Seventeen Years of the Advanced CCD Imaging Spectrometer

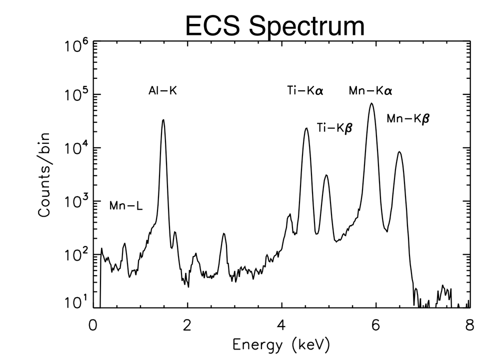
Catherine Grant (MIT Kavli Institute)

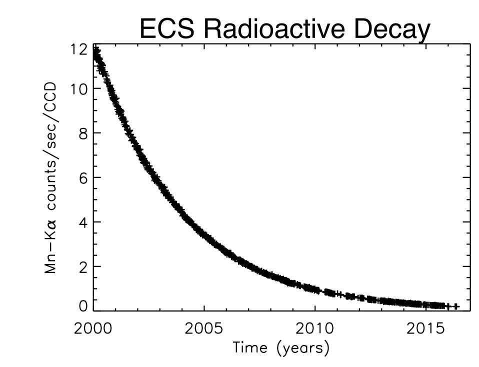
Summary

As the Advanced CCD Imaging Spectrometer (ACIS) on the Chandra X-ray Observatory enters its seventeenth year of operation on orbit, it continues to perform well and produce spectacular scientific results. The response of ACIS has evolved over the lifetime of the observatory due to radiation damage, molecular contamination, and aging of the spacecraft in general. Here we present highlights from the instrument team's monitoring program and our expectations for the future of ACIS. The ACIS calibration source produces multiple line energies and fully illuminates the entire focal plane which has greatly facilitated the measurement of charge transfer inefficiency and absorption from contamination. While the radioactive decay of the source has decreased its utility, it continues to provide valuable data on the health of the instrument. Performance changes on ACIS continue to be manageable, and do not indicate any limitations on ACIS lifetime.
(Adapted from Grant, Bautz, Ford & Plucinsky 2015, Proc. SPIE 9144)

Instrument and Data

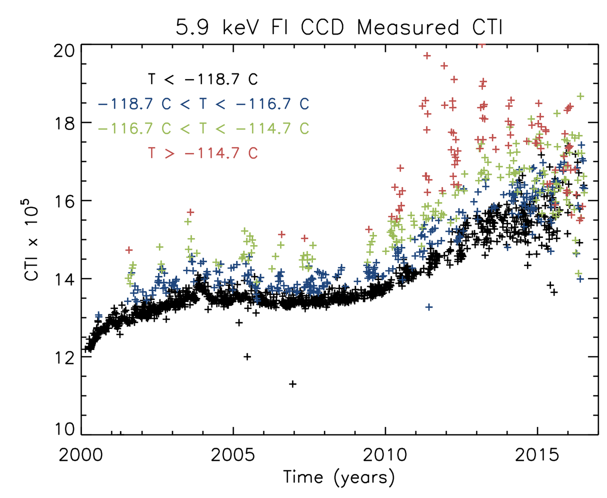
- Advanced CCD Imaging Spectrometer (ACIS)
  - 10 CCDs; 8 front-illuminated (FI), 2 back-illuminated (BI)
  - Simultaneous high-resolution imaging and moderate-resolution spectroscopy
  - Highly-elliptical 64-hour orbit transits radiation belts at perigee
  - Operating temperature −120° C
- ACIS External Calibration Source (ECS)
  - Radioactive Fe-55 with Al and Ti fluorescence targets
  - Strongest line is Mn-Kα (5.9 keV)
  - Observed twice each orbit; before and after radiation belt passages
  - Illuminates entire focal plane
  - Fe-55 half-life ~ 2.74 years

