Swift/XRT radiation damage and results from the lab using a proton-damaged CCD

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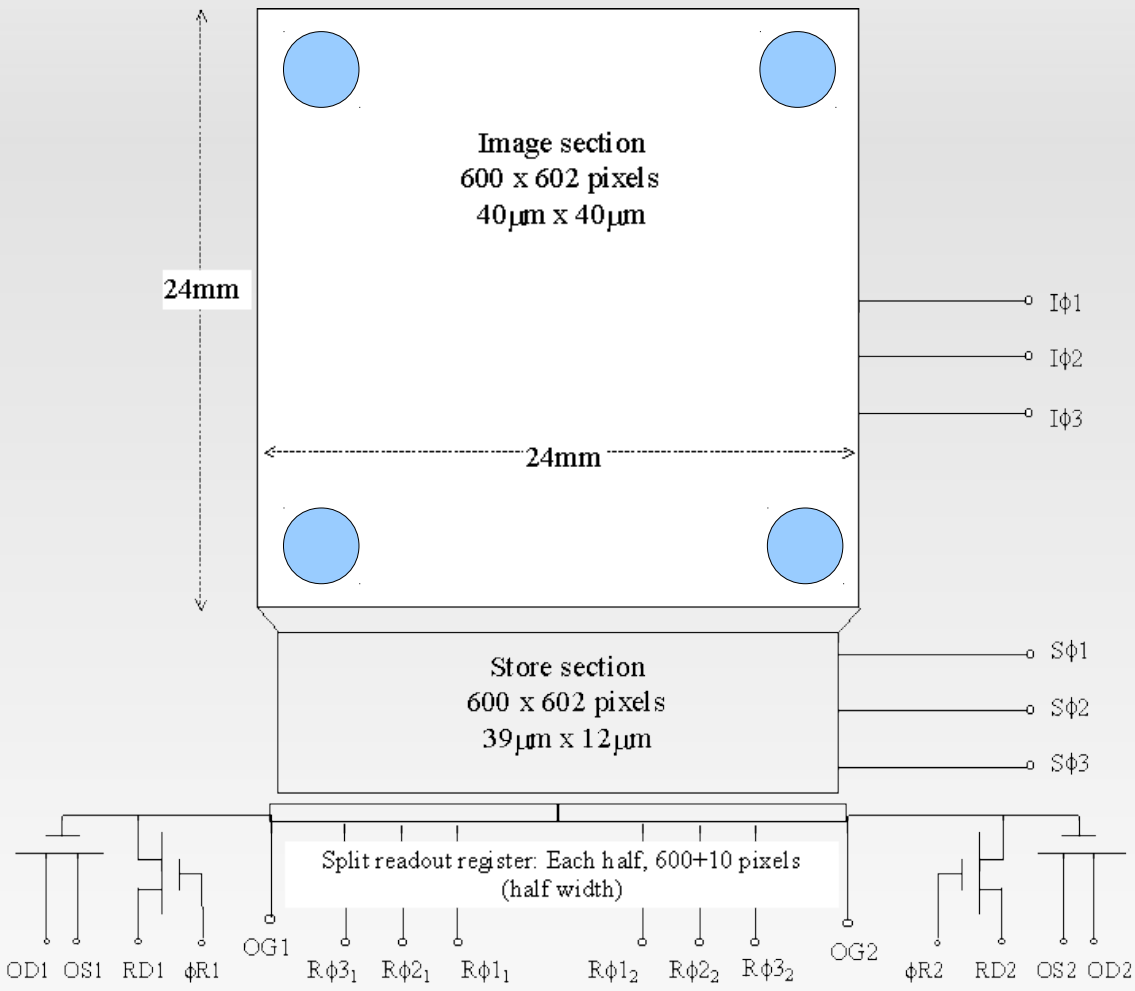
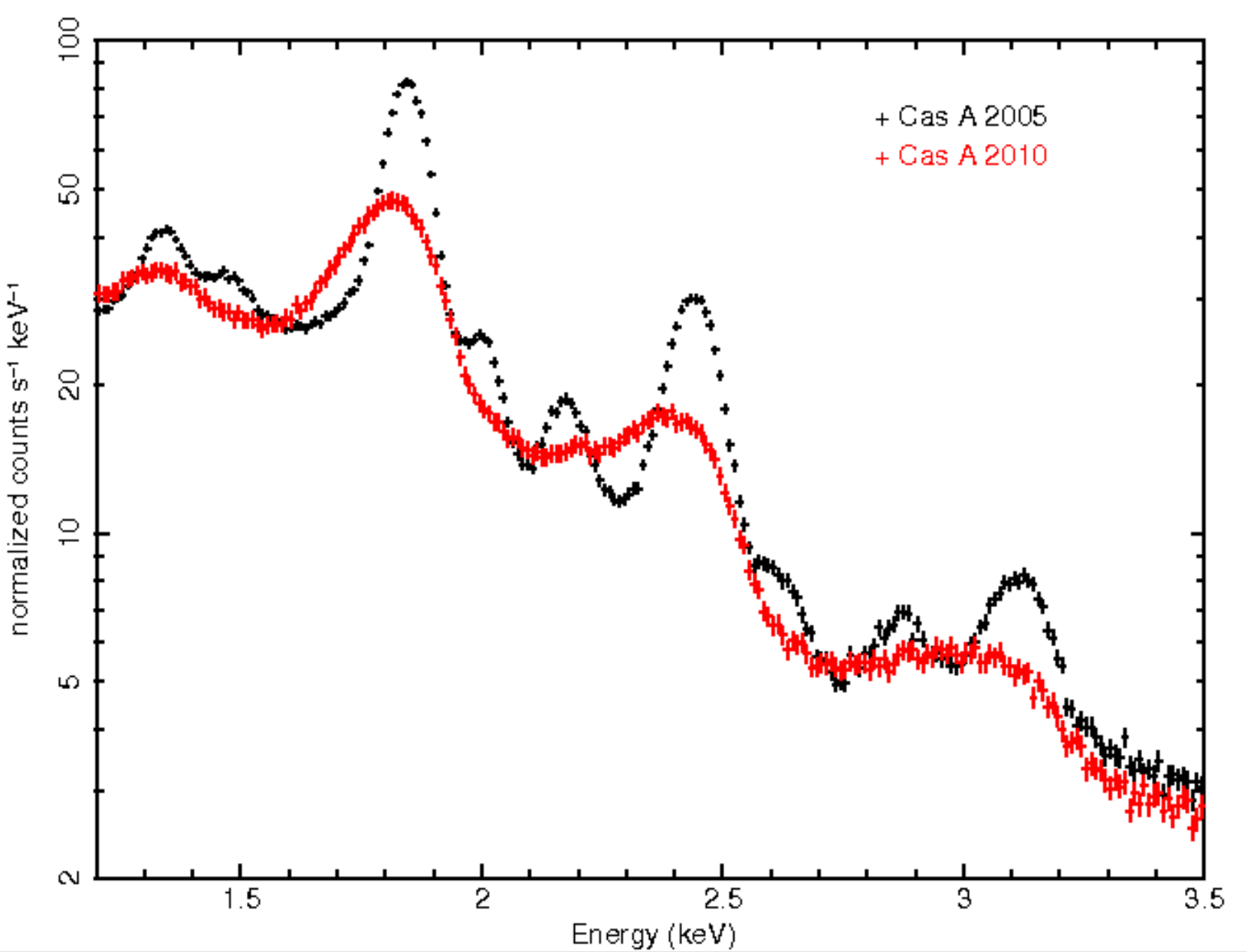
XMM Calibration Meeting, Leicester, 7/3/2012

XRT CCD



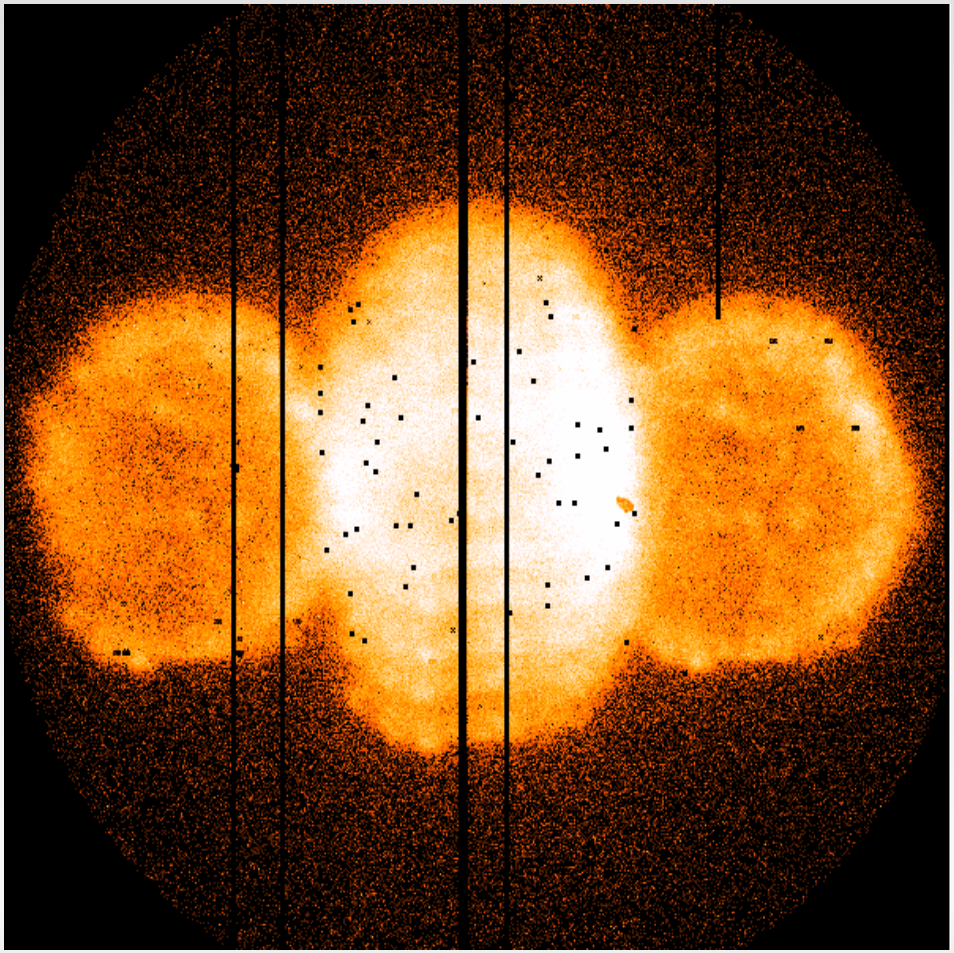
- e2v CCD-22 detector (developed for EPIC MOS camera on XMM)
- Operated in Photon Counting (PC) and Windowed Timing (WT) mode
- 4 ^{55}Fe corner sources continuously illuminate CCD corners, used to monitor CCD performance
- Spectral resolution at launch: FWHM = 135 eV at Mn K-α (5.9 keV)
- *Swift* in Low-Earth orbit, exposed to high flux of protons (South Atlantic Anomaly)

