# Real Time Space Weather Support for Chandra X-ray Observatory Operations


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## Abstract

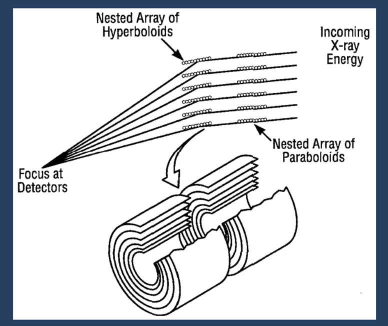
NASA launched the Chandra X-ray Observatory in July 1999. Soon after first light in August 1999, however, degradation in the energy resolution and charge transfer efficiency of the Advanced CCD Imaging Spectrometer (ACIS) x-ray detectors was observed. The source of the degradation was quickly identified as radiation damage in the charge-transfer channel of the front-illuminated CCDs, by weakly penetrating ("soft", 100–500 keV) protons as Chandra passed through the Earth's radiation belts and ring currents. As soft protons were not considered a risk to spacecraft health before launch, the only on-board radiation monitoring system is the Electron, Proton, and Helium Instrument (EPHIN) which was included on Chandra with the primary purpose of monitoring energetic solar particle events. Further damage to the ACIS detector has been successfully mitigated through a combination of careful mission planning, autonomous on-board radiation protection, and manual intervention based upon real-time monitoring of the soft-proton environment. The AE-8 and AP-8 trapped radiation models and Chandra Radiation Models are used to schedule science operations in regions of low proton flux. EPHIN has been used as the primary autonomous in-situ radiation trigger; but, it is not sensitive to the soft protons that damage the front-illuminated CCDs. Monitoring of near-real-time space weather data sources provides critical information on the proton environment outside the Earth's magnetosphere due to solar proton events and other phenomena. The operations team uses data from the Geostationary Operational Environmental Satellites (GOES) to provide near-real-time monitoring of the proton environment; however, these data do not give a representative measure of the soft-proton (< 1 MeV) flux in Chandra's high elliptical orbit. The only source of relevant measurements of sub-MeV protons is the Electron, Proton, and Alpha Monitor (EPAM) aboard the Advanced Composition Explorer (ACE) satellite at L1, with real-time data provided by NOAA's Space Weather Prediction Center. This presentation describes the radiation mitigation strategies to minimize the proton damage in the ACIS CCD detectors and the importance of real-time data sources that are used to protect the ACIS detector system from space weather events.

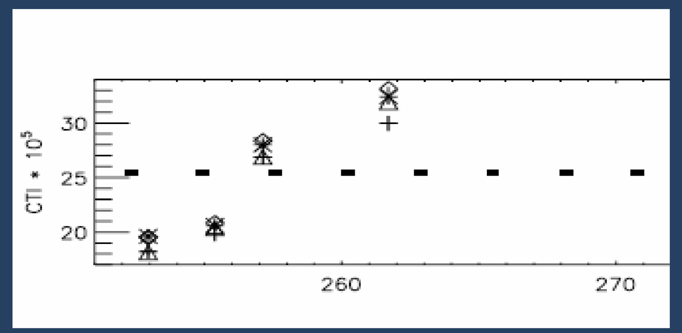

## ACIS

The Advanced CCD Imaging Spectrometer (ACIS) is CXO's premier science instrument, most often requested in observatory proposals. Shortly after launch, the degradation of the 8 front illuminated ACIS CCD detectors was observed to be much worse than expected.

– Initially observed ~5 years worth of degradation in a *single* perigee passage
– Damage mechanism identified as "soft" protons (~100 to 200 keV) depositing energy in CCD substrate (the two back illuminated CCD's are immune to the same damage mechanism)

The grazing incidence optics used to focus the short wavelength x-ray photons are also efficient at focusing the soft protons from the space environment onto the observatory focal plane which degrades the energy resolution and charge transfer efficiency of the Advanced CCD Imaging Spectrometer front-illuminated CCD's.




Damage to the ACIS detector has been successfully mitigated through a combination of careful mission planning, autonomous on-board radiation protection, and manual intervention *based upon real-time monitoring of the soft-proton environment*

Manual intervention for soft proton events in interplanetary space is based on monitoring 115 – 195 keV proton fluence using data from the P3' channel of the Electron, Proton, and Alpha Monitor (EPAM) instrument on the Advanced Composition Explorer (ACE) spacecraft

NOAA Space Weather Prediction Center (SWPC) currently provides ACE/EPAM as a component of the Real Time Solar Wind (RTSW) data stream. *ACE/EPAM is the only data source for real time measurements of the ~100-200 keV proton environment* primarily responsible for damage to ACIS CCD's in interplanetary space

## Overview

– The most often requested science instrument onboard CXO (ACIS) cannot be operated in high flux, soft proton environment within the magnetosphere and solar particle events due to a CD damage mechanism from ~100-200 keV protons.

– The ACE EPAM instrument remains the only data source available for directly measuring the soft protons in interplanetary space that damage ACIS CCD's.

– No other users of ACE EPAM RTSW data have been identified to date, it appears that Chandra is the only program using the EPAM data for operational support.

