XMM-Newton CCF Release Note

XMM-CCF-REL-XXX

Rate-dependent CTI correction for EPIC-pn Timing Modes

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1 CCF components

Name of CCF	VALDATE	List of Blocks changed	Change in CAL HB
EPN_CTI_0020	2000-01-01T00:00:00	BURST_GAIN	NO
EPN_CTI_0020	2000-01-01T00:00:00	RATE_DEPENDENT_CTI	NO

2 Changes

2.1 Rate-dependent CTI correction

As of SASv8.0, a new task (`epfast`) has been introduced, aiming at correcting rate-dependent CTI effects in pn event lists of exposures taken in Timing and Burst Modes. Readers are referred to the SAS documentation for a full description of the task and its functionalities. It suffices here to say that `epfast` corrects the energy of each individual photon on the basis of the source+background count rate measured at the photon arrival time.

The correction is formally expressed as a linear "gain" factor, G_{corr}

$$G_{corr} = a_0 * X^{a_1} + a_2$$

where X is the number of shifted electrons per pixel per second, and the a_i are numerical coefficients.

The new extension of the `pn_CTI` CCF contains the values of the a_i coefficients for Timing and Burst Mode.

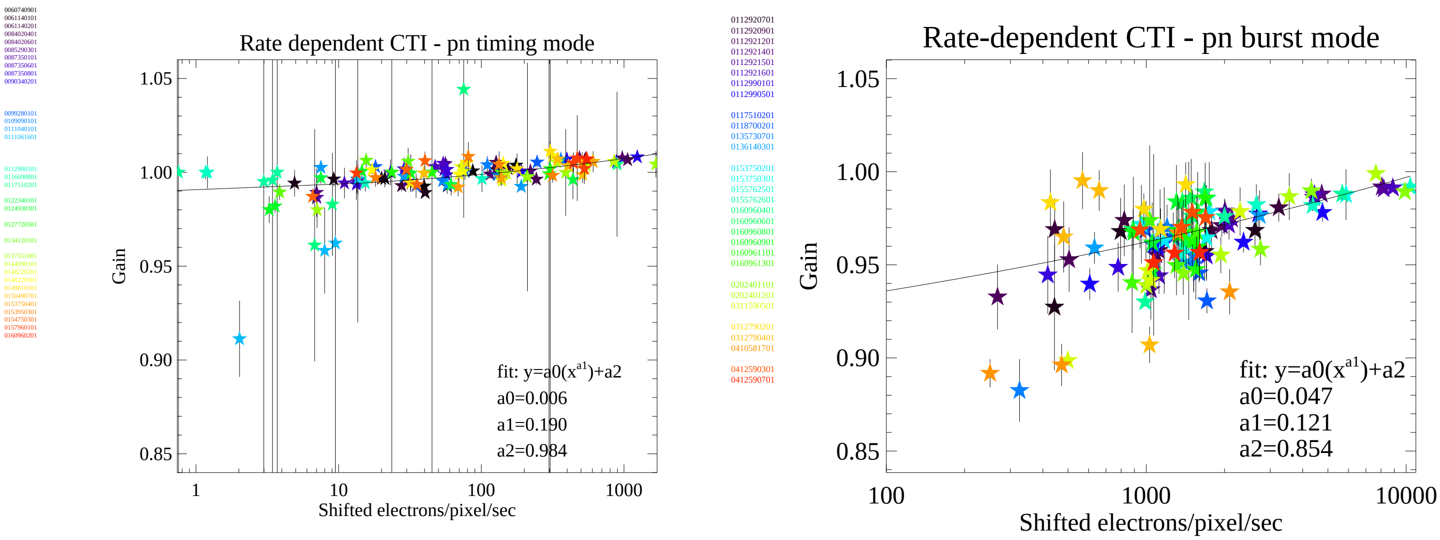

Figure 1: G_{corr} versus N_e relation for the sample EPIC-pn exposures in Timing (*left panel* and Burst (*right panel* Modes, respectively. The *solid line* indicates the best fit with the functional form: $a_0 * N_e^{a_1} + a_2$.