XRT Radiation Damage



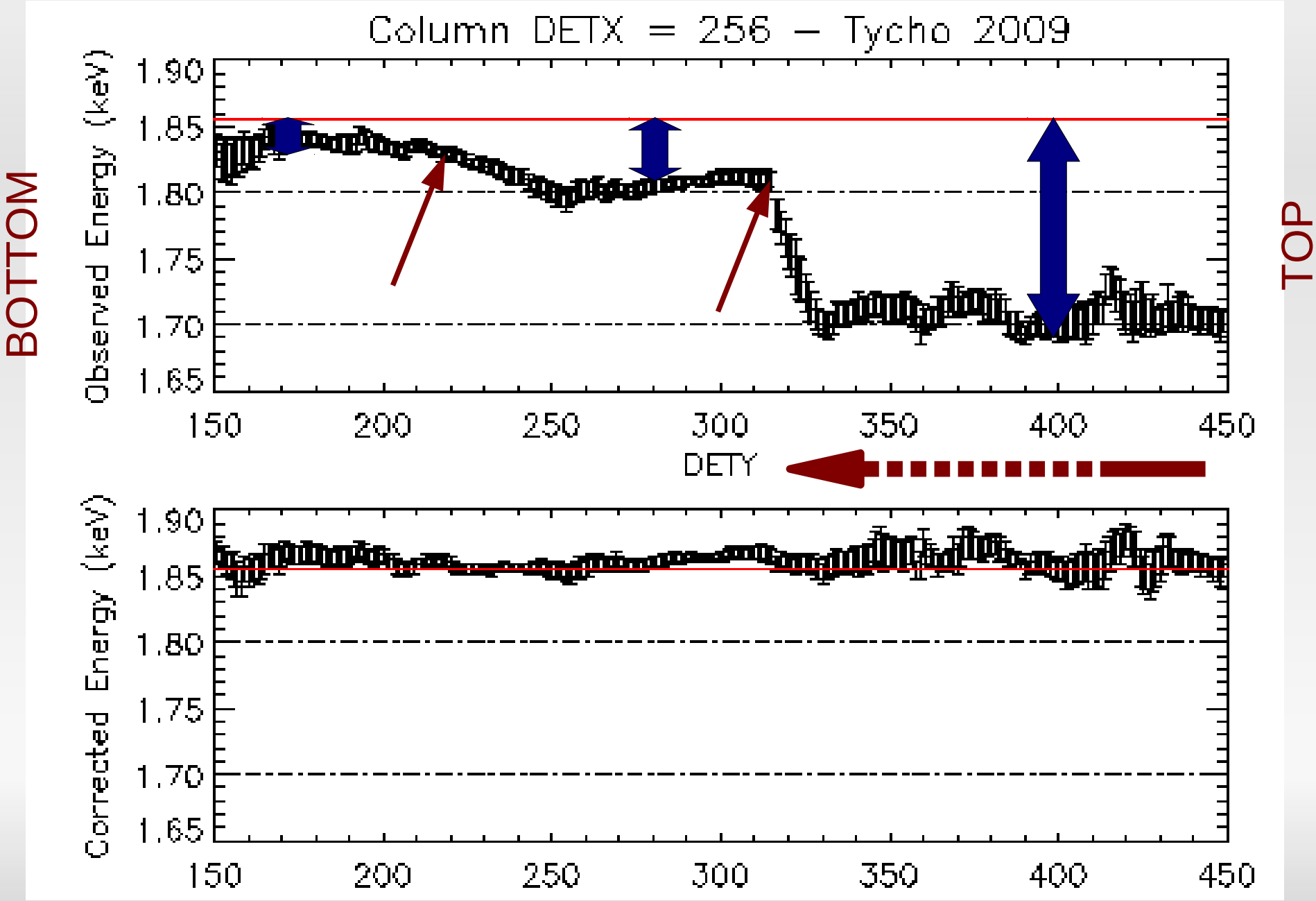
XRT Trap mapping

Trap mapping: map pixels affected by radiation damage, measure the charge losses of individual pixels

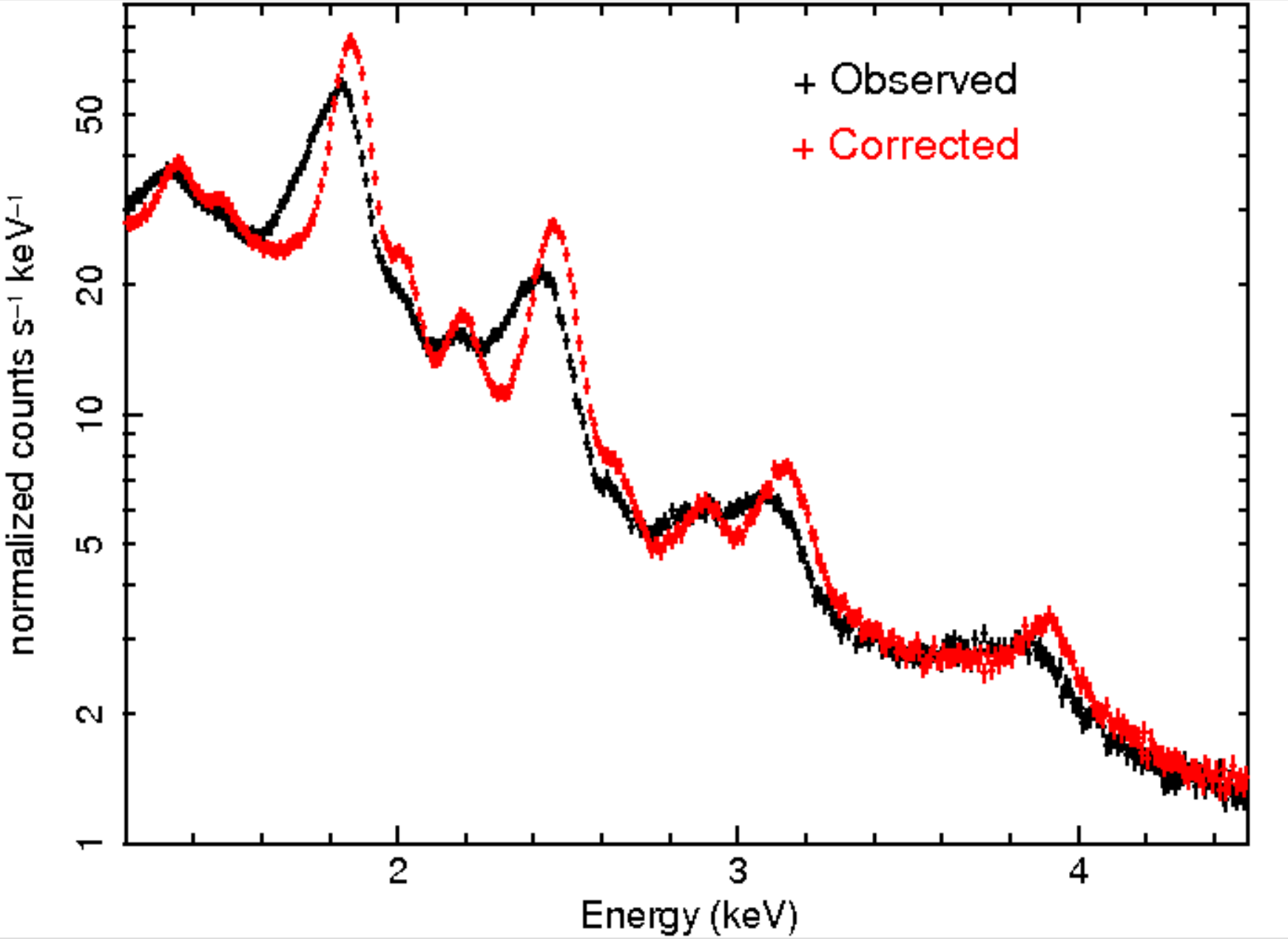


- Cas A, Tycho SNR offset pointings to cover (partially) CCD area
- Silicon line (1.85 keV) as reference energy, fit line to localize traps and measure trap depths

