CTI Correction on a Backside-illuminated CCD (S3): How and Why

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- The PSU CTI corrector was first developed to account for the CTI in the backside-illuminated (BI) ACIS CCDs.
- This CTI is modest compared to the radiation-induced CTI present in the frontside-illuminated (FI) chips; it comes about as part of the manufacturing process, so it was known to exist well before launch.
- Thus we developed a preliminary phenomenological model for this BI CTI, including both parallel and serial components, that was to form the basis for the FI CTI corrector that became necessary after launch.
- Here we review the details of the BI corrector and show why correcting BI data is worthwhile.

CORRECTING FOR CTI

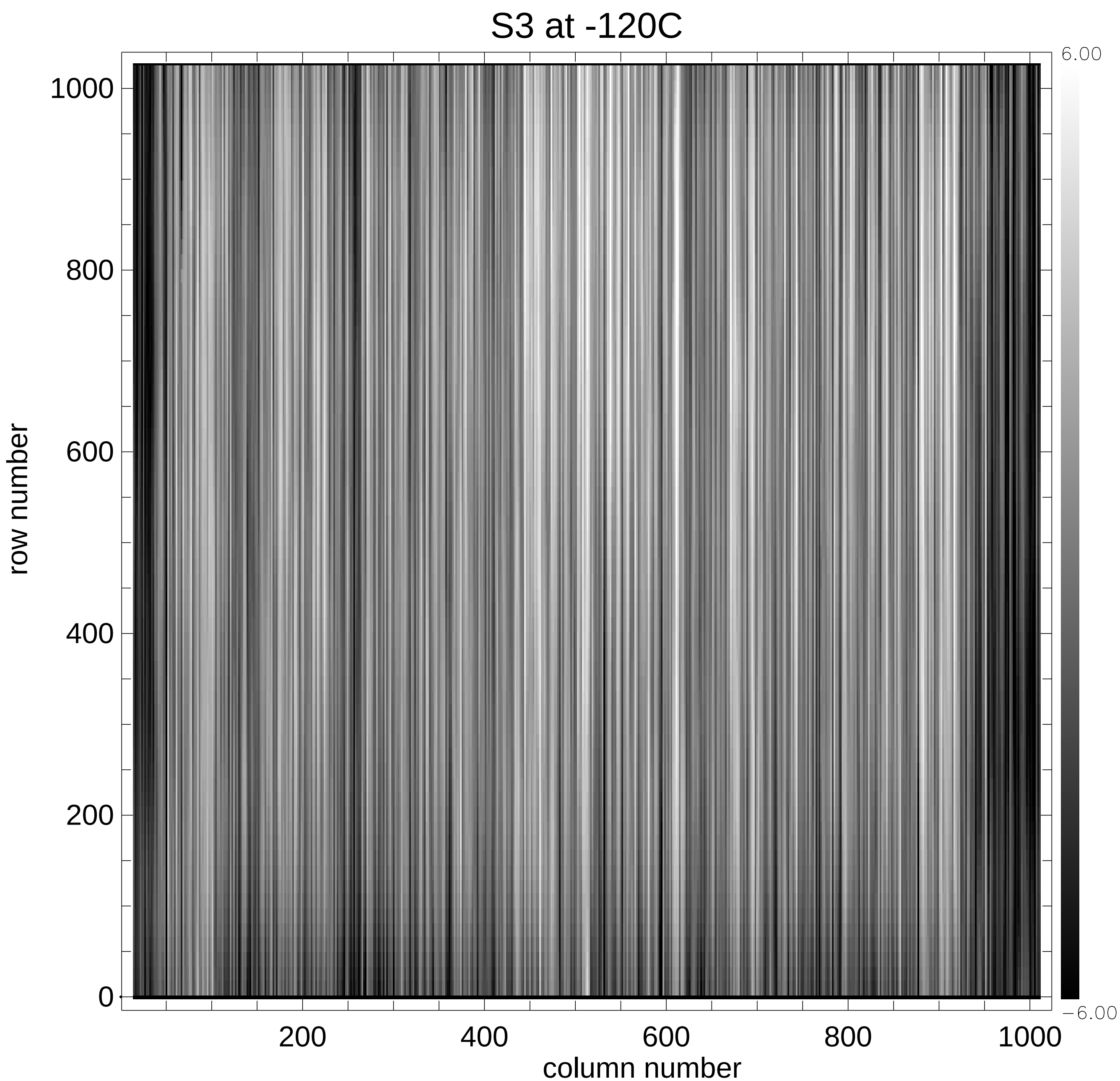
We use a forward-modeling approach:

- Hypothesize “clean” event C (a 3x3 pixel island)
- Pass it through CTI model to create “model” event M
- Compare M to the observed event O
- Iterate: $C_{new} = C_{old} + (O - M)$
- Convergence is $O - M < 0.1$DN
- Upon convergence, C returned as CTI-corrected event

