



Maintaining Access to ACE Real-Time Solar Wind Data

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Chandra Program Office, NASA
NOAA Space Weather Prediction Center
Universities Space Research Associates (USRA)







"Is it going to be stormy today?"

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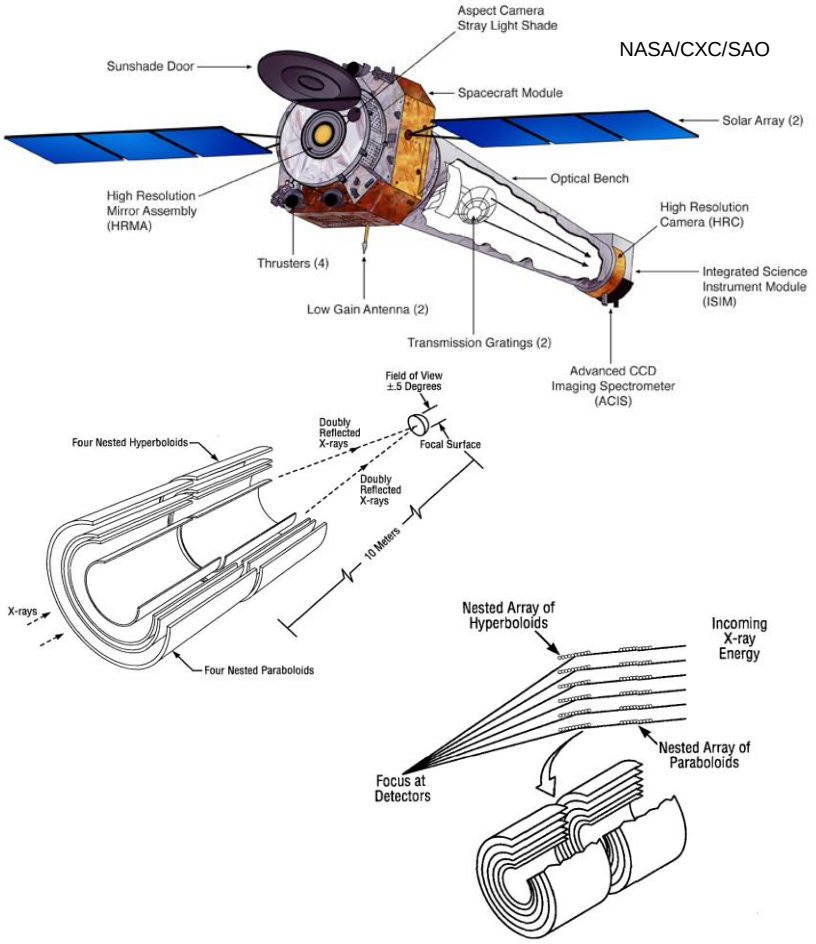


Summary

- Situation
  - Soft protons scatter off *Chandra*'s mirrors damaging front-illuminated CCDs.
  - Radiation protection in harsh radiation environments limits such damage.
- Issue
  - Radiation protection relies in part on ACE real-time data from NOAA.
  - NOAA planned to stop ACE real-time data when DSCOVR became operational.
- Consequences
  - Without radiation protection outside radiation belts, rate of damage to ACIS front-illuminated CCDs could double.
  - Continuing radiation protection outside radiation belts will be inefficient.
- Recommendations
  - Strive to limit rate of radiation degradation of CCDs to current levels.
  - NASA requested that NOAA SWPC investigate at least partially continuing access to ACE real-time data.

Background (Spacecraft)

- CXO launch: 23 July 1999 by STS-93
- Current orbit parameters (Sep 2016)
  ~2.8 R_E x 21.5 R_E x 75.4° inclination, ~63.4 hour period
  ~18,000 km x 137,000 km
- Operating successfully for 18 years:
  - Completed 5-year primary science mission
  - Current operations are the 3rd 5-year extension
  - Planning for 4th extension to 2027
- Two focal-plane x-ray science instruments
  - Advanced CCD Imaging Spectrometer (ACIS)
  - High Resolution Camera (HRC)
- Grazing incidence x-ray mirrors scatter x-rays onto detectors at focal plane
- ACIS is CXO's premier x-ray science instrument, most observatory proposals request observation time using ACIS



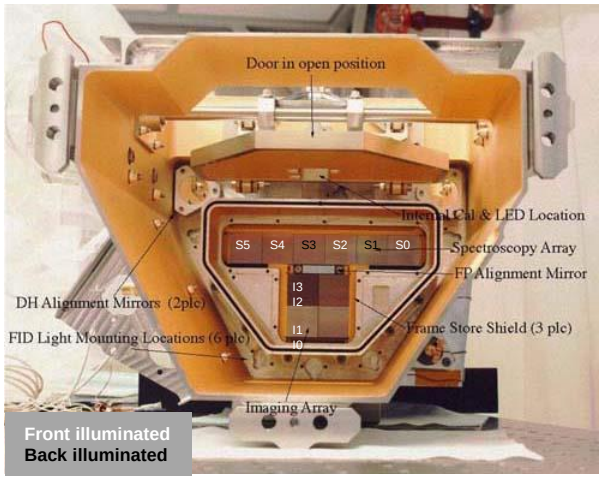
Background (Degradation)