2.2 Calibration results

The a_i coefficient have been calibrated according to the following procedure:

- a sample of 36 exposures in EPIC-pn Burst Mode and 42 exposures in EPIC-pn Timing Mode has been selected on the basis that the background-subtracted net source light curve was statistically consistent with being constant
- for each of the sample source, spectra have been extracted from each of the four columns surrounding the boresight column (this included)
- each spectrum was fit in the 1.5–3 keV energy band with a simple continuum model: power-law+black body corrected for photoelectric absorption. A constant gain shift G_{corr} was applied to the spectral model (through the `gain` function in XSPEC) and calculated for each spectrum under the condition to minimise the χ^2
- for each spectrum, the number of equivalent shifted electrons N_e was calculated, according to the following formula:

$$N_e = \frac{\Sigma_{i=1}^{N_p} E_i}{N_{pixels} \times T_{exp} \times 3.6}$$

  where E_i is the energy of the i-th photon, N_{pixels} is the number of pixels of the column whence each spectrum was extracted, N_p is the number of detected photons, T_{exp} is the exposure time and the factor 3.6 (in eV) represents the energy required to produce an electron-hole pair.

The relation between G_{corr} and N_e was fit with the functional form: $a_0 * N_e^{a_1} + a_2$ (see Fig. 1). The results of the above procedure for the selected sample are shown in Tab. 1.

Table 1: a_i parameters in the EPN-CTI CCF version #20

Mode	a_0	a_1	a_2
Timing	6.369×10^{-3}	1.900×10^{-1}	$9.836 \times 10{-}1$
Burst	4.700×10^{-2}	1.210×10^{-1}	8.540×10^{-1}

Table 2: Parameters of the special burst gain correction (extension BURST_GAIN) in EPN-CTI CCF versions#19 and #20

	CCF #19	CCF#20
A_1	1.0394	1.0414
A_2	1.0075	1.0075
E_0	4.7286×10^3	1.0061×10^3
ΔE	6.6123×10^2	6.6123×10^2

The application of the rate-dependent EPIC-pn CTI to the sample of Burst Mode exposures shows that the best results are obtained if the special Burst Mode gain values calibrated on ground are applied. This function represents a relative gain (G_{rel}) "tuning function", calibrated by comparing observations of the Crab in Small Window and Burst modes (Kirsch, 2003, Ph.D Thesis, Universität Tübingen, Der Andere Verlag). The fitting function has the following functional form:

$$G_{rel} = \frac{A_1 + A_2}{1 + e^{(E-E_0)/\Delta E}} + A_2$$

Later recalibration of this CTI contribution did not take into account the rate-dependent effect. The introduction of the rate-dependent CTI correction requires therefore that the parameters of the BURST_GAIN extension are changed to the values as listed in Tab. 2

3 Scientific impact of this update

The main aim of the rate-dependent CTI is to improve the quality of spectral fitting on bright sources in EPIC-pn Fast Modes by improving the accuracy of energy reconstruction. As shown in Sect. 5 of this document, the application of the new CCF yields improvements both in the systematic residuals around the Silicon and Gold edges ($\simeq$2 keV) and in the agreement between the measured and laboratory energy of narrow-band absorption features.

4 Estimated scientific quality

Systematic residuals around the Silicon and Gold edges are $\leq$5% for the overwhelming majority of the sources in the testbed sample. The accuracy of the energy reconstruction for narrow-band absorption features in the iron regime is now $\leq 1\%$.