Trap localization



Recovered energy resolution



Trap depths = f(T)

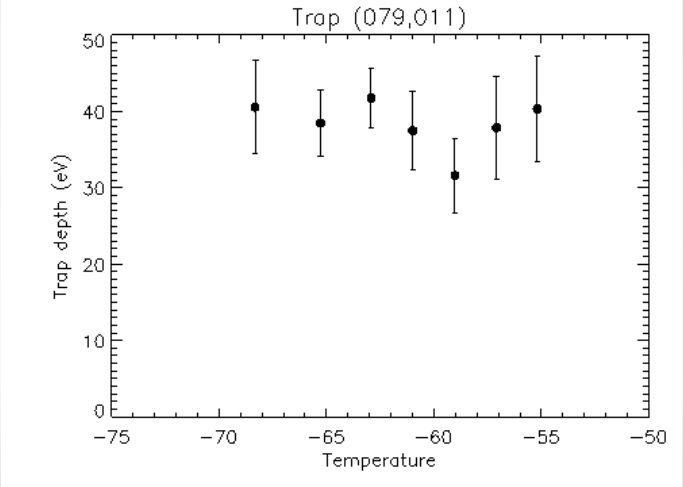
- *Temperature*

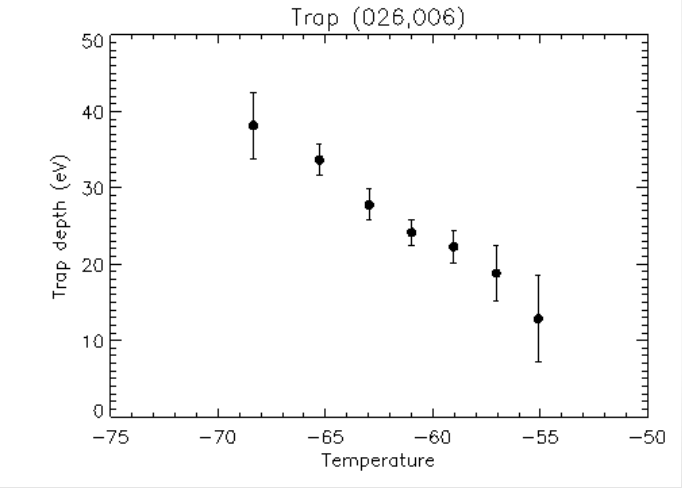
  XRT CCD relies on passive cooling after TEC failure, operating between -75 and -50C

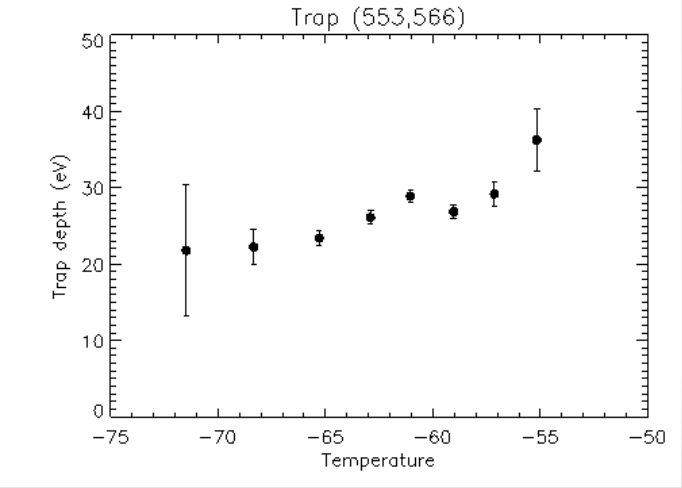
  Dark current, shorter emission line fills traps at higher T

  Average CTI is measured to be temperature-dependent

  Temperature dependence seen in calibration corner sources analysis







Trap depths = f(E,Flux)

- *Energy dependence*

  Larger charge cloud will interact with more traps

  Averaged energy dependence measured using emission lines in Tycho, E0102, but lines too weak to measure it for each damaged pixel

