XMM-Newton CCF Release Note

XMM-CAL-SRN-0322

Time-dependent width of the EPIC-pn spectral response

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1 CCF components

Name of CCF	VALDATE	EVALDATE	Blocks changed	XSCS flag
EPN_REDIST_0012.CCF	2000-01-01	-	NOISE_PARAMS	NO

2 Changes

Analysis of both calibration and celestial sources has revealed a gradual widening of the EPIC-pn redistribution function over the course of the mission. In figure 1 we plot the width of the Al-K (1.49 keV) and Mn-K (5.9 keV) lines, measured in each CCD from closed-calibration data. While there has been little change with time in the Al-K line, the width of the higher-energy Mn-K line has increased at a rate of between 0.1 and 0.25 ADU per year, depending on the CCD number.

In general it is difficult to use celestial sources to accurately measure line widths because of the lack of statistics and the ambiguity in modelling the underlying continuum. Nevertheless, *the Circinus Galaxy*, a nearby Seyfert 2, has the advantage of possessing a very strong iron line complex and having been observed on-axis in 2001 and again in 2014. Guainazzi et al. (1999), showed that the high-energy line structure could be modelled by Fe-K_α at $\sim$ 6.45 keV, with an equivalent width (eqw) of 2.25 keV, Fe-K_β at $\sim$ 7.1 keV, eqw=0.5 keV and Fe XXV (or Ni Kα) at 7.9 keV with eqw=0.2 keV. The Circinus observations were reduced with SASv13.5 and the spectra modelled in the energy range 5–8 keV with an absorbed power-law and three narrow (i.e. width=0) gaussian functions. Spectral fits were performed within `xspec (v12.8.1)` with free, independent, line energies for the single and double-event spectra[1] and free, independent, line normalisations. In figure 2 we show the results of these spectral fits to the Iron line complex. The fit is good for the 2001 observation (obsid=0111240101), confirming the quality of the current redistribution function (Haberl et al. 2010). In the 2014 observation (obsid=0656580601), residuals are seen which can be attributed to an increased instrumental line width.

[1]The apparent difference in the centroid energy of the lines in the single-event and double-event spectra is caused by a known energy offset problem which has been resolved in SAS v14 (see Smith et al. 2014).

The behaviour of the redistribution function, detailed above, can be modelled by introducing a time dependence in the noise parameters, which define the width of the main Gaussian peak of the response. In detail, the parameter N(4) has been made time dependent and the value of parameter N(3) has been changed. The structure of the NOISE_PARAMS block is now:

- MODE_ID - the observing mode
- PATTERN - 1 for single-pixel events and 2 for double-pixel events
- TIME - observation epoch (Modified Julian Date)
- NOISE_PARAMETER - a vector of 6 elements

The parameters, N(3) and N(4) define the change in width of the redistribution function with position on the detector, such that

$$dS/dY = N(1) + N(2) * N(3) * E - N(2) * N(4) * E^2 \tag{1}$$

where dY represents a change in RAW-Y coordinate, increasing towards the centre of the detector, and E is the photon energy in eV.

The values for N(4) are mode-independent and are given in table 1, while N(3), also mode-independent, has been set at 3.5E-4. Note that these parameters are also currently defined as being independent of the CCD number. The new parameter values have been tuned for the usual target position (RAWY=190) on CCD 4. They have also been tuned so that the change at lower-energies, around 1.5 keV and below, is negligible, whereas they have an increasingly important effect for higher energies.

EPN_REDIST_0012.CCF is compatible with the task *rmfgen v2.2* and above, which will be released with SAS version 14.

Table 1: Values of the parameter N(4)

PATTERN[a]	TIME (MJD)	N(4)
1	52127	1.4E-08
1	56717	-4.7E-08
2	52127	3.1E-08
2	56717	2.2E-08

[a] Pattern 1 denotes single-pixel events, pattern 2 denotes double-pixel events

3 Scientific Impact of this Update

The closed-calibration data has been reanalysed with *rmfgen v2.2* and EPN_REDIST_0012.CCF; results are presented in Fig. 3. The Al-K line widths are effectively unchanged while the