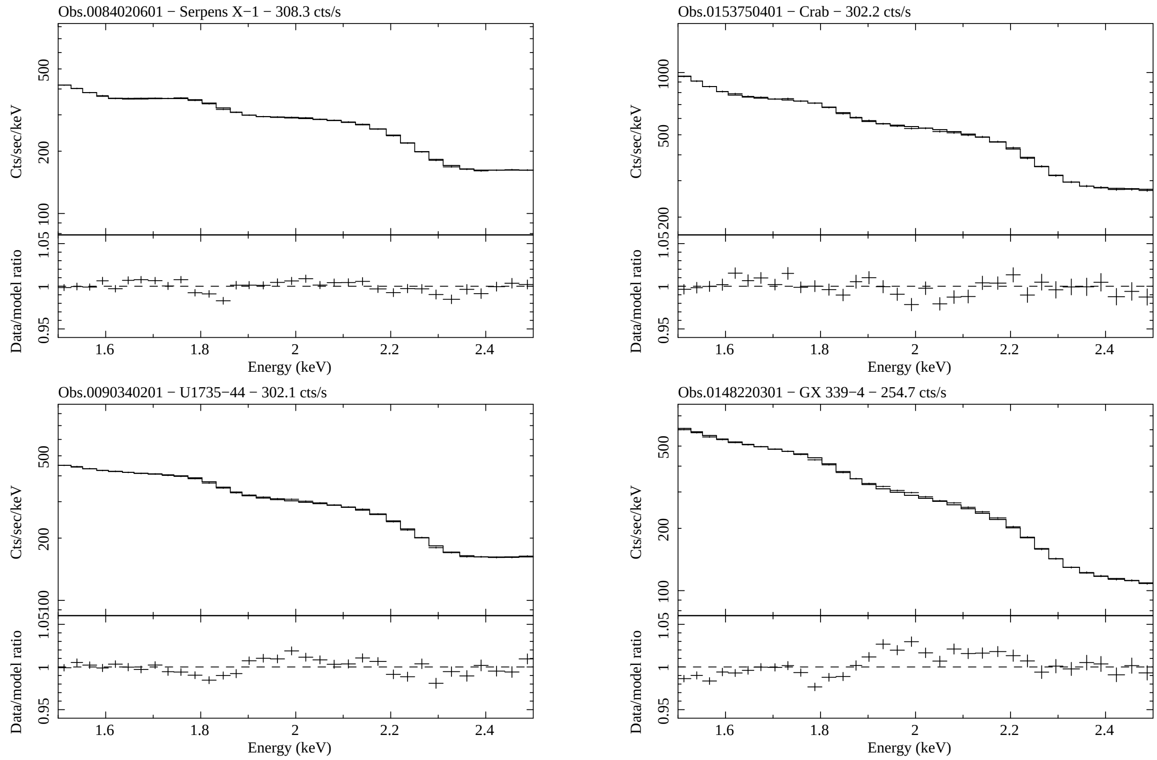

Figure 2: Systematic residuals around the Silicon and Gold edges with EPIC-pn CTI #20 in the four brightest observations (except Circinus X-1) belonging to the Timing Mode testbed sample.

5 Test procedure and results

5.1 Timing Mode

In Fig. 2 we show the residuals against the baseline model around the Silicon and Gold instrumental edges, once `epfast` coupled with the version #20 of the EPIC-pn CTI CCF is applied to the event list of the four brightest sources (except Circinus X-1) in our Timing Mode testbed sample. In all cases the maximum systematic uncertainties are within ±2.5%.

In Fig. 3 we compare the count spectra of 4 recent observations of GX13+1 without (*left panel*) and with (*right panel*) the `epfast` correction coupled with CCF#20. The visual inspection already suggests that the resonant Fe XXV and Fe XXVI absorption features are closer to their nominal laboratory energies in the latter spectra. This is confirmed by a quantitative analysis (Tab. 3). The difference against the nominal laboratory energy decreases from 1.5% to 0.7%.

Users shall be aware that the date-dependent CTI correction does not produce the same level of improvements to all spectra of our testbed sample. The reasons of this uneven behaviour are still under investigation, but are probably due to a combination of the intrinsically stochastic nature of this correction and to additional residual effects which are not currently taken into account by `epfast` and the associated CCF. Examples of observations where residuals ≃5% are still present once the rate-