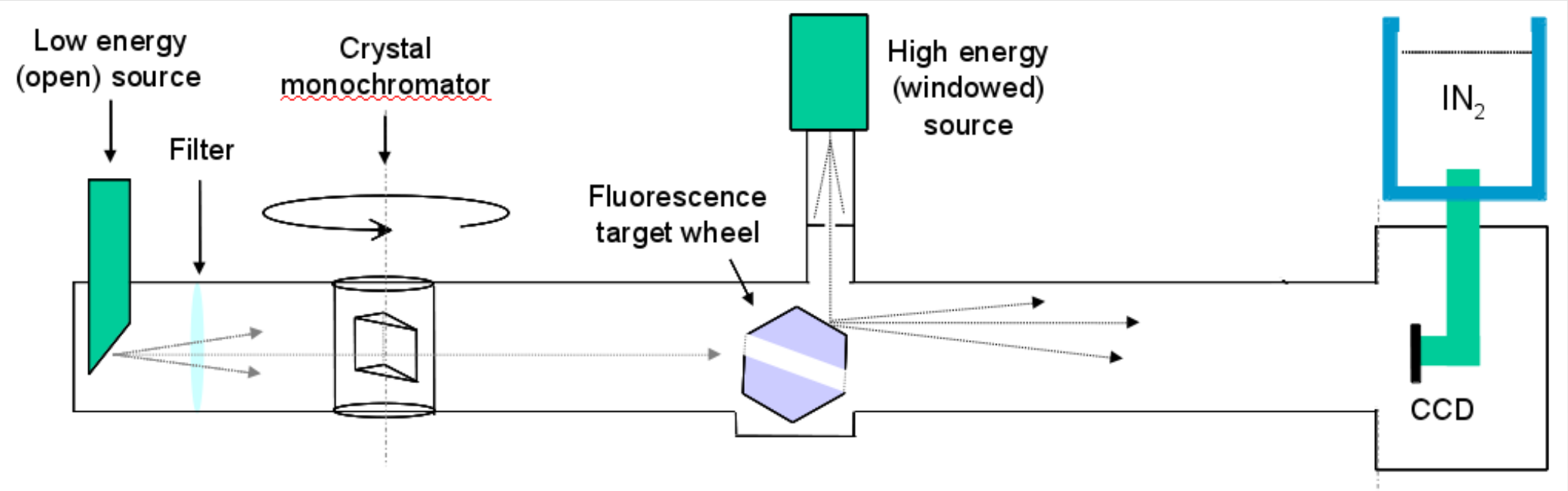
- *Source flux dependence*

  “Sacrificial” charge effect

  No bright source with emission lines to test the effect on-board the XRT

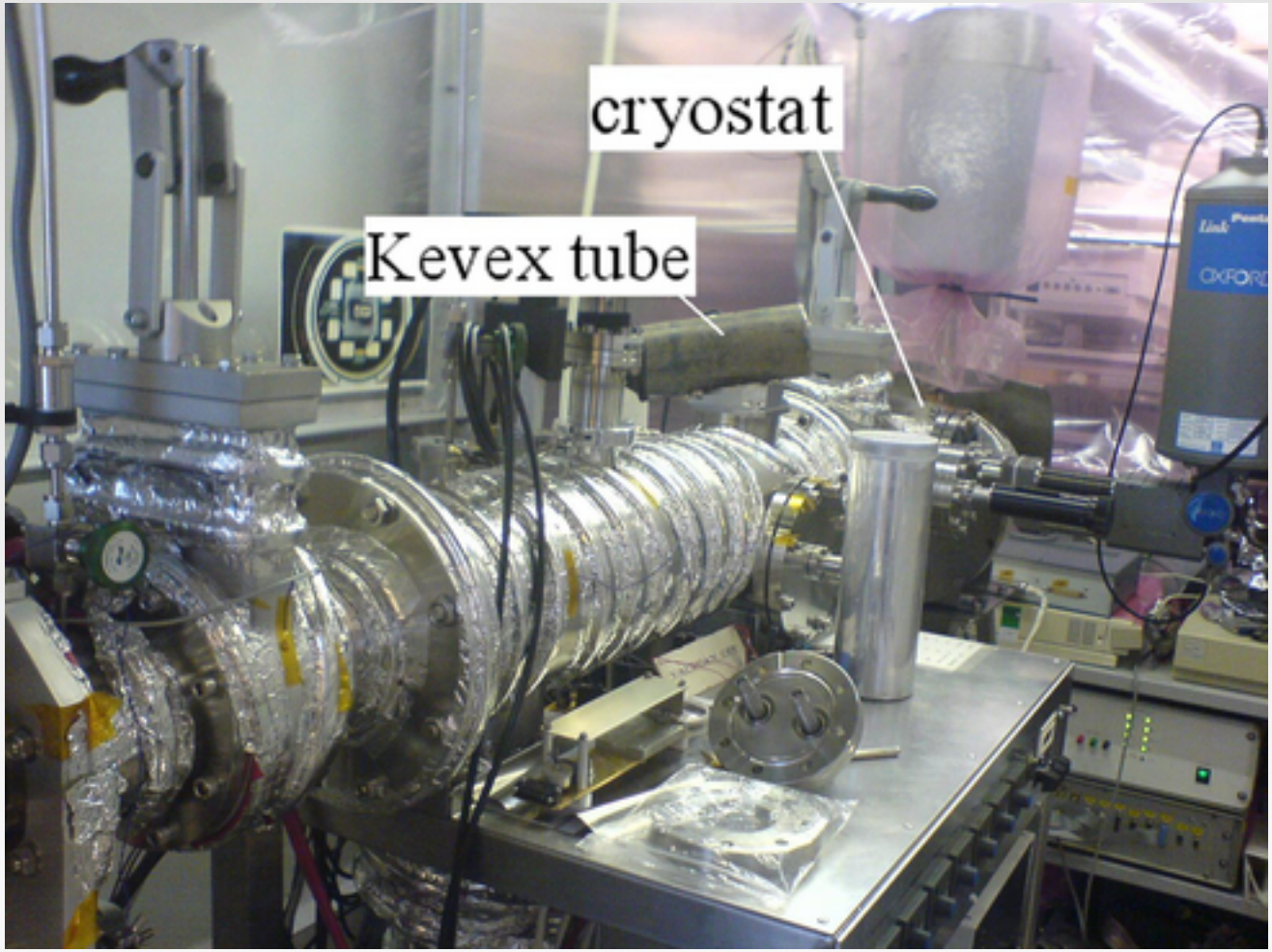
Laboratory experiment

- Experimental set-up



SRC camera test facility

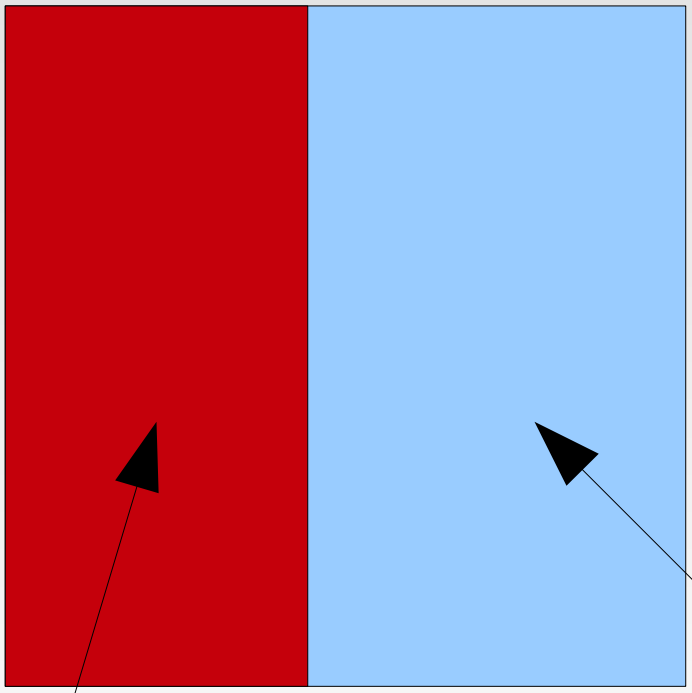
Space Research Centre camera test facility



Thanks to *David Vernon, SRC*

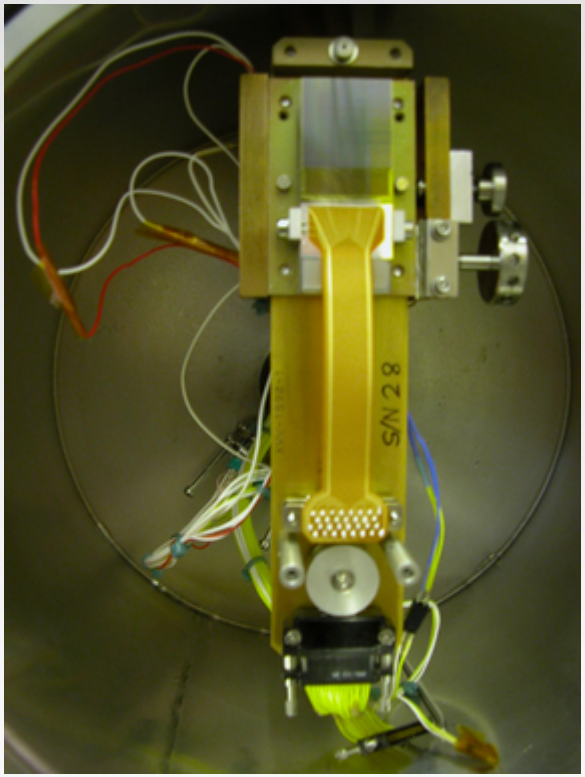
Proton-damaged CCD

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



Dose of $5x10^8$ 10 MeV protons

Dose of $2.5x10^8$ 10 MeV protons



Laboratory datasets

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)

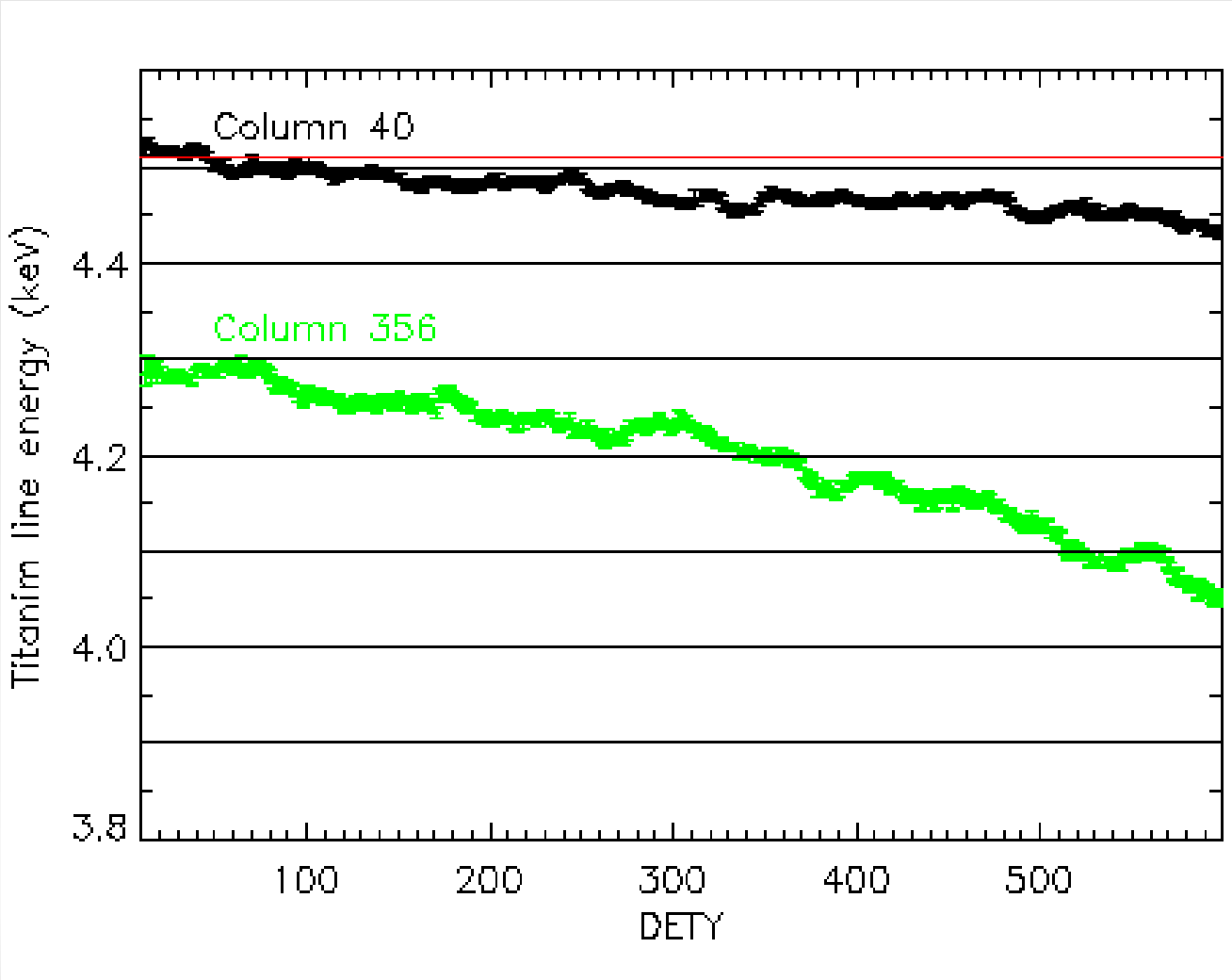
- **TEMPERATURE**: Camera cooled at set of temperatures comparable to *Swift*/XRT operational range (Ti and Si):

  CCD_T = [-100, -75, -70, -65, -60, -55, -50C]