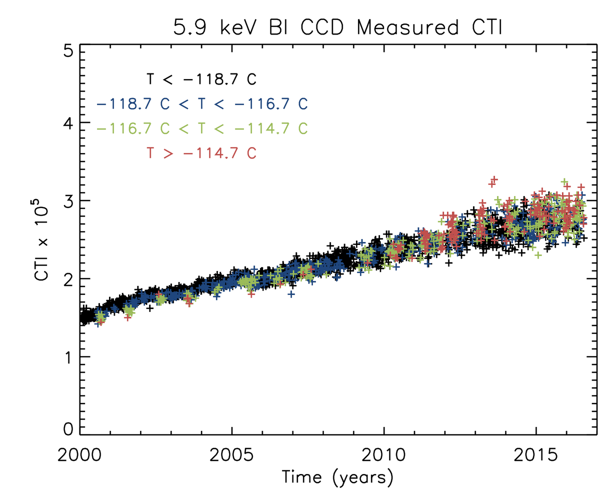




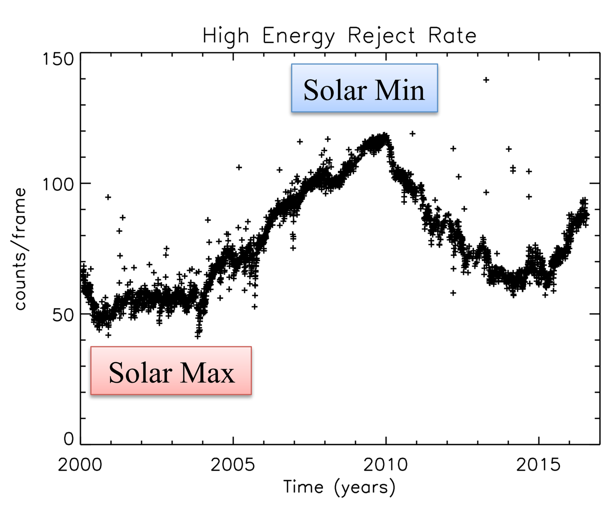
Charge Transfer Inefficiency

- CTI: Charge transfer inefficiency
  - Caused during manufacturing and by radiation damage
  - Degrades spectral resolution and detection efficiency
  - Sensitive to temperature and sacrificial charge from the particle background
  - ACIS FI and BI CCDs behave differently
  - BI CCD CTI is much less sensitive to temperature and sacrificial charge
- Parallel transfer CTI:
  - Pre-launch: CTI (FI CCDs) < 10^{-6}, CTI (BI CCDs) ~ 10^{-5}
  - After initial radiation belt passages (Aug-Sep 1999): CTI (FI) ~ 10^{-4}, CTI (BI) ~ 10^{-5}
  - After correcting for variations in sacrificial charge and temperature:
    dCTI/dt (FI) ~ 2×10^{-6} / yr
    dCTI/dt (BI) ~ 1×10^{-6} / yr

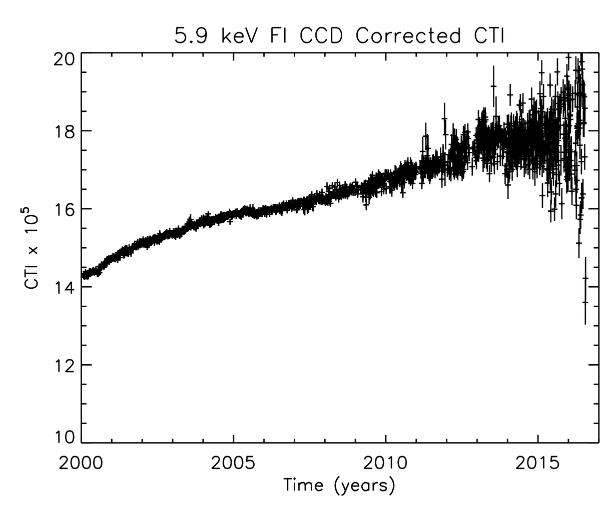


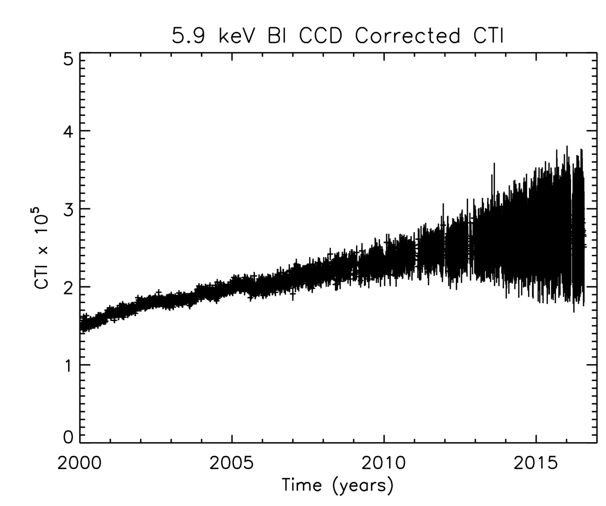


Evolution of measured CTI for the FI and BI CCDs. The colors indicate times of warmer focal plane temperature which increases CTI. The remaining structure is a combination of real radiation damage and changing particle background. Due to radioactive decay of the calibration source, it is difficult to measure CTI from a single observation in the most recent data.



Particle background at the ACIS detector. Correlated with cosmic-ray protons (E > 10 MeV); anti-correlated with the solar cycle. Many of the structures are also seen in reverse in the measured CTI.

