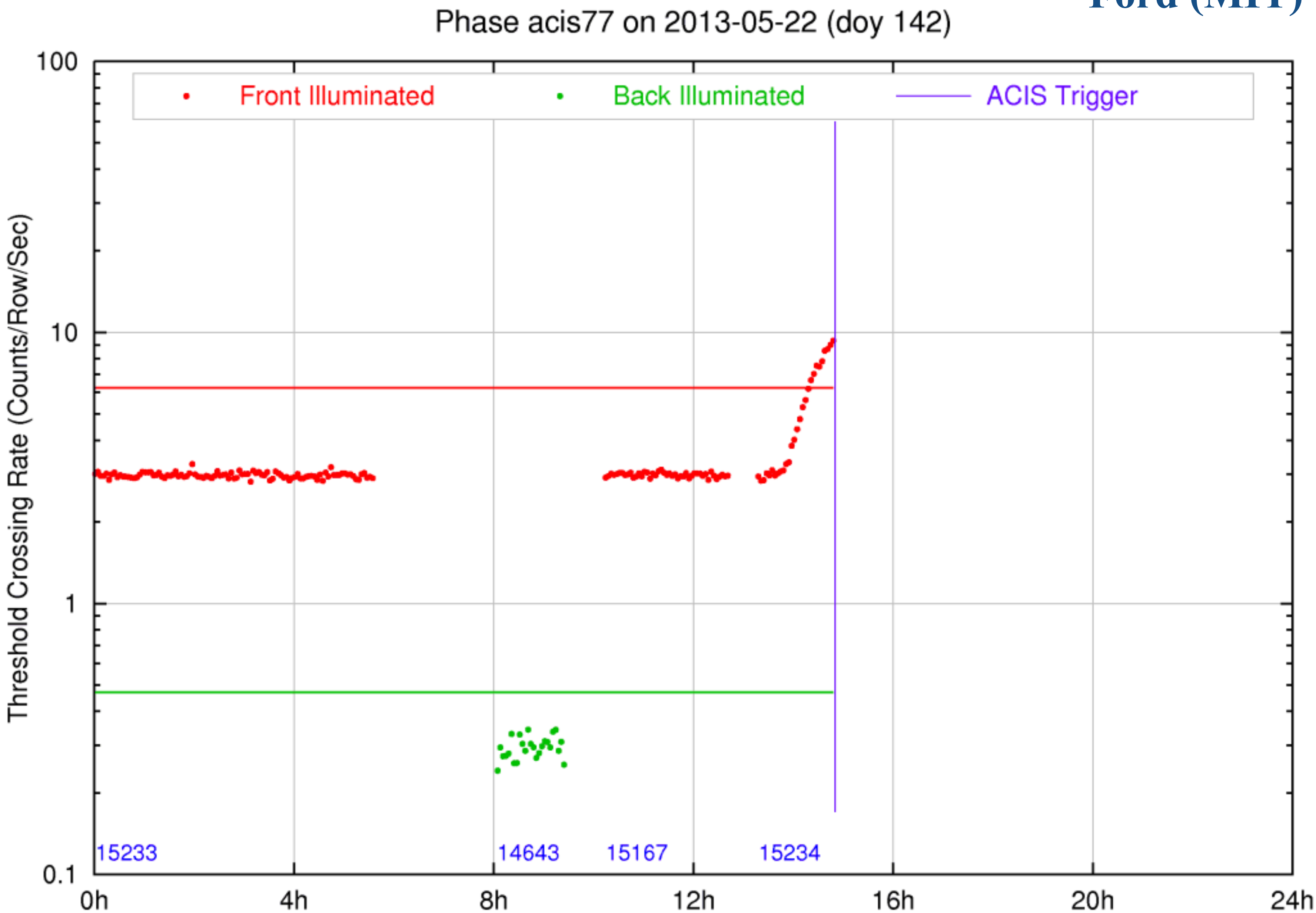
The ACIS txings Process

- Flight software patch installed in Nov 2011 (**Ford & Grant (MIT)**, algorithm described in three flight SW reports and three SPIE papers)
- Two instances where ACIS triggered an SCS107 due to a high radiation environment
- Algorithm requires the data from standard event processing
- Algorithm sums the threshold crossing counts in 3 minute intervals from all BI chips and, separately, all FI chips, and signals the OBC if either sum exceeds predetermined values and increases for each of five consecutive intervals.