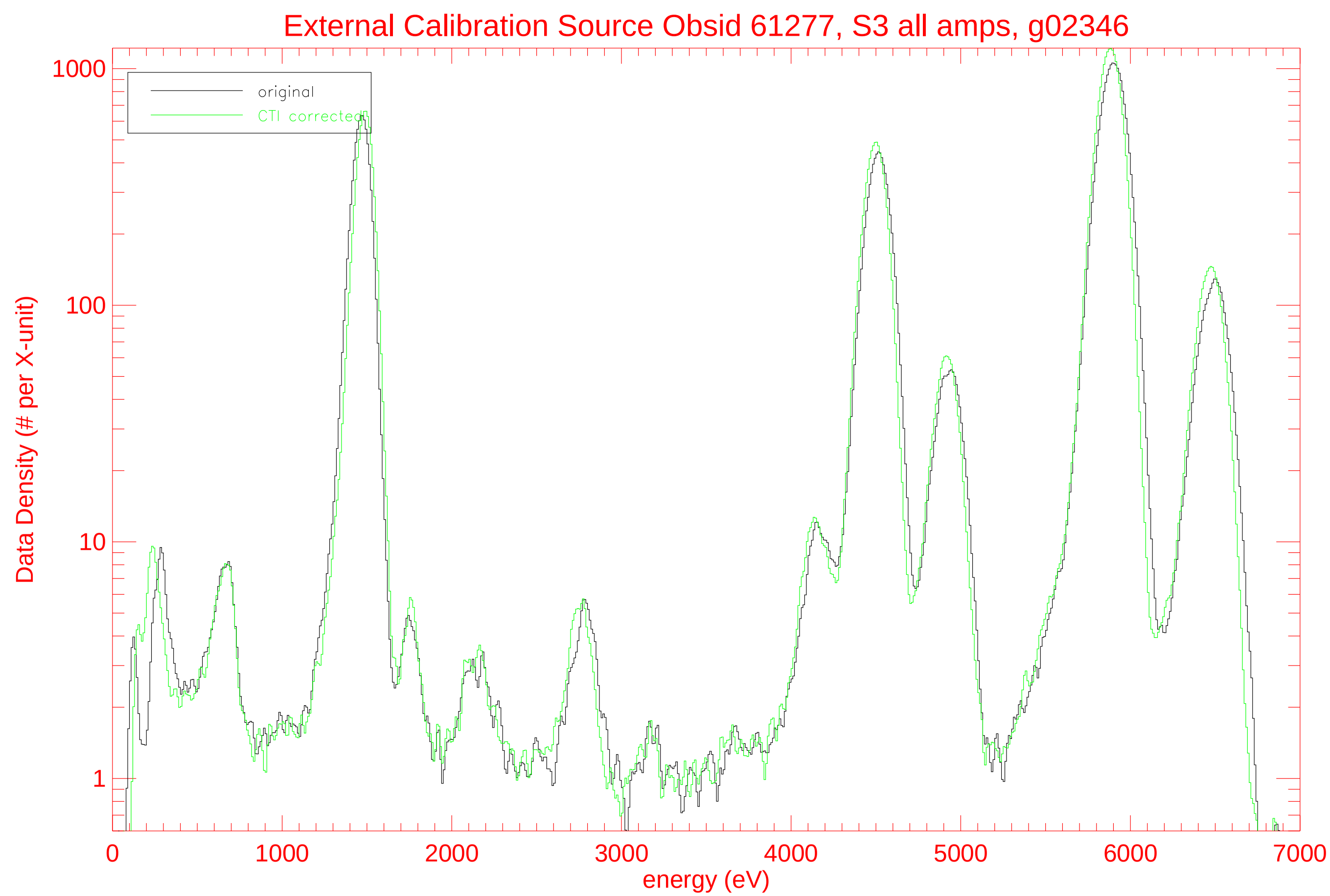
- Corrector input: Level 1 event list
- Corrector output: Modified Level 1 event list
- Tuned for full-frame data (frametime = 3.24 sec)
- Sub-array and CC-mode have different CTI manifestations

The BI Corrector

- Serial and parallel charge loss and trailing are separately parameterized
- Column-wise deviation map improves spectral resolution:
- CTI time-dependence measured by C. Grant was included in model in May 2002
- Details in Townsley et al. 2002, NIM-A 486, 751



S3 at -120C
row number
column number
0
200
400
600
800
1000
6.00
−6.00


External Calibration Source Obsid 61277, S3 all amps, g02346
original
CTI corrected
Data Density (# per X-unit)
1000
100
10
1
0
1000
2000
3000
4000
5000
6000
7000
energy (eV)

THE PSU MONTE CARLO CCD SIMULATOR

- Based on David Lumb's code (Leicester University)
- Incorporates many advances made by MIT (via papers by Prigozhin, Bautz)
- Incorporates new solution to diffusion equation in field-free regions (Pavlov & Nousek 1999) and a channel stop model
- Optionally includes PSU CTI model (/on, /off, or /on + /correct)
- Models row-dependent FI spectral resolution