- Radiation degradation was detected in the 8 front illuminated ACIS CCD detectors soon after launch, 2 back illuminated CCD's immune to the damage
  - Degradation from ≥10's MeV charged particles penetrating the spacecraft walls was anticipated, but observed degradation was worse than expected
  - ~5 years worth of degradation in a single perigee passage through the radiation belts (occurred during first 8 observing orbits of mission)

- Damage is due to "soft" protons with energies of 100 to 200 keV
  - Protons scatter off x-ray mirrors and are focused on ACIS (not anticipated before launch!)
  - Earth's ring current ion population (component of the radiation belts) have energies of a few hundred keV
  - Solar particle events are often rich in few hundred keV ions

- ACIS can't be operated in high flux, soft proton environments within the magnetosphere and during solar particle events

Chandra ACIS Detector

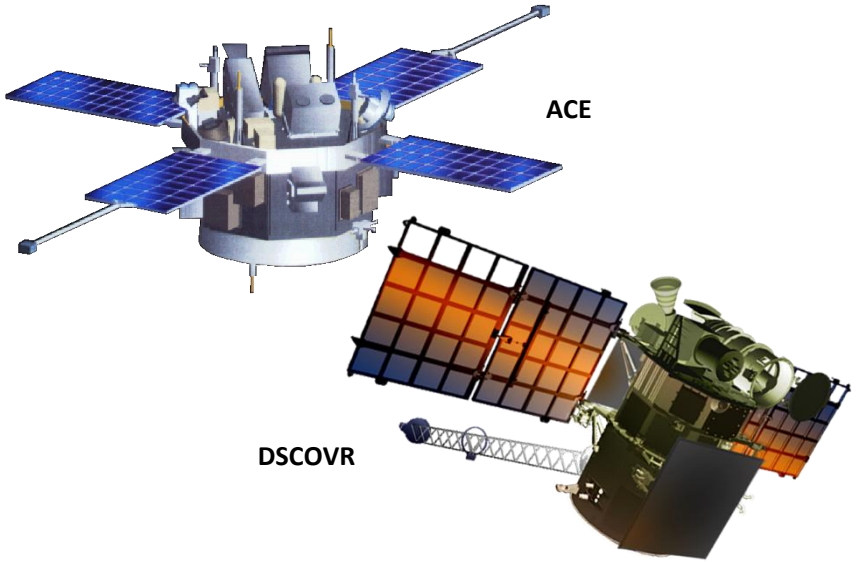


CXO Radiation Mitigation Strategy

- **Schedule science observations** outside of Earth's magnetosphere to avoid high soft proton flux using Chandra Radiation Model, AP-8/AE-8, and other environment modeling tools
- **Interrupt science observations** and move ACIS to protected position during periods of high solar particle flux when required based on in-situ (autonomous) and other data sources (manual)
- CXO Monitoring and Trends Analysis (MTA) Team utilizes data from a variety of sources for real-time monitoring of CXO radiation environment
- Most data sources are proxies assuming ion populations at 100's keV are well correlated with ions at 1-100's MeV (not always true!!)
- ACE Real-Time Solar Wind (RTSW) signal is the only real-time source of information on 100's keV protons outside of the Earth's magnetosphere

Satellite	Instrument	Species	Energy	Notes
CXO (NASA)	*EPHIN rates*	*H^+, e^-*	*H^+ 25 – 41 MeV e^- 2.6 – 6.2 MeV*	*In-situ, autonomous ACIS safing*
	HRC rates	H^+	>10's MeV	In-situ, autonomous ACIS safing
	ACIS rates	H^+	>10's MeV	In-situ, autonomous ACIS safing
GOES (NOAA)	EPS P2 (P4GM proxy)	H^+	4 – 8 MeV	NOAA real time (5 min), manual
	EPS P5 (P41GM proxy)	H^+	38-80 MeV	NOAA real time (5 min), manual
	EPS E	e^-	>2 MeV	NOAA real time (5 min), manual
ACE (NASA)	LEMS 120 P3'	H^+	115 – 195 keV	NOAA real time (5 min), manual
XMM (ESA)	Radiation Monitor	H^+, e^-	H^+ >1 MeV e^- > 130 keV	ESA real time (2 to 60 minutes), manual

NOAA Change from ACE to DSCOVR



- ACE EPAM LEMS120 P3' (115-185 keV) RTSW record used to monitor interplanetary ~100-200 keV protons that damage ACIS front illuminated CCD's

