Conclusions

- Evolution of the line energy and spectral resolution for ACIS and XIS CCDs are quite different
- After compensating for differences in temperature and sacrificial charge from the particle background and charge injection:
  - CTI increase is much larger for XIS than ACIS
  - 3x for FI CCD, 5x for BI CCD

Instrument and Data

- Both front (FI) and back-illuminated (BI) CCDs
- Similar format, architecture, pixel size
- Different orbits, particle background levels, operating temperatures
- Chandra's Advanced CCD Imaging Spectrometer (ACIS)
  - Elliptical 64-hour orbit, transits radiation belts
  - Operating temperature ≈ 120°C
- Suzuki's X-ray Imaging Spectrometer (XIS)
  - Low-Earth orbit, transits South Atlantic Anomaly
  - Operating temperature ≈ 90°C
  - Capable of charge injection
- Calibration sources
  - Radioactive Fe-55
  - Strongest line is Mn-Kα (5.9 keV)
- ACIS observes twice each orbit, uniform illumination
- XIS always viewing, illuminates upper corners
- Data Analysis
  - Unprocessed eventlists; no CTI or gain correction
  - GO2346 filtered
  - Results do not reflect what typical user would find with standard data products
- XIS source illumination doesn't allow for true CTI measurement; comparing line centroid and width in upper corners

Evolution of Energy Scale

- Measured energy scale evolution is due to radiation damage modified by sacrificial charge

Particle Environment in Low- and High-Earth Orbit

- Both Chandra and Suzuki shut off their CCDs during transits of the radiation belts and the South Atlantic Anomaly. These trapped protons do not contribute to the observed particle background.
- During observations, the background is primarily due to Galactic cosmic rays, which are partially shielded by the Earth's magnetic field. Suzuki in low-Earth orbit receives more shielding than Chandra.
- The trapped proton spectrum in the South Atlantic Anomaly is much harder than the outer radiation belts transited by Chandra.
- Even though the integral flux of trapped protons seen by Chandra is higher, they have low energies and, for the most part, cannot reach the stowed ACIS CCDs. The harder protons seen by Suzuki can pass through the spacecraft and damage the CCDs.

Evolution of Line Width

- Complicated interplay between increasing CTI, trailing charge and event/split thresholds

Sacrificial Charge and Particle Background

- Particle background on the ACIS detector is highly variable and is well correlated with cosmic-ray protons (E > 10 MeV) and anti-correlated with the solar cycle. Similar structures are seen in the line energy due to sacrificial charge.

Conclusions

- Line width increase is much larger on XIS than for ACIS; no strong dependence on sacrificial charge from particle background
- Suzuki low-Earth orbit: lower, stable particle background, but higher accumulated radiation damage
- Chandra high-Earth orbit: higher, more variable particle background, but lower accumulated radiation damage
- XIS charge injection provides substantial performance improvement

Summary

X-ray telescopes, such as NASA's Chandra X-ray Observatory and Japan's Suzaku, have flown in space for several decades, however the effects of this hostile environment on sensitive astrophysics instruments are still not completely documented. Both observatories use CCD cameras for imaging spectroscopy of the X-ray sky. The CCDs themselves are similar in design, being fabricated at MIT's Lincoln Laboratory. We compare the on-orbit performance evolution of the Chandra ACIS and Suzuki XIS, to better understand the effect of the radiation environment in low- and high-Earth orbit. After more than a combined twenty years in space, both instruments have suffered performance degradation due to radiation damage, but comparison must take into consideration the operational differences, such as the presence of charge injection and the warmer focal plane temperature of the XIS. The low-Earth orbit of Suzuki has the advantage of a lower and stable particle background during observations, while the Chandra particle background during observations is higher and subject to variations due to the solar cycle and solar storms. This is in contrast to the rate of damage accumulation, which is about four times higher for Suzuki, even after correcting for operational differences. We present models of the particle environments for both Suzuki and Chandra which can explain the apparent discrepancy. While the choice of orbit for future missions is obviously dependent on many factors beyond radiation environment, we hope this study will be useful for better informing that choice.