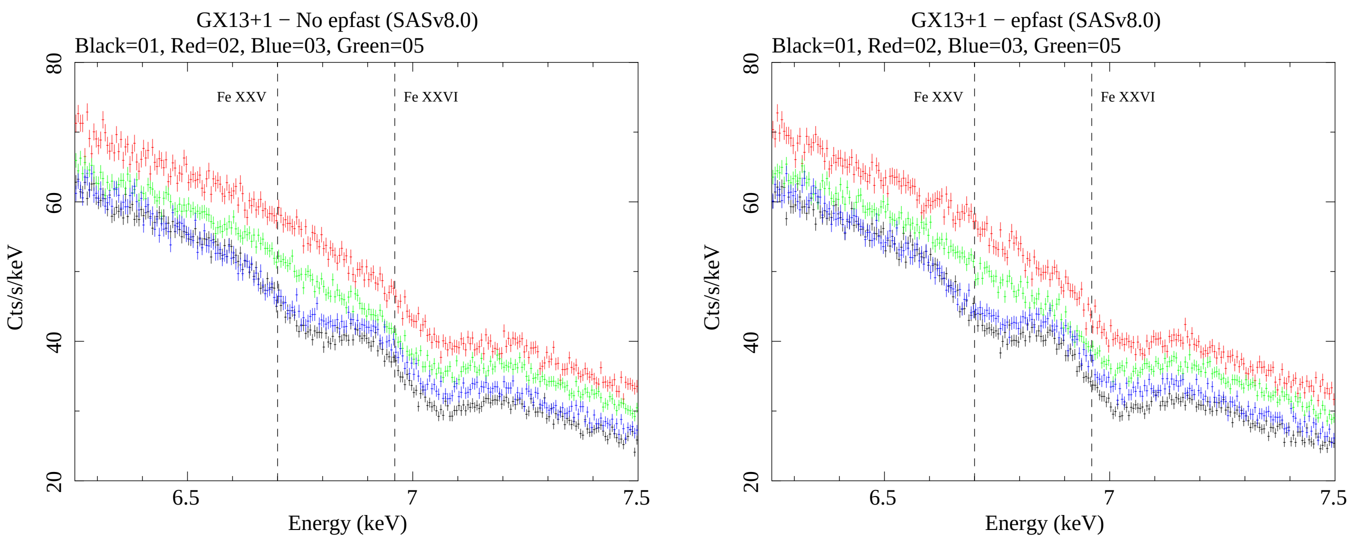

Figure 3: Count spectra of four recent observations of GX13+1 once the rate-dependent EPIC-pn CTI correction (*right panel*) is compared against the not-corrected spectra (*left panel*). The *vertical dashed lines* indicate the laboratory energy of the resonant Fe xxv and Fe xxvi absorption lines.

Table 3: Centroid energies in keV of the Fe xxv and Fe xxvi resonant absorption features in four recent observations of GX13+1. Errors are 90% confidence level for one interesting parameter. A systematic error of 10 eV in included.

Observation#	Fe xxv (6.70 keV)		Fe xxvi (6.96 keV)	
	no `epfast`	`epfast`	no `epfast`	`epfast`
0505480101	$6.81^{0.06}_{0.01}$	$6.75^{0.01}_{0.06}$	7.07 ± 0.01	7.02 ± 0.01
0505480201	...	...	7.08 ± 0.01	7.02 ± 0.01
0505480301	$6.81^{0.07}_{0.05}$	6.75 ± 0.03	7.06 ± 0.01	7.01 ± 0.01
0505480501	$6.78^{0.03}_{0.01}$	6.746 ± 0.016	$7.06^{0.04}_{0.01}$	7.02 ± 0.01

dependent CTI correction is performed are: Obs.#0122330801 (Crab Pulsar), Obs.#0148220201 (GX339-4), Obs.#0124930301 (PKS2155-304).

5.2 Burst Mode

In Fig. 4 we show four examples of improvements in the systematic residuals around the Silicon and Gold instrumental edges, due to the application of `epfast` coupled with the version #20 of the EPIC-pn CTI CCF to some of the brightest objects in the Burst Mode exposure sample. In all cases the maximum systematic uncertainty decreases from $\simeq$5% to $\leq$2%.