- *txings* limitations
  * Only operational when ACIS is taking event data, not during biases or slews
  * Threshold crossings include both particle radiation and astrophysical X-rays
    - Trade off between sensitivity of the algorithm and false triggers due to bright X-ray sources
  * Algorithm does ***not*** trigger on high, but decreasing rates
  * Statistical noise in *txings* data increases with decreasing number of CCDs of a given type (BI/FI), but only weakly with "active area" since subarrays will be read out at higher rates than full frames. So 1/8-frame S3 samples ~50% of the maximum BI area, or ~25% of the FI area assuming 4 FIs active.

The First ACIS txings Trigger

Ford (MIT)



Short Term Plan Requirement #1

Radiation Belt Entry Requirements

On the descending leg, ACIS requires a realtime COM after the SIM translation to the HRC-S position and before the electron belt entry as determined by the EEF1000 time. Scheduling a DSN COM during the nominal radiation belt pad time may not be possible. In such an instance, the pad time should be extended to include the nearest DSN COM time with at least 20 (TBD) minutes of overlap.

The HETG should be inserted before belt entry, and retracted after belt exit (or left inserted if the first science observation uses the HETG), preferably in the vehicle load.

Mitigates Risk of Concern #1

Short Term Plan Requirement #2

Solar Flare Response

In the event of any M or X class flare, ACIS Ops will evaluate the probability of a major radiation event. Based on that analysis, ACIS Ops may require that the science loads be terminated within 24 hours of the flare by executing SCS-107 even if the proton fluxes as observed by ACE and GOES have not yet shown significant increases or reached damaging levels. ACIS Ops will evaluate the evolution of the storm and the projection for enhanced radiation, and only after it is deemed safe, will give approval for resumption of science.

In the event of a prolonged ACE data gap, ACIS Ops will assess potential risk to the instrument and may require executing SCS-107.

Mitigates Risk of Concern #2

Potential Conflict between HRC Activities and Science Loads

- We need to be cognizant of a potential conflict between HRC activities and science loads in the short term.
- The RADMON process must be enabled for ACIS to conduct science observations.
- If HRC activities were to be interleaved with a science load, HRC could potentially trigger a radiation safing action as the instrument is reconfigured and if the RADMON process is enabled.
- We have several approaches to deal with this potential conflict. We could cleanly separate the HRC activities from the normal science observations, safe ACIS, disable the RADMON process, execute the HRC activities, enable the RADMON process, and resume science observations with ACIS. Or we could change the thresholds for safing based on the HRC channels. The final approach will depends on further analysis and the objectives for the HRC activities.

Long Term Plan Requirements

Anticipated Requirements if Extending to the Long Term

1. A DSN COM must be scheduled within 8 (TBD) hours of the start of the first science observation on the ascending leg such that a safing action may be taken if there is a high radiation environment. The current *txings* algorithm requires increasing rates to trigger a shutdown, which could be missed if the storm hits during a radiation belt passage or at another time when ACIS is not taking event data.

2. DSN COMs should be scheduled every (TBD) hours throughout the orbit to allow action to be taken in the case of high radiation.

Mitigates Risk of Concern #2

Long Term Plan Items for Investigation

- SOT & FOT will investigate the option of leaving RADMON permanently enabled, which would allow a safing action to trigger during an ECS measurement (this assumes that the HRC anti-Co shield is not available).
- ACIS will investigate potential modifications to the *txings* monitor to
  (1) assess trade-off between increased sensitivity and larger false-trigger probability
  (2) include other modifications such as detecting declining radiation signals.
- ACIS will calculate potential CTI damage from prolonged radiation exposure to determine a conservative maximum time between COMs
- SOT & FOT will investigate the possibility of the equivalent of a deadman load for each orbit that would safe ACIS if the normal load stopped executing

Conclusions

- If the two requirements of the short term plan are implemented, science observations may resume with ACIS but ***at a higher risk***.
- SOT & FOT must adjust plans depending on the status of the HRC recovery.
- Investigation of the Long Term plan items may proceed regardless of the HRC status but implementation of the Long Term plan depends on the HRC status.