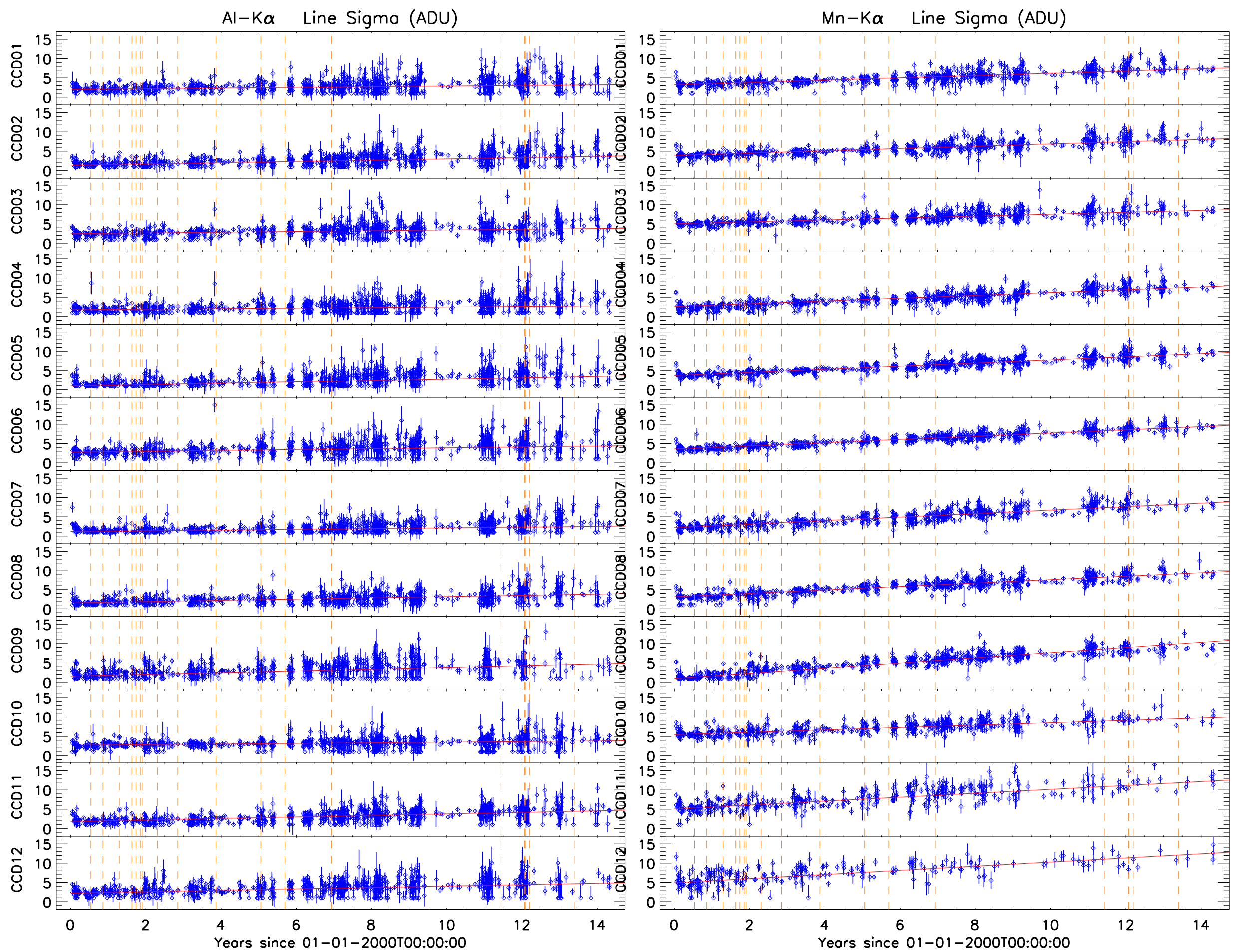

Figure 1: Al-K (left) and Mn-K (right) line widths (in ADU) versus time for single-pixel events taken from each CCD. Data is taken from FF mode, closed-cal observations averaged over the full CCD. While nearly flat at Al-K (1.49 keV), the measured widths of the Mn-K (5.9 keV) line are seen to be increasing at rates of 0.1 - 0.25 ADU / year.