Users shall be aware that the date-dependent CTI correction does not produce the same level of improvements to all spectra of our testbed sample. The reasons of this uneven behaviour are still under investigation, but are probably due to a combination of the intrinsically stochastic nature of this correction and to additional residual effects which are not currently taken into account by `epfast` and the associated CCF. Examples of observations where residuals $\simeq$5% are still present once the rate-dependent CTI correction is performed are: Obs#202401201 (Cyg X-1), Obs.#0412590301 (Crab), Obs.#0160960401 (Crab), Obs.#0093562701 (GX339-3).

In Fig. 5 we show the count spectrum extracted from the pn exposure in Obs.#0155762501. The target in this observation (GROJ1655-40; Díaz Trigo et al., 2007, A&A, 462, 657) is known to show a prominent resonant absorption feature associated with Fe XXVI. The best-fit energy with SASv8.0 CCF#19 is $E = 6.93 \pm 0.02$ keV, whereas the best fit energy with CCF#20 is $E = 6.982 \pm 0.017$ keV (both errors are purely statistics at 90% confidence level for 1 interesting parameter). Measurements of the FeXXIV with the RGS and of several lines with the *Chandra* gratings suggest a blue-shift corresponding to an outflow velocity comprised between 400 and 1000 km s^{-1}. Such a shift should bring the centroid energy of the FeXXVI transition to the energy range 6.969–6.983 keV, in excellent agreement with the measurement yielded by CCF#20.

6 Expected Updates

Further studies will concentrate on those sources, where still residuals $\simeq$5% are seen around the Silicon and Gold edges.