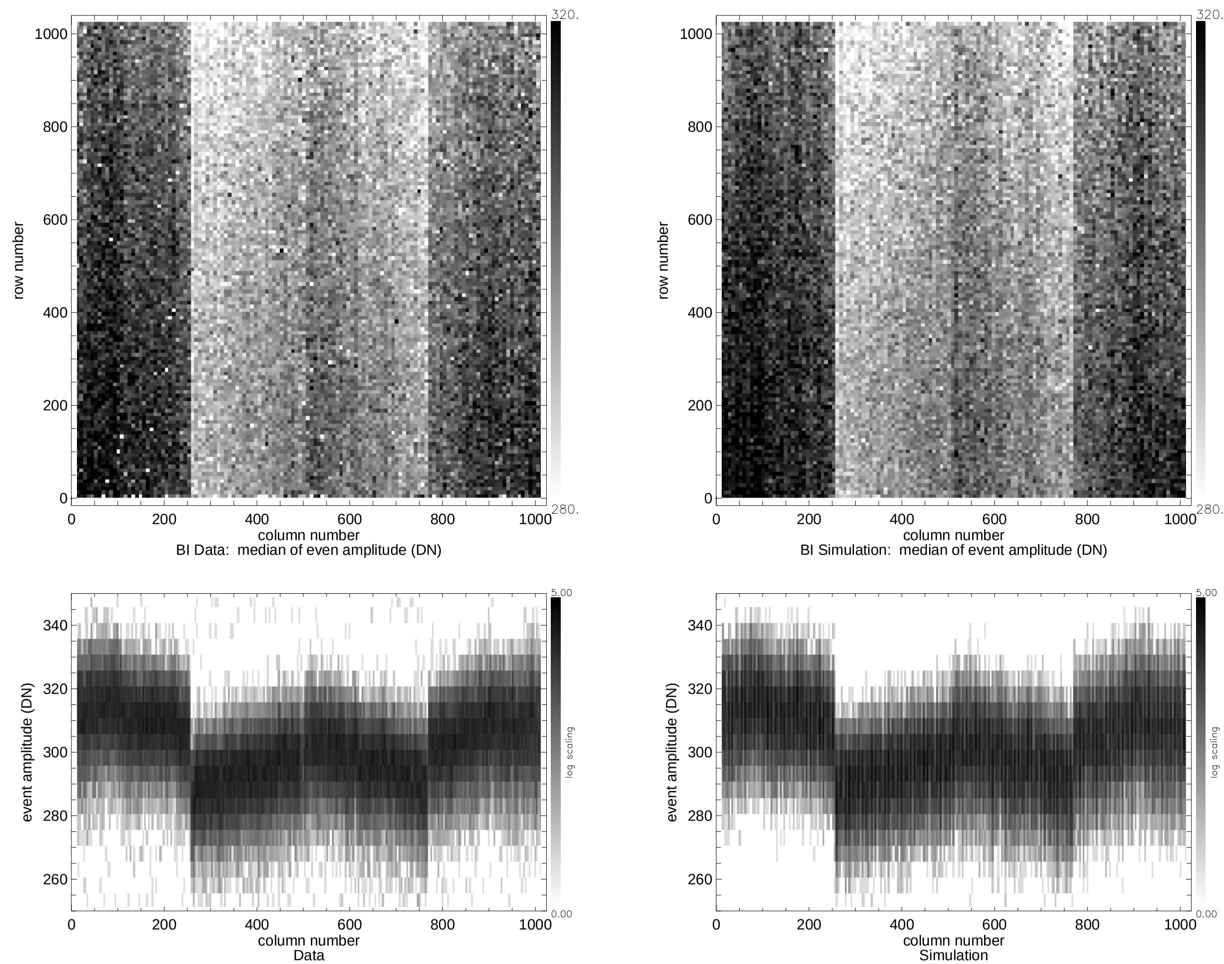


Figure 1: Data (left) and simulation (right) of Al on the BI device S3 at −120C. Top: Median images of Al line in units of DN, binsize 8 × 8 pixels. Bottom: Al line in units of DN, as a function of column number. All 4 amplifiers are shown.

RMF GENERATION

- Generate simulated events, CTI turned on
- Discard grades rejected on-orbit
- CTI-correct remaining events
- Write a standard FITS event list
- Currently generating 10^6 events per energy
- Currently using 430 energies:
  - 0.2 – 2.0 keV with 10 eV spacing
  - 2.0 – 4.0 keV with 20 eV spacing
  - 4.0 – 9.96 keV with 40 eV spacing
- Takes about 1100 CPU hours, 16 GB per device/temp
- The monochromatic event lists are samples of the CCD spectral redistributi on function
- They are directly instantiated as rows of the matrix

- They can be filtered as required
- Gains at -110C match -120C so datasets can be combined