**– Current NOAA plans are to discontinue ACE RTSW data starting late 2014 or early 2015 when the Deep Space Climate Observatory (DSCOVR) spacecraft becomes the primary NOAA space weather data source from Sun-Earth L1 Lagrange point, and DSCOVR does not have instrumentation onboard to monitor the proton energy range required to protect the ACIS detector.**

– The loss of this real-time data stream could cause a significant impact to the science lifetime and data quality for this Great Observatory.

## Current CXO ACE EPAM Data Requirements

– Chandra requires real-time ACE EPAM data for monitoring and implementing manual interruptions of Chandra science operations if necessary, ACE Science Center Level 2 (verified) and Browse (unverified) science products are not updated often enough to be useful for operational support

– Access to 5-minute average ACE EPAM RTSW data product (status quo) is the preferred option for Chandra since it allows continued, uninterrupted operation of our radiation mitigation software tools

– However, data rates are negotiable as ACIS radiation damage is a *fluence* issue, with long exposure periods to soft proton flux required for significant damage to CCD's

– Lower real-time data rates are acceptable as long as sufficient information is available to estimate soft proton fluence, ACE EPAM RTSW data at periods up to once per hour can be used by Chandra to monitor soft proton environment

## The Future of ACE Real-time Data

The ACE/EPAM RTSW records are the only real-time data currently available for detecting soft ~100-200 keV proton events in interplanetary space that impact the ACIS instrument.

NOAA plans to replace ACE with Deep Space Climate Observatory (DSCOVR) in late 2014
– DSCOVR will become the primary NOAA space weather plasma data source
– ACE RTSW coverage will be discontinued
– DSCOVR carries a MAG/SWEPAM type cold solar wind plasma and magnetic field instrument
– No replacement for non-thermal EPAM, SIS energetic particle instruments on DSCOVR

DSCOVR is planned as an interim solution for an ACE replacement with release of an RFP for a full replacement after DSCOVR is on orbit
– Full ACE replacement satellite could have a more complete set of cold plasma, energetic particle instruments including an EPAM replacement but there will be a gap in service for a few years for the real-time energetic particle data
– None of this has been authorized by Congress so it is all uncertain at best
– The gap could be many years

Loss of ACE/EPAM soft proton data will impact CXO operations.
Are there other spacecraft or space weather users that require the RTSW ACE/EPAM data for operations that will be similarly impacted?

The CXO Program would like to know….

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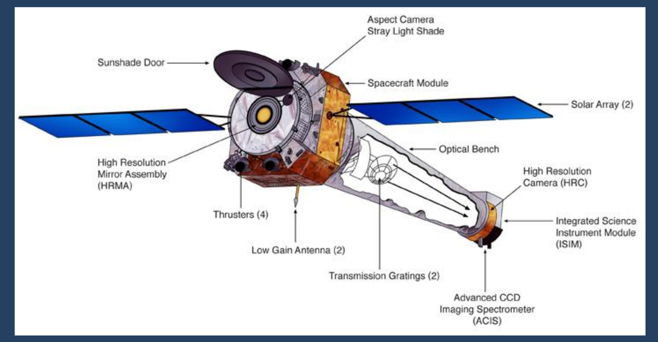
## Introduction to the Chandra X-ray Observatory (CXO)

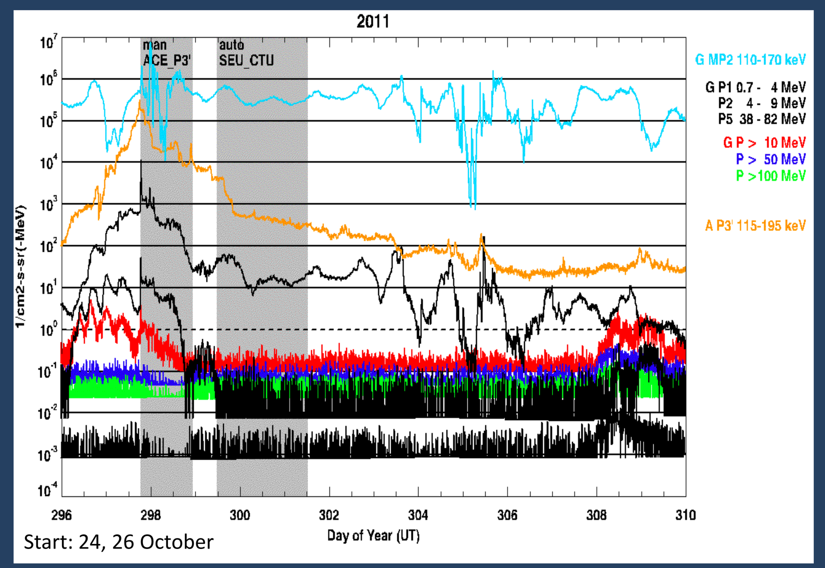
CXO Launched 23 July 1999 onboard STS-93
Current orbit:
~1.6 Re x 23.7 Re x 74°, ~63.5 hour period
Mission:
– 5-year primary science mission
– Currently in 2nd 5-year extension
– Planning for 3rd to 2019 and 4th to 2023