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

Laboratory results - CTI

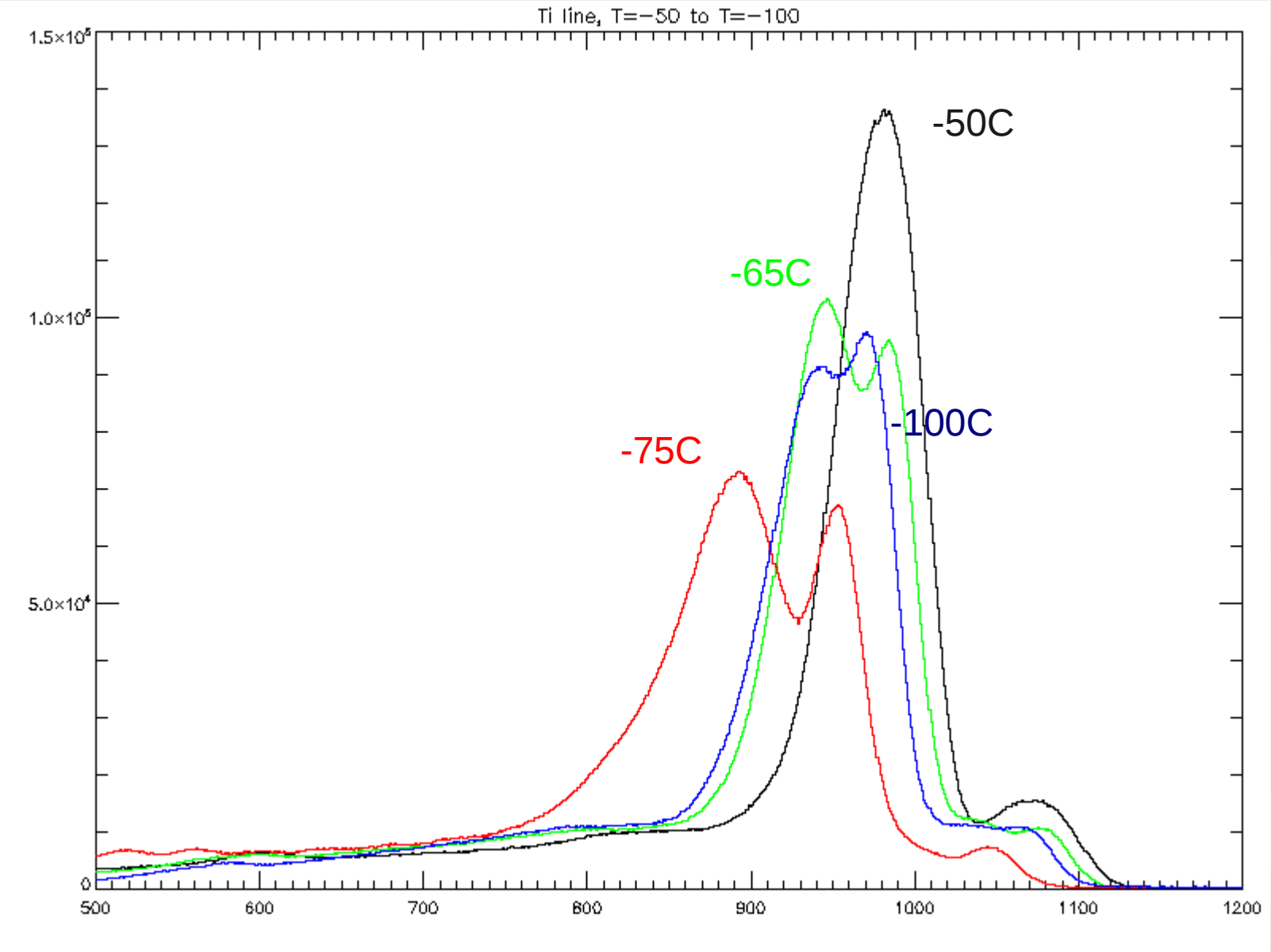
Columns with no large traps



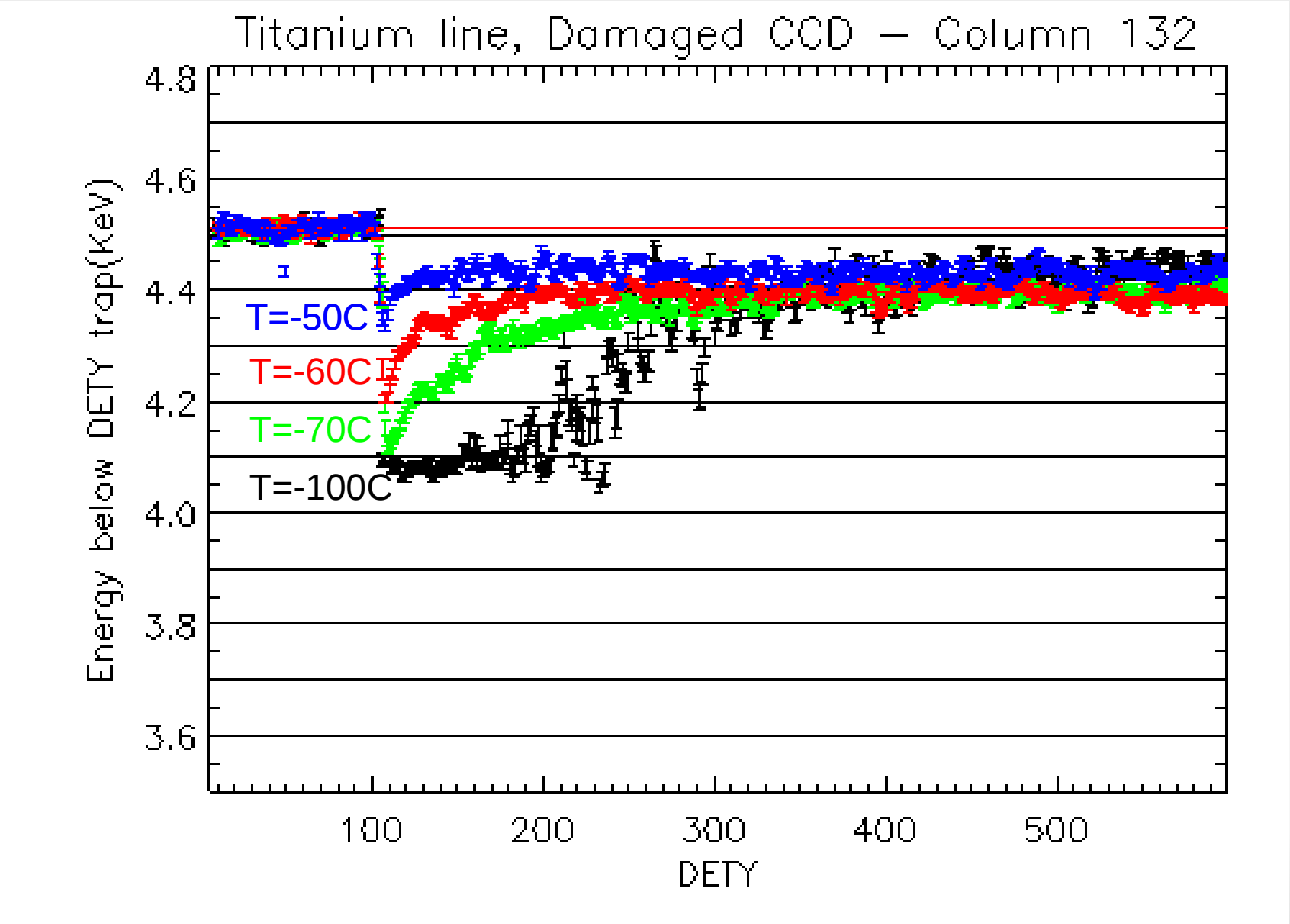
Double radiation dose:

Shifted in energy
Higher noise
Higher CTI

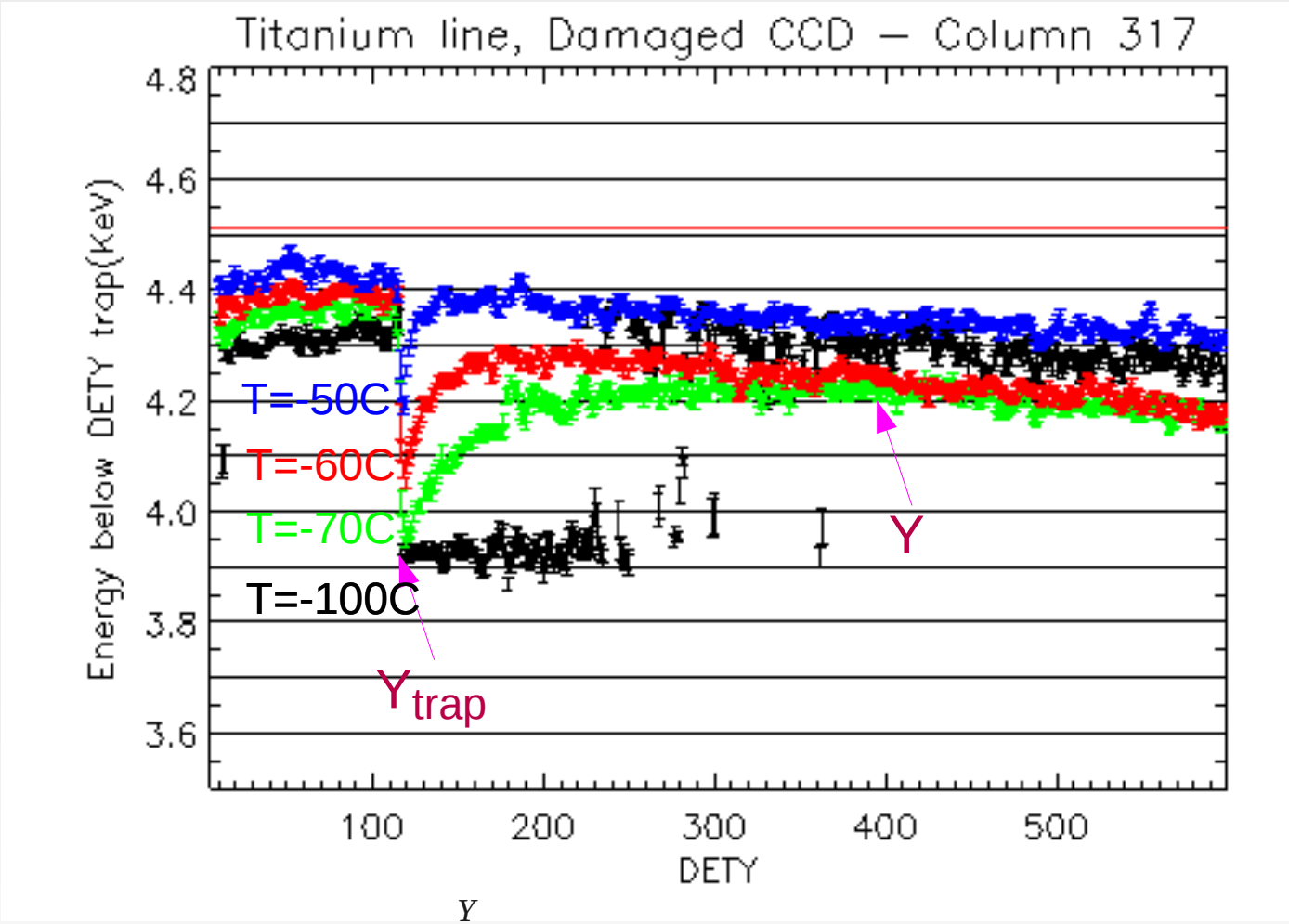
Laboratory results - Temperature



Laboratory results - Temperature



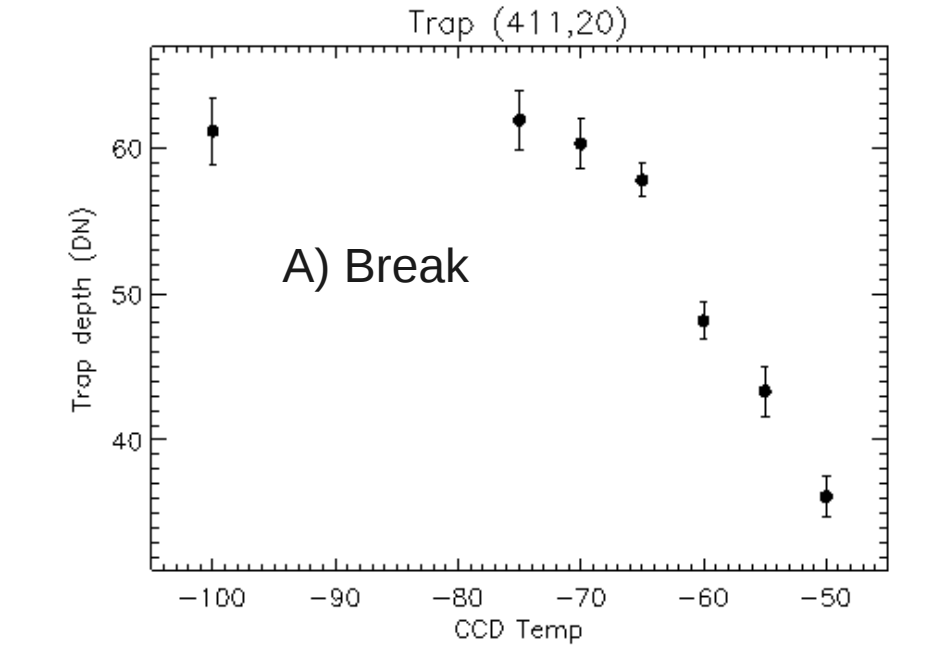
Laboratory results - Temperature

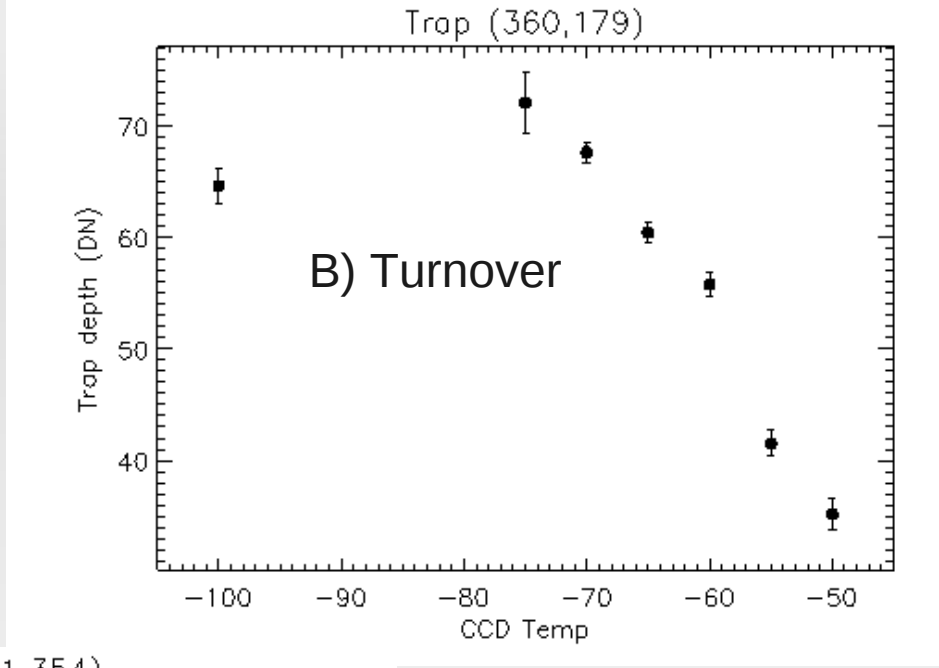


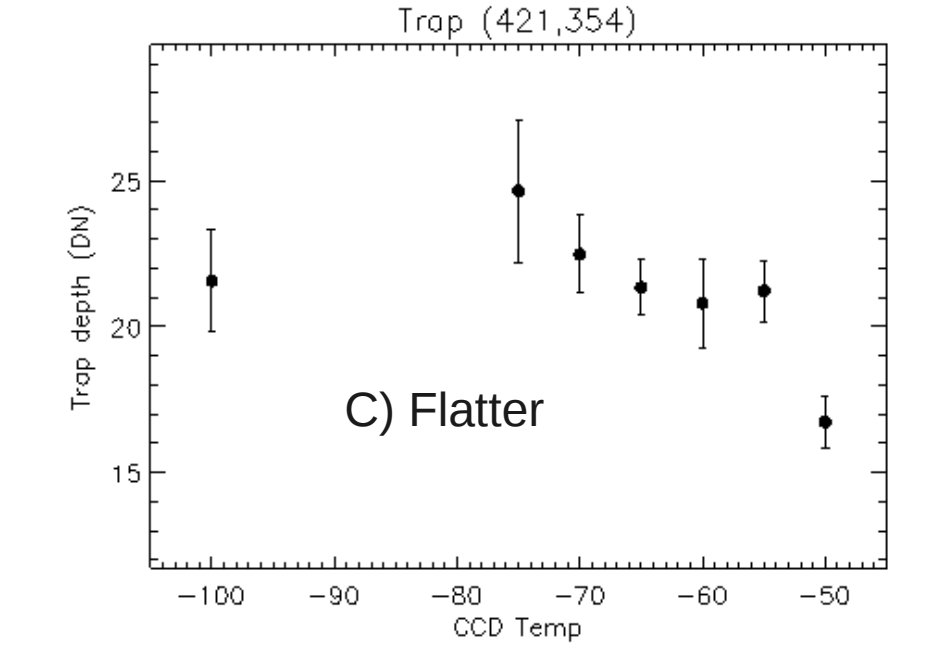
$$Trap(Y)=\gamma_{trapped}(Y)-\gamma_{emitted}(Y)+\sum_{Y_{trap}}^{Y}[(E_{trapped}(y)-E_{emitted}(y))+(\gamma_{trapped}(y)-\gamma_{emitted}(y))]$$

$E_{emitted}$ is a function of the emission time constant, depends on CCD temperature