The CTI-corrected BI RMF

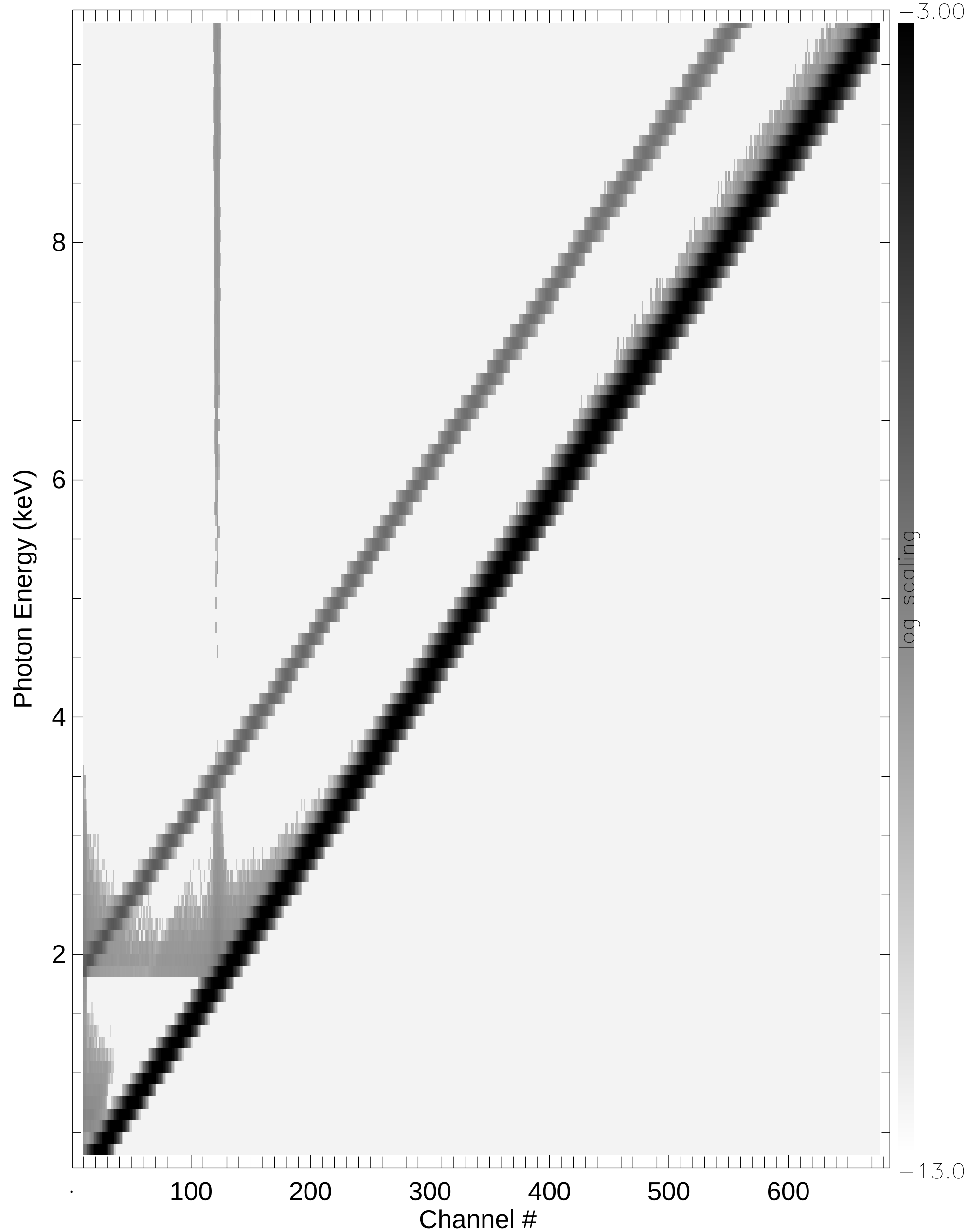
- A single RMF describes the entire S3 chip
- Gain constructed such that -110C and -120C data use same RMF; this allows data from both epochs to be combined and analyzed together
- Details in Townsley et al. 2002, NIM-A 486, 716

We illustrate the BI corrector performance with an observation of Cas A, a diffuse source with strong lines that covers much of the S3 chip. Such targets will benefit the most from BI CTI correction.