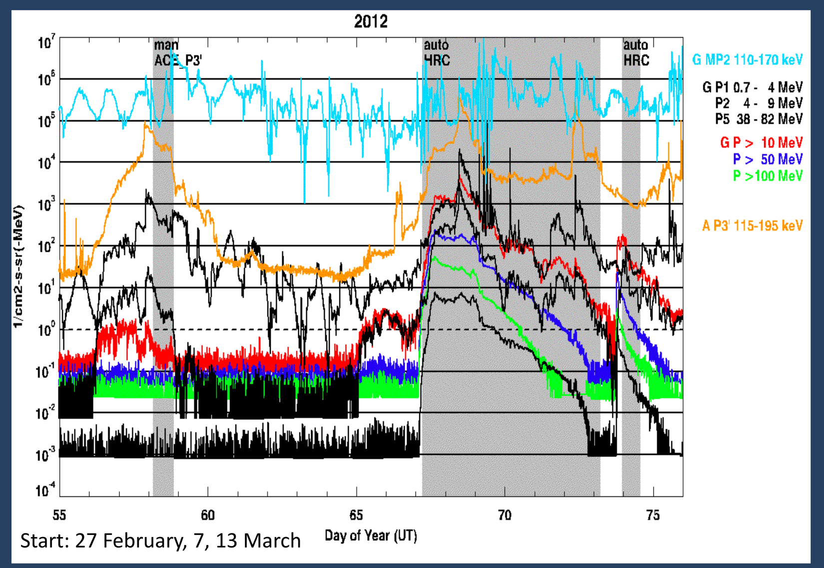


## CXO Solar Cycle 24 Radiation Interruptions

| Event | Start | End | Lost time | Man/Auto | Cause |
|---|---|---|---|---|---|
| **2011** | | | | | |
| 1** | 7 Jun 15:23 UT | 8 Jun 12:50 UT | 74.9 ks (20.8 hr) | auto | HRC |
| 2 | 4 Aug 07:03 | 7 Aug 10:25 | 270.4 (75) | auto | HRC |
| 3 | 24 Oct 18:27 | 25 Oct 22:35 | 61.1 (17.0) | manual | ACE P3' |
| 4 | 26 Oct 11:40 | 28 Oct 12:33 | 154 (42.8) | auto | SEU, Command Telemetry Unit |
| **2012** | | | | | |
| 5 | 23 Jan 06:00 | 26 Jan 08:27 | 192.1 (53.4) | auto | HRC |
| 6 | 27 Jan 19:39 | 30 Jan 02:20 | 163.4 (45.4) | auto | HRC |
| 7 | 27 Feb 03:24 | 27 Feb 20:23 | 61 (16.9) | manual | ACE P3' |
| 8 | 7 Mar 05:30 | 13 Mar 05:14 | 440 (122.2) | auto | HRC |
| 9 | 13 Mar 22:41 | 14 Mar 13:57 | 53.3 (14.8) | auto | HRC |
| 10 | 17 May 02:18 | 18 May 04:52 | 93.8 (26.1) | auto | E1300 |
| 11 | 12 Jul 19:59 | 14 Jul 00:09 | 61.7 (17.1) | auto | E1300 |
| 12 | 14 Jul 21:08 | 16 Jul 05:16 | 80.1 (22.3) | manual | ACE P3' |
| 13 | 19 Jul 11:44 | 20 Jul 04:09 | 56.5 (15.7) | auto | HRC |
| 14 | 3 Sep 12:57 | 4 Sep 12:41 | 44.5 (12.4) | manual | ACE P3' |

The table above indicates Solar Cycle 24 events where ACIS science data was lost due to radiation events. Autonomous "auto" events are triggered by a high flux of solar energetic particles that generate high count rates in either the anti-coincidence shield of the High Resolution Camera (HRC) or the EPHIN E1300 channel. The on-board radiation monitoring system sends a signal to autonomously move the ACIS instrument from the focal plane position to a protected location that cannot be accessed by the soft protons for these events. Manual events require operator intervention based on ground based monitoring of the ACE P3' channel from the NOAA RTSW data stream. In addition, there is one period of lost science that was due to a single event upset (SEU) in the on-board Command Telemetry Unit that put the spacecraft in safe mode. Of note is that four out of fourteen events that result in lost science observations are manual events due only to soft protons that would not have triggered the autonomous on-board radiation protection systems, leaving the ACIS instrument vulnerable to additional radiation degradation.




The above graphs represent two examples of periods with lost ACIS science observations (gray boxes) and the corresponding temporal variations in the radiation environment measured over a range of energies by GOES and ACE instruments. Radiation interruptions during the current solar cycle stemmed from a number of sources including autonomous HRC events, a single event upset that put the spacecraft in safe mode, and the manual events based on the ACE P3' rates. The autonomous HRC and E1300 events guard the spacecraft from high energy solar particle events and sometimes, but not always, from the high flux of soft protons. The ACE P3' instrument is the only source of real time data that can be used to guard against soft proton events that are not accompanied by high energy particles. All of the on-board autonomous systems are driven by high energy particle events.