Swift-XRT Calibration Update

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With help from
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(& Tony Abbey - now retired)

on behalf of the XRT cal team.
Introduction

• Swift has now been operating for 7+ years.
• Typically performs 70 slews/day → high observing efficiency
• Last 4 months: 6.5% Cal (c.f. 36% TOOs, 23% GRBs, 26.6% fill-ins, 3.1% GI)

Updates to report on:
• Gain/CTI
• Trap Mapping
  – Lab-work
• New CCD22 modelling code

Cheap plug: Swift-XRT products from www.swift.ac.uk
XRT CCD

- e2v CCD-22 detector (developed for EPIC MOS camera on XMM)
- Operated in Photon Counting (PC) and Windowed Timing (WT) mode
- 4 $^{55}$Fe corner sources continuously illuminate CCD corners, used to monitor CCD performance
- Spectral resolution at launch: FWHM = 140 eV at Mn K-α (5.895 keV)

Swift in Low-Earth orbit and exposed to high flux of protons during SAA
CS3 Gain and CTI

• Gain is measured from the Fe-55 line centroid from CS3 (bottom left, closest to readout node)
• CTI measured from differences in CS centroids
• However, parallel CTI evolution in the CCD imaging section causes gain to increase
• Both gain and CTI are temperature dependent (XRT CCDTemp varies from -75 to -50C)
CS3 Gain and CTI

\[ GC_2 = GC_0 \times CTI_p \]

- Time and temperature gain and CTI coefficients are updated in the CALDB ~ 6 monthly
Noise Peak

- Noise peak position (and width) also evolves with time and temperature

- Jamie has recently updated the on-board temperature dependent threshold tables to improve the telemetry rate
CS3 Gain and FWHM

PC W3 CS3 gain

All cols

PC W3 CS3 FWHM

All cols

PC W3 CS3 gain

'Best' 5 cols

PC W3 CS3 FWHM

'Best' 5 cols
XRT Radiation Damage

Cas A spectral degradation 2005 vs 2010

WT mode
Trap Mapping

- XRT CCD does not have the luxury of charge injection to improve spectral response now significant charge traps have formed
- XRT has no internal calibration source which will illuminate the entire CCD to measure the traps
- Largest charge traps in the central regions of the CCD have been identified using Si Kα observed in Cas A and Tycho
- Updated gain CALDB file format and xrtcalcpi s/w to perform charge trap correction
Trap Mapping Observations

**Goal**: map pixels affected by radiation damage, measure the charge losses of individual pixels

- Cas A, Tycho SNR offset pointings to cover (partially) CCD area (~105 ks)
- Use Si line (1.85 keV) as reference energy, fit line to localize traps and measure individual trap depths and global column offsets
Trap localisation

Column DETX = 256 – Tycho 2009

Observed Energy (keV)

Corrected Energy (keV)

1.90
1.85
1.80
1.75
1.70
1.65
1.60
150 200 250 300 350 400 450

DETY

IACHEC ’12, Napa Valley, CA – May 25th - 29th 2012 (Page 12)
Recovered Energy Resolution

- Trap corrections included in CALDB and xrtcalcpi for the last year.
Reconstructed FWHM

Silicon FWHM

- WT observed
- PC observed
- WT corrected
- PC corrected

YEAR

2007 2008 2009 2010 2011 2012
Limitations (1)

- RMF is broadened to match the trap corrected data.
Limitations (2)

RXJ1856 (WT)

• Performance degrading at low E due to events disappearing below the 80DN (~0.225 keV) event threshold
Difficulties

- Energy dependence - higher energies → larger charge cloud which can interact with more traps
  - $E^\beta$ with $\beta \sim 0.8$ (determined in an averaged manner using Tycho & E0102)
- XRT CCD temperature varies from $T \sim -75$ to $-50C$ (typically $-60C$)
  - Dark current fills traps at higher $T$ → temperature dependent trap depths
  - Temperature dependent CTI (seen in corner source data)
- Source flux dependence
  - Sacrificial charge effect
  - No astrophysically bright line source!
LU SRC Camera test facility

• Lab programme on a damaged CCD

Thanks to David Vernon, SRC
Proton damaged CCD

Copy of XRT e2V CCD-22 irradiated with 10 MeV proton beam at Harwell tandem accelerator facility

Dose of $2.5 \times 10^8$ 10 MeV protons

Dose of $5 \times 10^8$ 10 MeV protons
Lab data

High statistics datasets at selected energies and CCD operating temperatures:

- **ENERGY**: Oxygen (0.5 keV), Copper (0.9 keV), Aluminium (1.2 keV), Silicon (1.8 keV), Titanium (4.5 keV) and Iron (6.4 keV)

- **TEMPERATURE**: Camera cooled at set of temperatures comparable to Swift/XRT operational range (Ti and Si):
  \[
  \text{CCD}_T = [-100, -75, -70, -65, -60, -55, -50^\circ C]
  \]

- CCD uniformly illuminated, 10k frames at each setting, flux of ~ 600 single pixel X-rays/frame.
Deep trap temperature dependence

- At -70°C no "step" in profile is seen, but gradual "recovery"
- Lower temperatures (-100°C) needed to see the step.
Lab data – Temp dependence

A) Break

B) Turnover

C) Flatter
Lab data – energy dependence

Increasing depth vs energy

- Aim to use the average energy and temperature dependences in the gain correction
CCD22 Simulator MkII

• Rewrite of our CCD22 simulator (in C++)

• Aims
  – to get back to a single code base for both PC and WT mode (without the need for ad-hoc corrections)
  – Improve WT redistribution modelling
  – Explore WT mode powerspectrum properties
  – Study effects of pile-up

• Full details in working group talk
• CCD simulator model
  – Detailed electrode structure (allowing different depletion depths under the open/closed part of the electrode)
  – Interactions in the depletion, field-free and substrate regions
  – Correct charge-cloud spreading
  – Readout appropriate to either PC or WT mode
  – Event grading (as per ground s/w)
Initial results

- Current CALDB WT RMF
Initial results

- test WT RMF