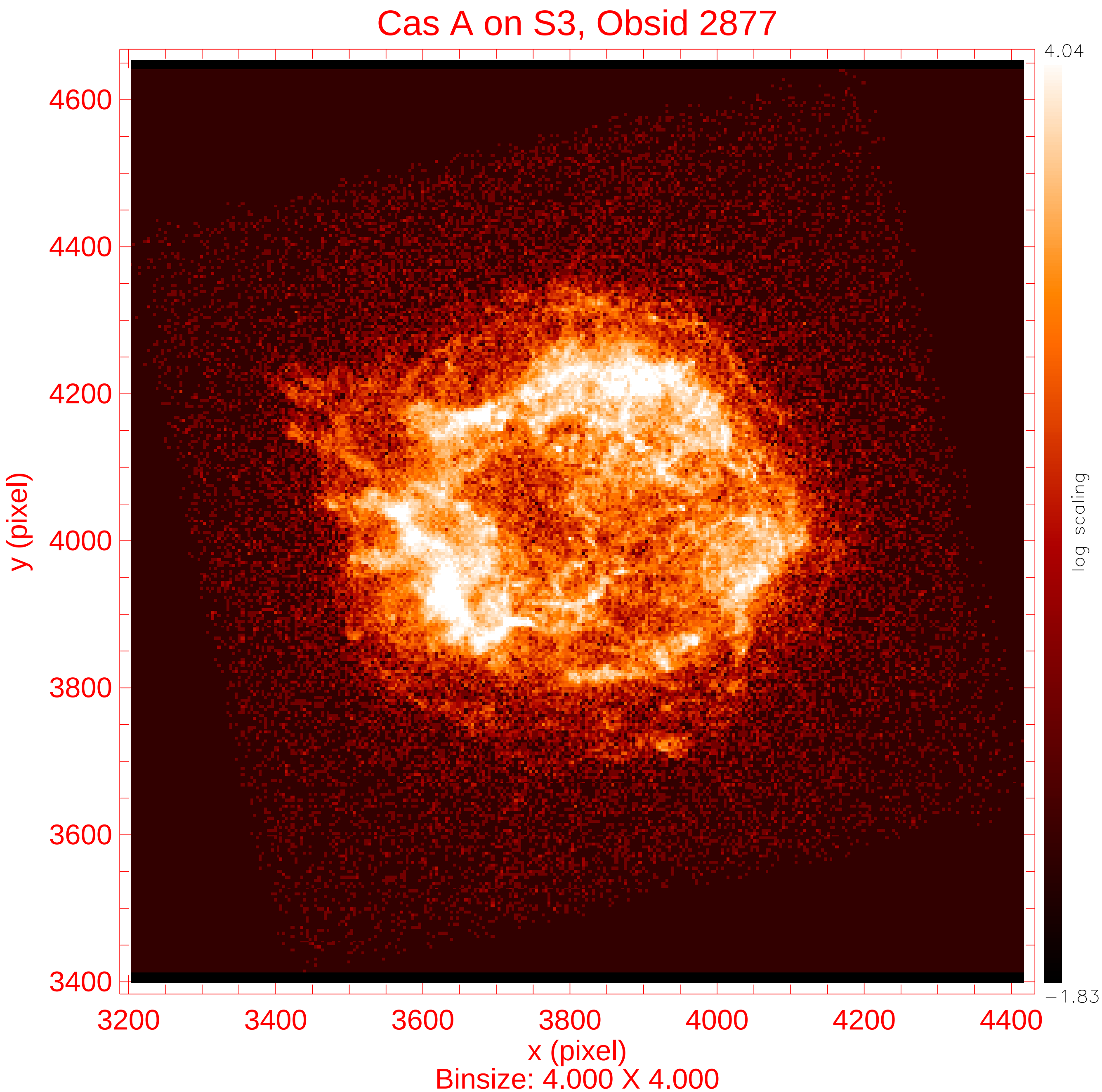
The full spectrum (log display): gain differences between the two calibrations are apparent; spectral resolution is improved (note the iron line especially).