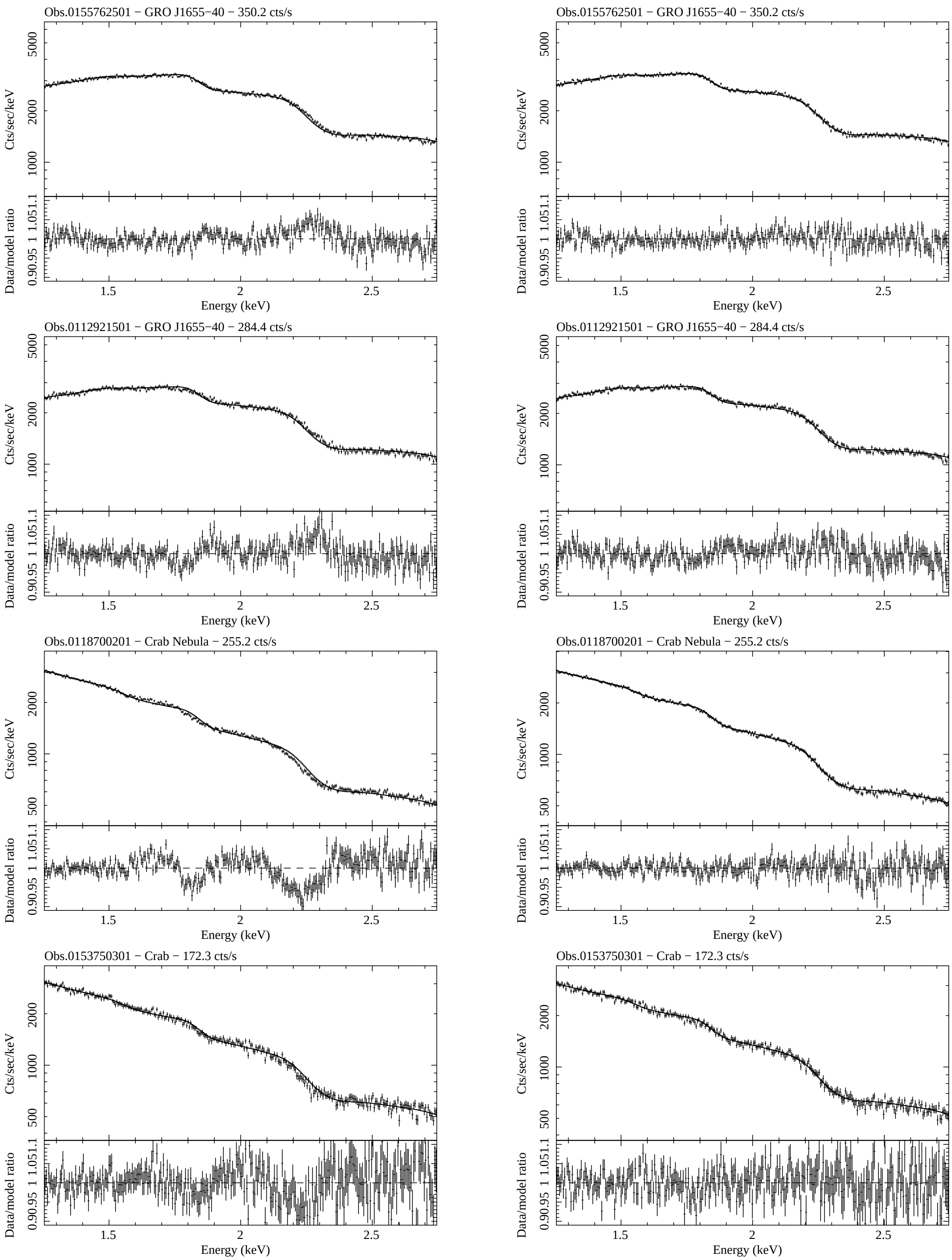

Figure 4: Systematic residuals around the Silicon and Gold edges with EPIC-pn CTI version #19 (*left panel*) and #20 (*right panel*) in four observations belonging to the Burst Mode testbed sample.

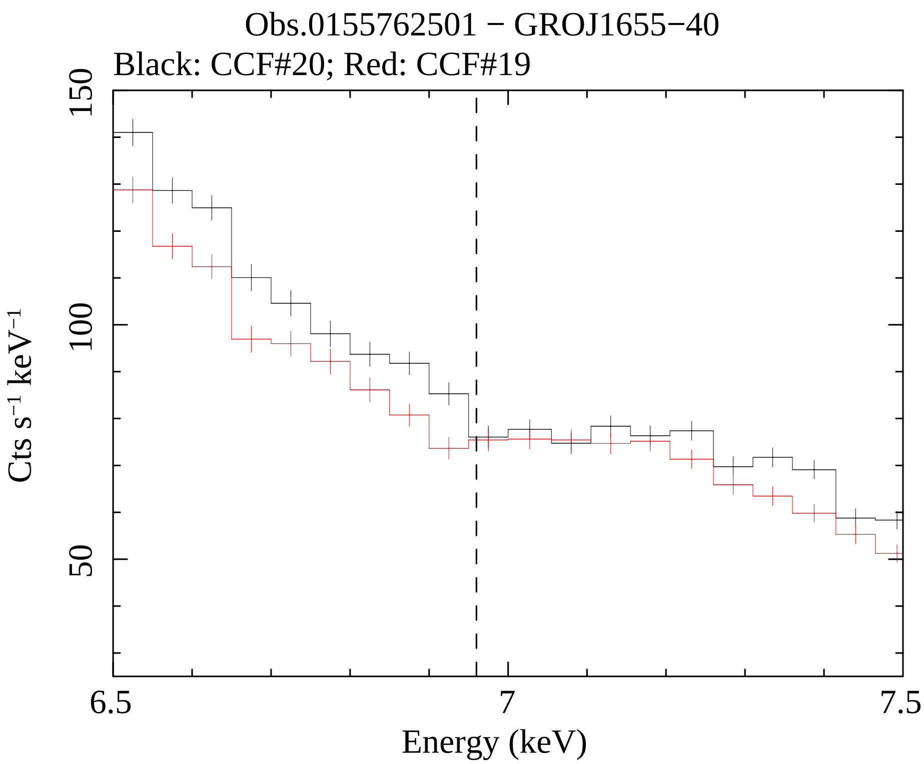

Figure 5: Count spectrum of GROJ1655-40 (Obs.#0155762501) around the Fe XXVI resonant absorption feature. The *black histogram* is the spectrum extracted with EPIC-pn CTI CCF#20, the *red histogram* with CCF#19. The *vertical dashed line* marks the nominal laboratory energy of the Fe XXVI line (6.96 keV).