Laboratory results - Temperature

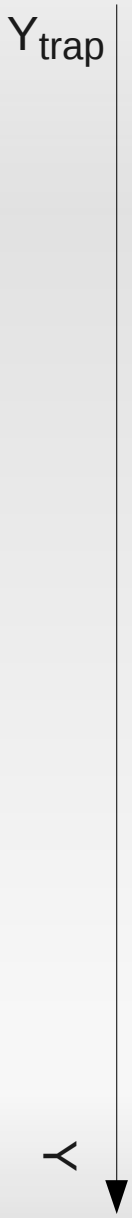


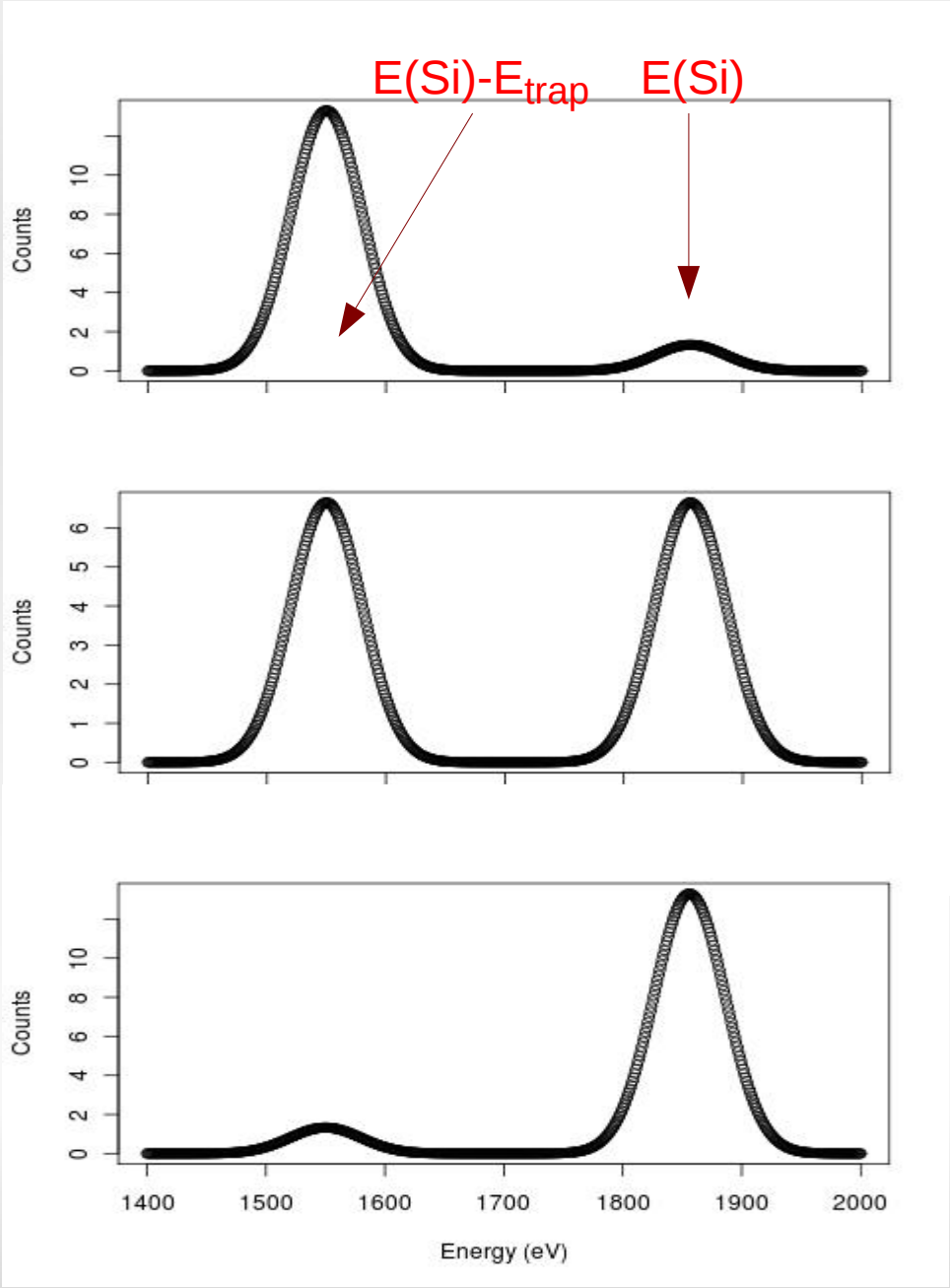




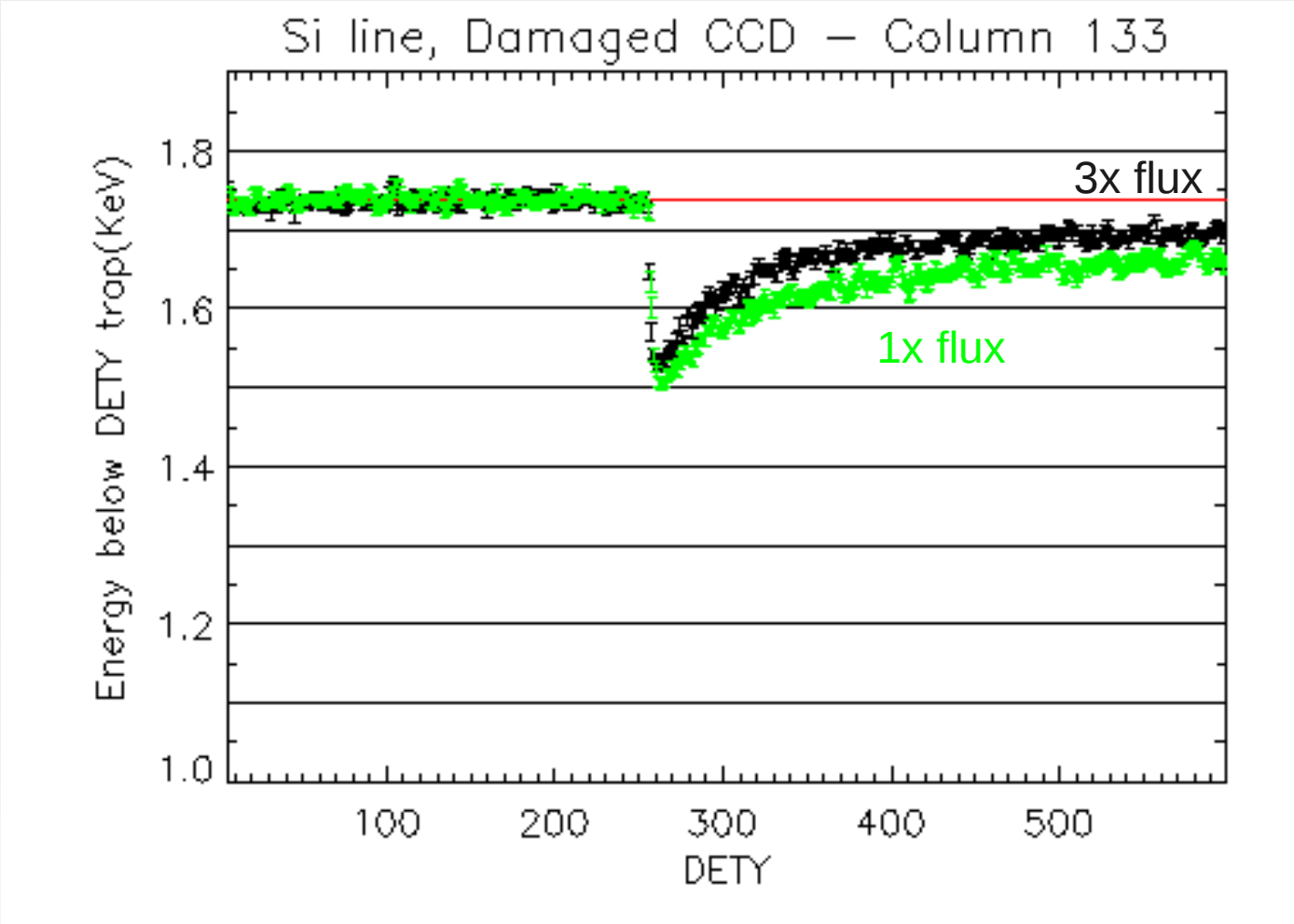
Lab results – Sacrificial charge

- Dataset with 3x flux
  - X-rays between trap position and measured X-ray event could fill the trap





Lab results – Sacrificial charge

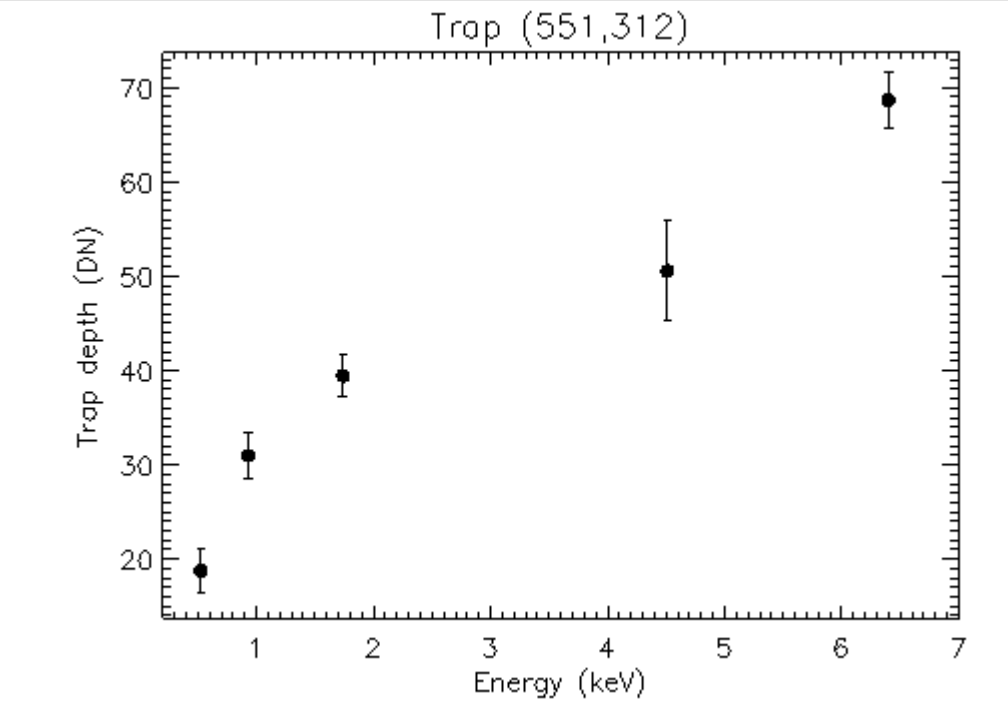


At -75C no “step” in energy profile is seen, but gradual energy “recovery”, $t_{emission}(T=-75)<t_{readout}$