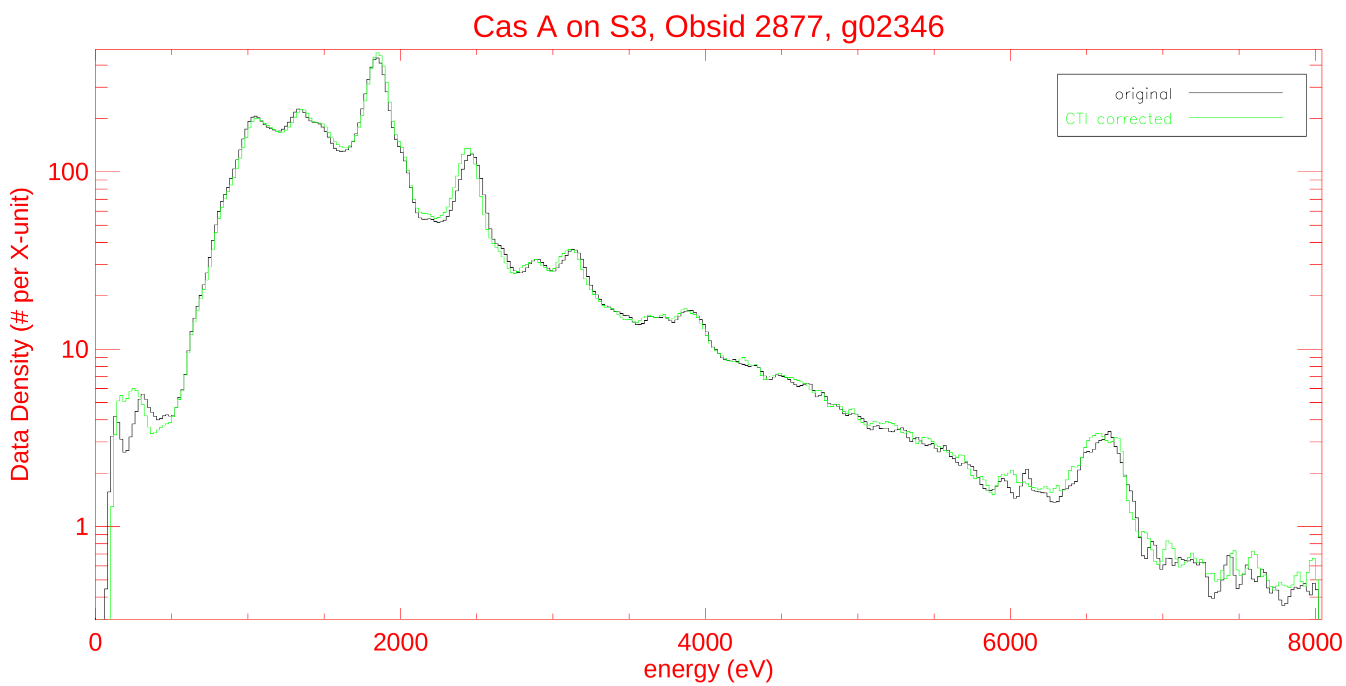
An expanded view of the spectrum showing the strong lines (linear display): spectral resolution is improved even at relatively low energies.