- Deep Space Climate Observatory (DSCOVR) replaced ACE on 27 July 2016 as NOAA's primary L1 real-time space weather monitor
  - DSCOVR does not include an EPAM replacement instrument
  - 100's keV ion data not available from DSCOVR

Consequences

- Absence of ACE real-time data would have undesirable—albeit not dire—consequences.
  - Radiation protection would be limited.
    - Scheduled protection during radiation-belt passages would continue to prevent rapid damage to FI CCDs in the harshest radiation environment.
    - Autonomous intervention based upon on-board hard-proton monitoring would be inefficient and only partially effective without soft-proton data.
      - Would not know when soft-proton flux falls to level acceptable to resume ops.
    - Manual intervention based upon soft-proton data would be infeasible.
      - Would not identify soft-proton events that lack a hard-proton component.
  - Rate of CTI increase of ACIS FI CCDs could double, due to radiation damage.
    - Energy resolution would also degrade at about twice the current rate.
    - Impact on science over 15 years would not of itself be excessively adverse.
    - Thermal issues also threaten to result in increased CTI of ACIS CCDs.
      - Raising focal-plane temperature will increase operating CTI.
- It is prudent to continue radiation protection to minimize CTI increases.

Issue

- Real-time monitoring of the soft-proton environment relies entirely upon NASA's Advanced Composition Explorer (ACE).
  - ACE resides at the Sun–Earth L1 Lagrange point sampling an environment similar to much of *Chandra*'s high elliptical orbit.
  - The ACE Electron, Proton, and Alpha Monitor (EPAM)—particularly its P3′ (115–195 keV) channel—directly measures the soft protons most damaging to the ACIS front-illuminated (FI) CCDs.
  - NOAA's Space Weather Prediction Center (SWPC) provides ACE EPAM data as part of its Real-Time Solar-Wind (RTSW) data stream.
- Despite continuing ACE operation, NOAA planned to discontinue ACE RTSW data when the Deep-Space Climate Observatory (DSCOVR) became NOAA's primary solar-wind data source at L1.
  - DSCOVR has no instrument to measure the relevant soft protons.
  - Current ground-station net cannot monitor 2 L1 satellites full time.

Recommendations

- Continue current radiation-protection program for *Chandra*.
  - Goal is to limit rate of radiation damage to current levels.
    - Partially offset other probable increases in CTI as mission progresses.
      - Thermal issues will likely result in higher focal-plane temperature and CTI.
  - Without ACE EPAM real-time data, radiation protection would be inefficient and less effective, missing some soft-proton events.
    - Lacking soft-proton data, conservative criteria for restarting science operations could cost 170 ks/y (8 h/event, 6 event/y) in lost science time.
    - Pro-rata value of lost science time is roughly 500 k$/y opportunity cost.

Work Completed To Date

- Established point of contact in NOAA's SWPC for pursuing options to continue to provide ACE RTSW data
  - NOAA doesn't have sufficient ground tracking stations to support both spacecraft
  - NOAA agreed to a formal NASA request (from CXO management through NASA SMD and NOAA senior management) to continue processing and distributing ACE RTSW data if NASA can provide the data to NOAA

Work Completed To Date

- NASA, with NOAA SWPC support, is working on identifying additional tracking stations for acquiring the ACE RTSW signal:
  - ACE program provides ~3.5 hours/day during science data downlink (Goldstone and White Sands)
  - NOAA Wallops Command and Data Acquisition (WCDA) Station continues to provide ~6 hours/day
  - John Hopkins University/ Applied Physics Laboratory has a demonstrated capability to acquire ACE RTSW data, agreed to support ACE RTSW effort for 0.5 to 1.5 hours/day if necessary (backup to WCDA)
  - DLR in Europe provides 1 to 2 hours/day
  - Kiel, Germany provides ~5.5 hours/day (backup to DLR)

- RTSW available ~16 to 17 hr/day with ~7 to 8 hr/day gap, minimally acceptable for CXO needs (CXO satellite contacts are once every ~8 hr, prefer ACE data every 4 to 6 hr)

In Progress Work

- Confirm future plans for WCDA and DLR for continued ACE RTSW support
- Exploring options for coverage in the Asian sector. Korean Space Weather Center has access to tracking station at Incheon, Korea and is considering supporting the ACE RTSW effort
- Investigating ability of DSN to acquire ACE RTSW during Madrid, Canberra contacts (~1 to 1.5 hours about every other day)
- Supporting RBC Signals effort to acquire ACE RTSW signal using Alaska Satellite Facility antenna in Fairbanks, Alaska (primarily coordination between RBC and GSFC Flight Data Facility)

Summary

- The research done in space weather and environment reaches far beyond research for the sake of research
- Operational and future scientific missions are further enhanced and their efficiency improved through a better situational awareness of the environment they operate in.
- In the particular case of Chandra, there is a direct correlation between an improved understanding of the radiation environment and our ability to operate the mission for longer and at the maximum efficiency possible.
- THANK YOU!!!