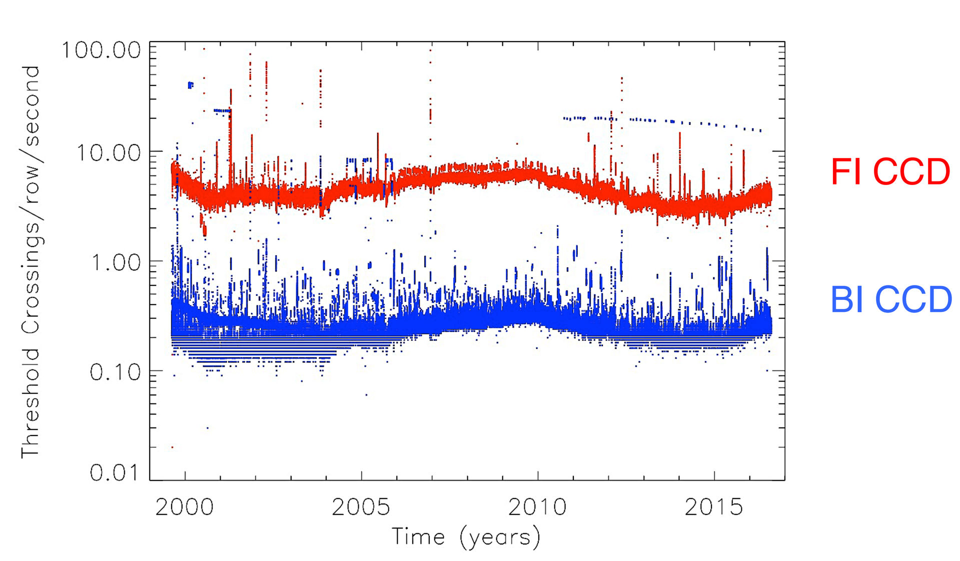




Evolution of CTI for the FI and BI CCDs after removing variations due to temperature and sacrificial charge from the particle background. Scatter increases toward the end due to reduced count rate from the decaying radioactive source.

Radiation Monitoring

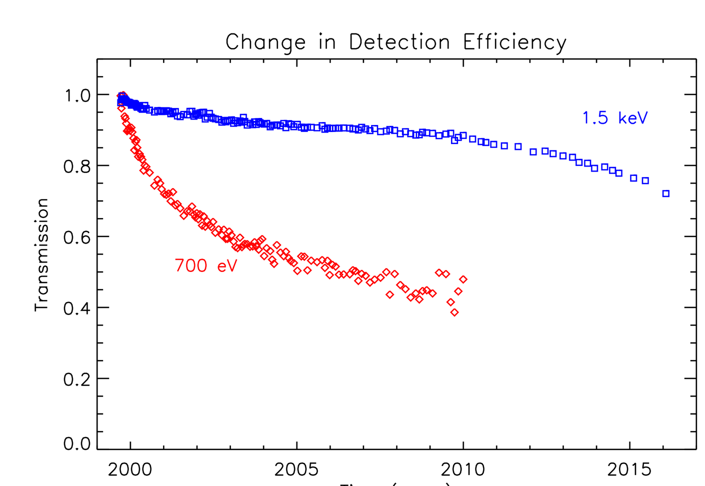
- Effectiveness of on-board particle detector (EPHIN) reduced due to elevated spacecraft temperatures; no longer used as of 2013.
- ACIS can act as its own radiation monitor which provides some protection against solar storms
- ACIS team has developed a flight software patch; examines ACIS data in real-time and sends alert to Chandra On-Board Computer when it detects high radiation levels
- ACIS flight software patch installed Nov 2011; OBC patched to respond to ACIS on May 2012
  - Operating as expected, no anomalies
  - No impact on science data
  - No false triggers from bright X-ray sources
  - Two real triggers from high radiation environment; prompted Chandra radiation shutdowns
- Patch parameters adjustable to better match changing quiescent particle background. Most recently updated in July 2016.
- Grant+ 2012, Proc. SPIE 8443; Ford+ 2012, Proc. SPIE 8443



ACIS threshold crossing rate as a function of time over the entire history of Chandra. The data from each type of CCD (FI/BI) have been averaged into three minute time bins. This threshold crossing rate includes contributions both from X-ray sources in the field and from the particle background. Vertical enhancements are due to radiation events. Horizontal structures are repeated observations of bright sources (Crab and Cas-A).

Molecular Contamination

- Hydrocarbon contaminant is accumulating on the ACIS filter
- Strong absorption at low energies, not important above 2 keV
- Thicker near the edges of the focal plane than in the middle
- Deposition rate increasing, related to increasing spacecraft temperatures?
- Marshall+ 2004, Proc. SPIE 5165; O'Dell+ 2015, Proc. SPIE 9601



Drop in low-energy detection efficiency due to accumulating contamination on the optical blocking filter measured at 700 eV and 1.5 keV for the ACIS-S3 CCD. The 700 eV line is too weak to measure after ~2010.

Future Prospects

- Chandra lifetime not limited by consumables or orbit; no known limitations to a mission of 25 years or longer (Tananbaum+ 2014, RPPh 77, p. 6902)
- Thermal control becoming more difficult, reducing flexibility in operations & mission planning; not a hazard to continued operation
  - Software tools have been developed which follow small temperature variations, adjust calibration products accordingly
- Instrument anomalies have been infrequent with limited impact on science
- Performance changes continue to be manageable, do not limit ACIS lifetime
  - CTI increase is relatively small, requires periodic calibration
  - Loss of low-energy efficiency due to contamination potentially more significant
  - Reduced count rates from ECS will require rethinking of calibration plan
- Reduced thermal control may require raising nominal focal plane temperature
  - Requires substantial recalibration effort; spectral resolution will be decreased
- We look forward to many more years of spectacular ACIS science!