For bright sources, more stringent grade selection may result in even higher spectral resolution.

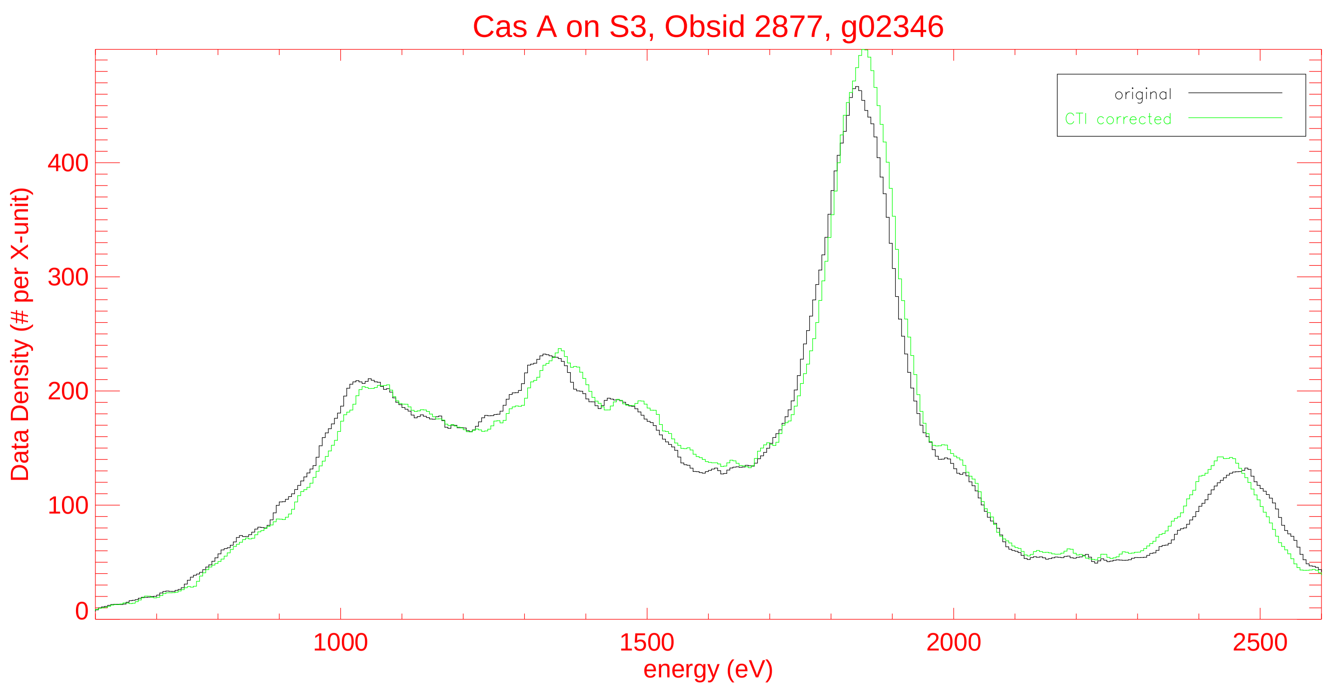


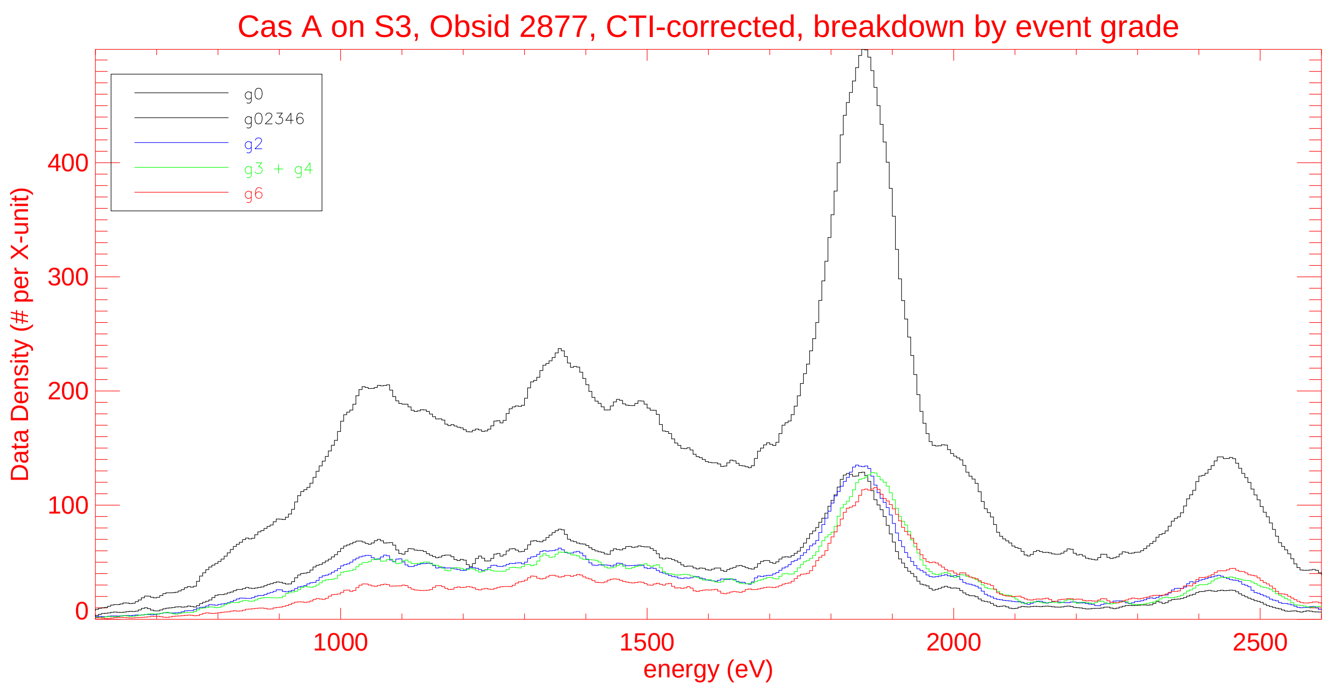
Full-frame matrix valid for any location on S3


Cas A on S3, Obsid 2877
y (pixel)
4600
4400
4200
4000
3800
3600
3400
3200
3400
3600
3800
4000
4200
4400
x (pixel)
Binsize: 4.000 X 4.000
4.04
log scaling
−1.83



Cas A on S3, Obsid 2877, g02346
Data Density (# per X-unit)
100
10
1
0
2000
4000
6000
8000
energy (eV)
original
CTI corrected


Cas A on S3, Obsid 2877, g02346
original
CTI corrected
Data Density (# per X-unit)
0
100
200
300
400
1000
1500
2000
2500
energy (eV)



Cas A on S3, Obsid 2877, CTI-corrected, breakdown by event grade
g0
g02346
g2
g3 + g4
g6
Data Density (# per X-unit)
0
100
200
300
400
1000
1500
2000
2500
energy (eV)

Event Grade Distributions

For Cas A Obsid 2877, in the range 0–8 keV, the event grades are:

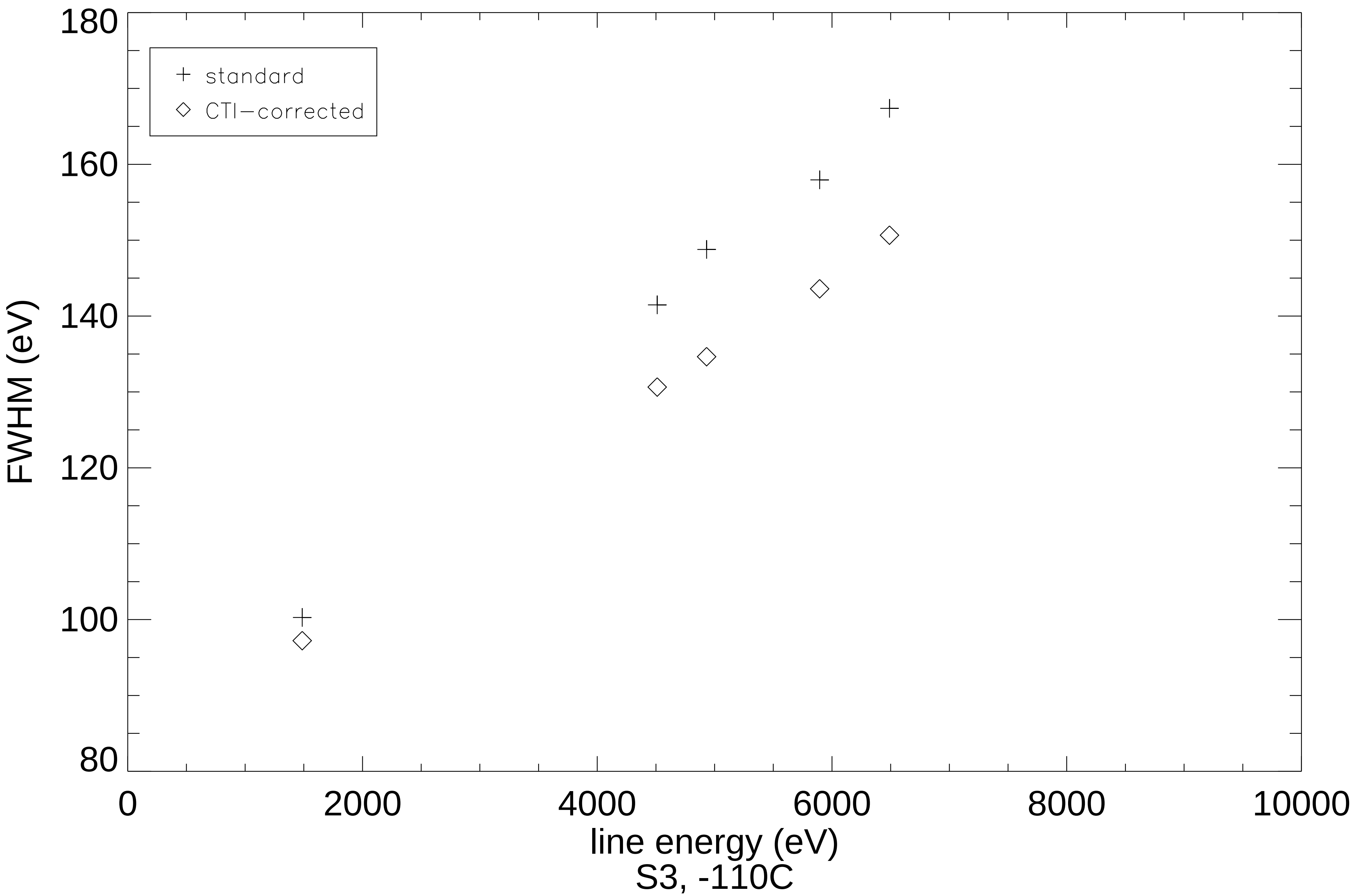
```
Original:                              CTI corrected:

g0,  77870 events = 22.6%             g0,  88994 events = 25.8%
g1,   1490 events =  0.4%             g1,   1913 events =  0.6%
g2,  94223 events = 27.3%             g2,  84468 events = 24.5%
g3,  36241 events = 10.5%             g3,  41144 events = 11.9%
g4,  36442 events = 10.6%             g4,  41981 events = 12.2%
g5,   5627 events =  1.6%             g5,   5371 events =  1.6%
g6,  83715 events = 24.3%             g6,  74818 events = 21.7%
g7,   9104 events =  2.6%             g7,   5524 events =  1.6%
```

Example Studies Using the BI Corrector

- Buote et al. 2002, em Chandra Evidence of a Flattened, Triaxial Dark Matter Halo in the Elliptical Galaxy NGC 720, ApJ 577, 183
- Swartz et al. 2002, *Chandra Discovery of Luminous Supersoft X-Ray Sources in M81*, ApJ 574, 382
- Michael et al. 2002, *The X-Ray Spectrum of Supernova Remnant 1987A*, ApJ 574, 166
- Lewis et al. 2002, *Chandra Observations of Abell 2029: No Cooling Flow and a Steep Abundance Gradient*, ApJ 573, 13
- Elsner et al. 2002, *Discovery of Soft X-Ray Emission from Io, Europa, and the Io Plasma Torus*, ApJ 572, 1077
- Gotthelf, Halpern, and Dodson 2002, *Detection of Pulsed X-Ray Emission from PSR B1706-44*, ApJ 567, L125
- Park et al. 2002, *Monitoring the Evolution of the X-Ray Remnant of SN 1987A*, ApJ 567, 314

- Park et al. 2002, *The Structure of the Oxygen-rich Supernova Remnant G292.0+1.8 from Chandra X-Ray Images: Shocked Ejecta and Circumstellar Medium*, ApJ 564, L39
- Ho et al. 2001, *Detection of Nuclear X-Ray Sources in Nearby Galaxies with Chandra*, ApJ 549, L51



FWHM (eV)
180
160
140
120
100
80
0
2000
4000
6000
8000
10000
line energy (eV)
S3, -110C
standard
CTI–corrected

Summary

- CTI correction on backside-illuminated ACIS CCDs provides improved spectral resolution and allows the detector response to be described with a single position-independent RMF
- This simplifies data analysis and enhances the results from ACIS BI studies, especially for diffuse targets
- Several groups are using the BI corrector for a wide range of applications and astrophysical targets

The IDL code and calibration products are available to the community at http://www.astro.psu.edu/users/townsley/cti/.