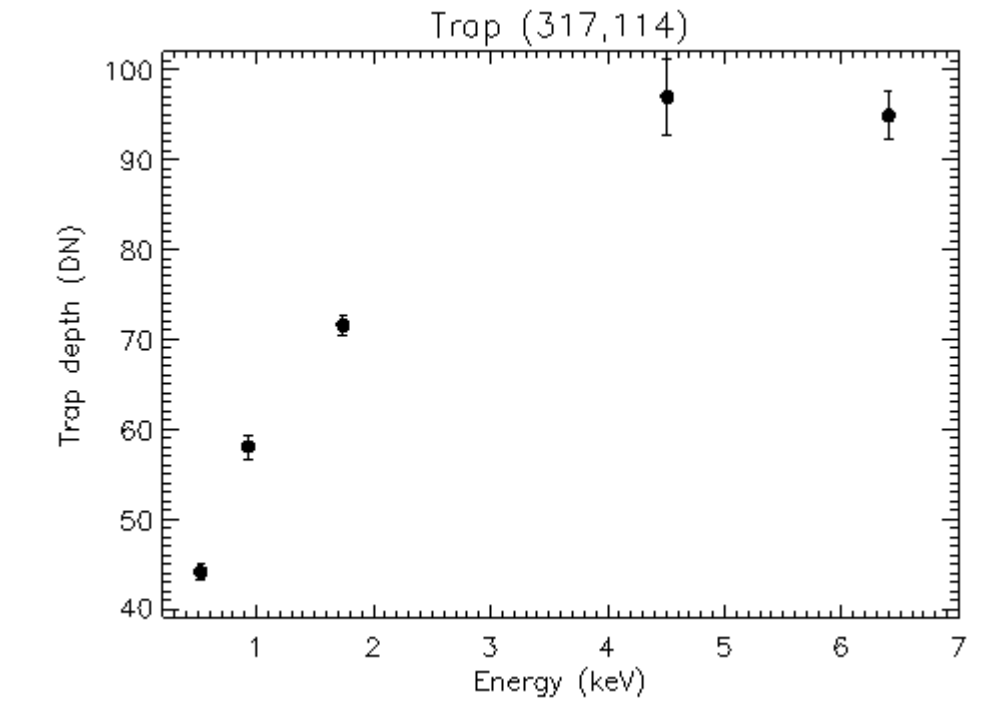
Lower temperatures (-100C) needed to see the step.

Laboratory results - Energy

Increasing depth vs energy



Saturation effect



Different behaviour of trap depths on energy is an indication of different trap properties (i.e., size of defects in pixels).

Work and analysis in progress

Laboratory

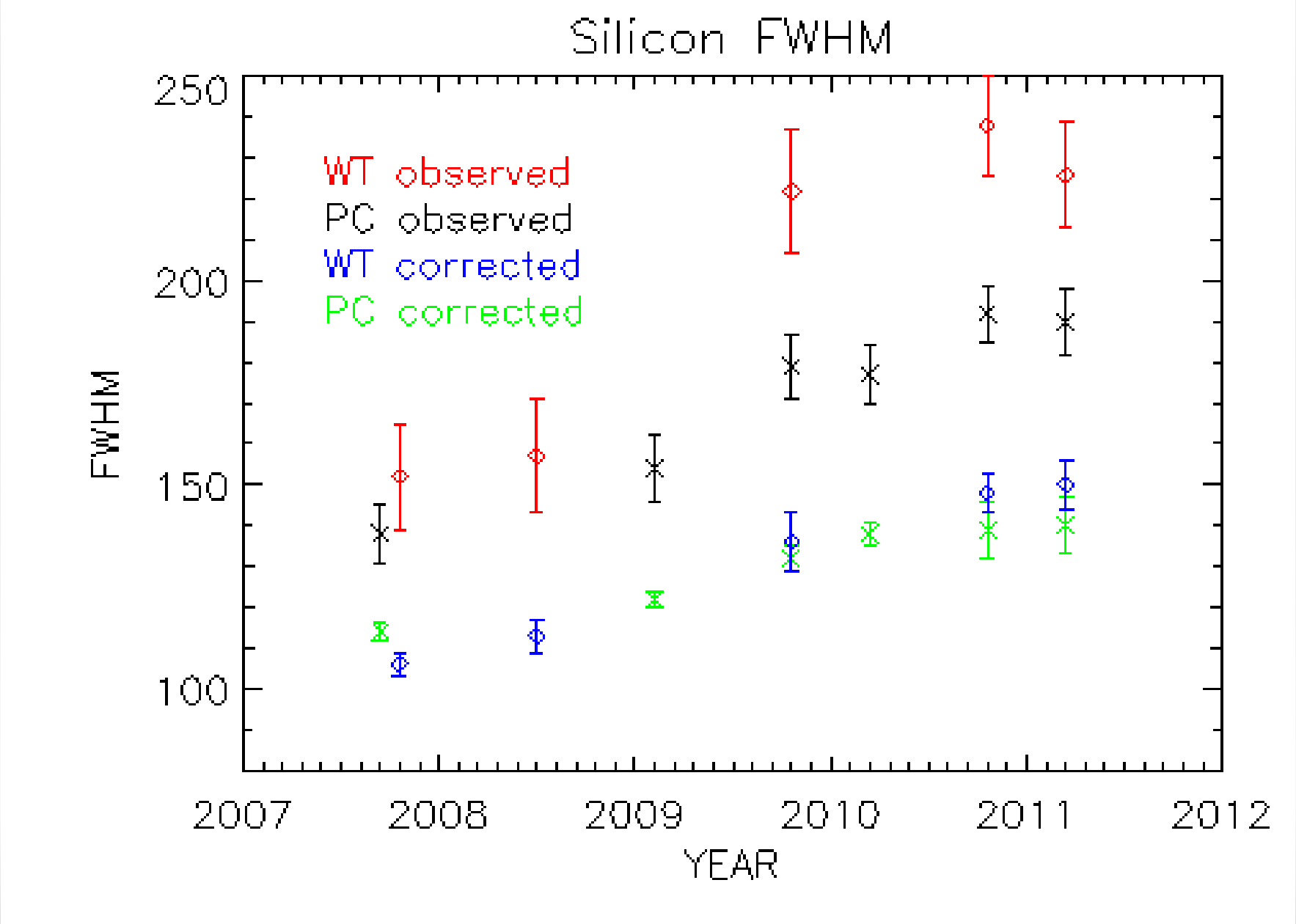
- Dataset at high flux at T=-100C to investigate ”sacrificial charge” effect
- Complete analysis, and introduce classification of traps based on their observed properties

Secondary neutrons

- Possible XRT damage by secondary neutrons
- Model secondary emission, if significant possibility of irradiation of CCD with neutron beam

Details of XRT trap mapping analysis in Pagani et al. 2011, A&A

Backup slides



Backup Trap properties

Readout time

- XRT Windowed Timing mode observations: higher timing resolution (1.8 ms) at the expense of limited spatial information
- Use of trap info from Photon Counting mode observations does not provide the desired energy correction; also, a single scaling factor for the trap depths did not work
- Differences between modes show influence of readout times on XRT CCD traps and hints at different trap species

CTI = f(T, E, flux)

- Choong-Ki Kim CTI equation

Source flux

Readout time

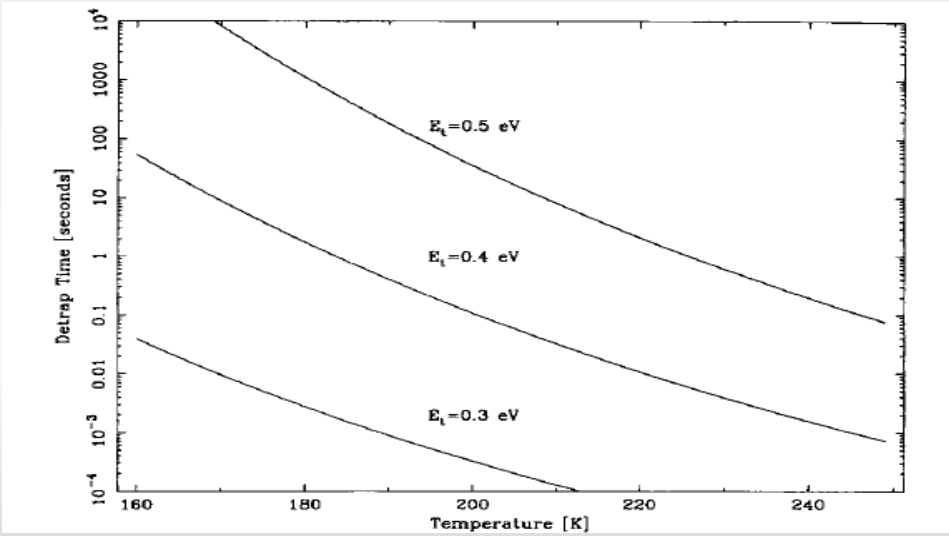
$$CTI = N_T V_V \exp\left(-\frac{t_{PT}}{3\tau_e}\right)\left[1-\exp\left(-\frac{t_{PT}}{3\tau_e}-\frac{N_Z t_{PT}}{3\tau_e}\right)\right]$$

Energy

CCD Temperature

- Emission time constant

$$\tau_e = \frac{\exp[E_T/(kT)]}{\sigma_n v_{th} N_C}$$



Radiation Damage

- *Swift* in Low-Earth orbit, exposed to high flux of protons (South Atlantic Anomaly)
- Effects of displacement damage seen in the XRT CCD:
  - *hot pixels*
  - *increased dark current*
  - *charge trapping sites*
- Initial strategy to deal with with decreased resolution: broadened RMFs for different epochs
- Trap energy corrections in gain files (Sept 2007-now)