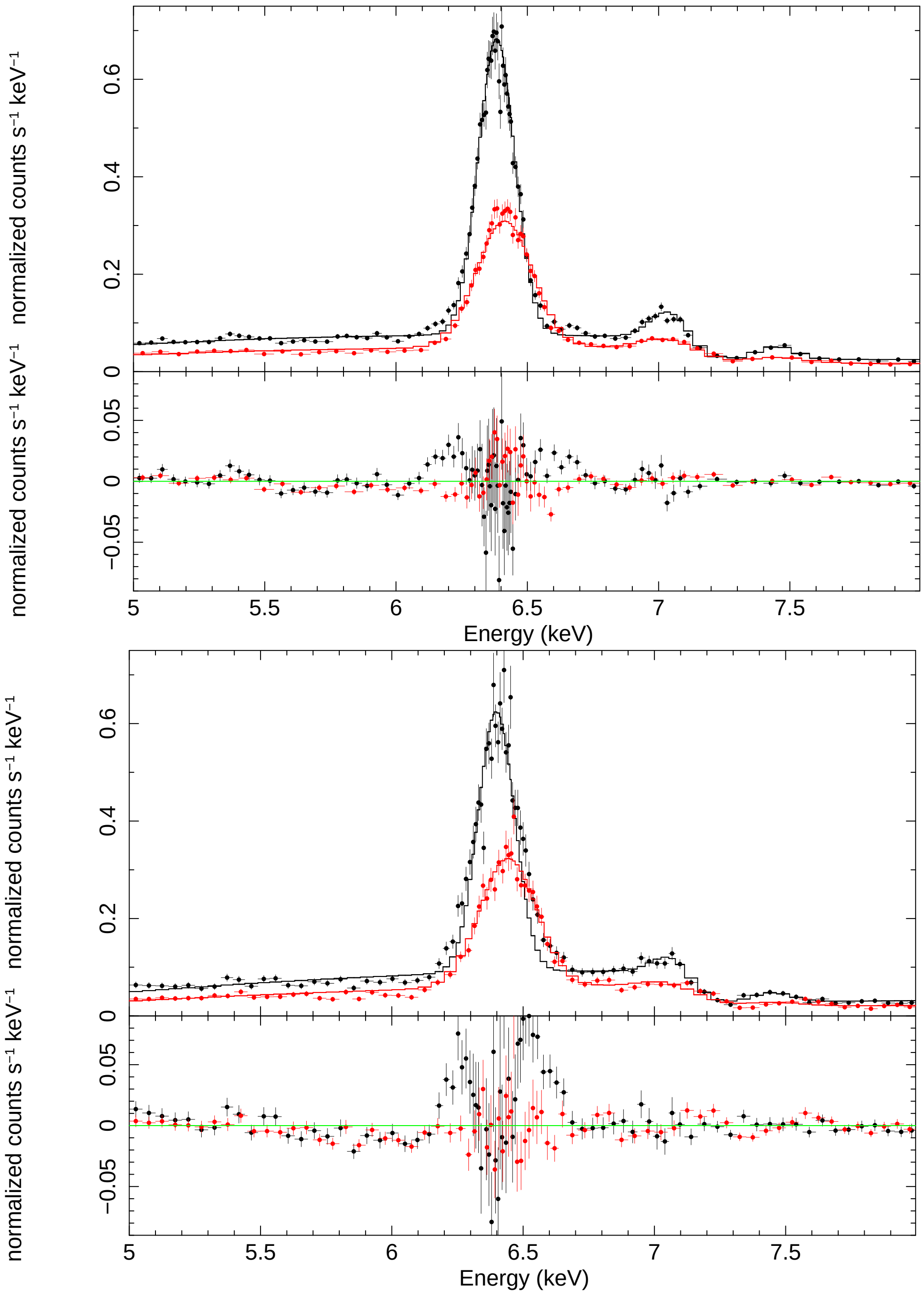

Figure 2: A fit of an absorbed power-law plus three narrow (width=0) Gaussian functions to the 2001-08-06 (top) and 2014-03-01 (bottom) observations of the Circinus Galaxy, with the current CCF. Black points denote the spectrum extracted exclusively from single-pixel events while the red points show the double-pixel event spectrum. The upper panel shows the fit to the data points while the lower panel shows the residuals of this fit.

temporal behaviour of the Mn-K line has been broadly flattened, especially on CCD 4, where the target is usually located. Some other CCDs, such as CCD 11 and 12, still show a noticeable increase in measured width with time, suggesting that a future CCD-dependent correction may be necessary. It can be seen that the apparent line width does not go to zero even at the beginning of the mission. The initial width was $\sim$ 20 eV for CCD 4 at the beginning of the mission and that has not changed with this update.

In Fig. 4 we show the effect of this change on the fitting of the Fe line complex in the Circinus Galaxy. The fit quality is comparable to the previous fit for the observation of 2001-08-06 but shows a noticeable improvement for the 2014 observation. If we allow the line width to be free, but linked between the single and double-pixel event spectra, then the best statistical fit is obtained with an artificial line width of 24 eV for both observations. This represents a considerable improvement for later observations (table 2) which should result in generally better statistical fits for narrow Fe lines in astrophysical sources. It should also help to avoid false broad lines being reported from later observations.

Table 2: Apparent width of Gaussian lines fitted to the Circinus galaxy spectra

Date[a]	Obsid	Gaussian width (eV)[b]	
		Current CCF	EPN_REDIST_0012.CCF
2001-08-06	0111240101	26 ± 4	24 ± 5
2013-02-03	0701981001	61 ± 4	50 ± 4
2014-03-01	0656580601	58 ± 5	24^{+6}_{-11}

[a] The 2001 and 2014 observations were made close to the optical axis while in 2013 the galaxy fell on CCD 4 at an off-axis angle of $4.5'$.
[b] Single and double-pixel spectra were simultaneously modelled with a continuum plus Gaussian lines, whose width was free but linked between the two spectra. Quoted errors are 90% confidence.

4 Estimated Scientific Quality

Fits to narrow line spectra, taken on-axis, are now modelled reasonably well. Best statistical fits will return an artificial width of $\sim$ 25 eV for targets placed on CCD 4, close to the nominal boresight, regardless of the observation date.

Spectra taken from other CCDs, or at other positions, may have a different behaviour. As an example we have looked at an off-axis observation of the Circinus Galaxy from 2013-02-03 (obsid=0701981001), which was placed $4.5'$ away from the optical axis. Spectral fits before and after the application of this update are presented in Fig. 5. In this case the quality of the spectral fit is also much improved. The best spectral fit gives an apparent width of 50 eV (Tab. 2), for the tied single and double-pixel event spectral lines, after this update. While this is better than the previous value of 62 eV it is noticeably larger than the on-axis values.

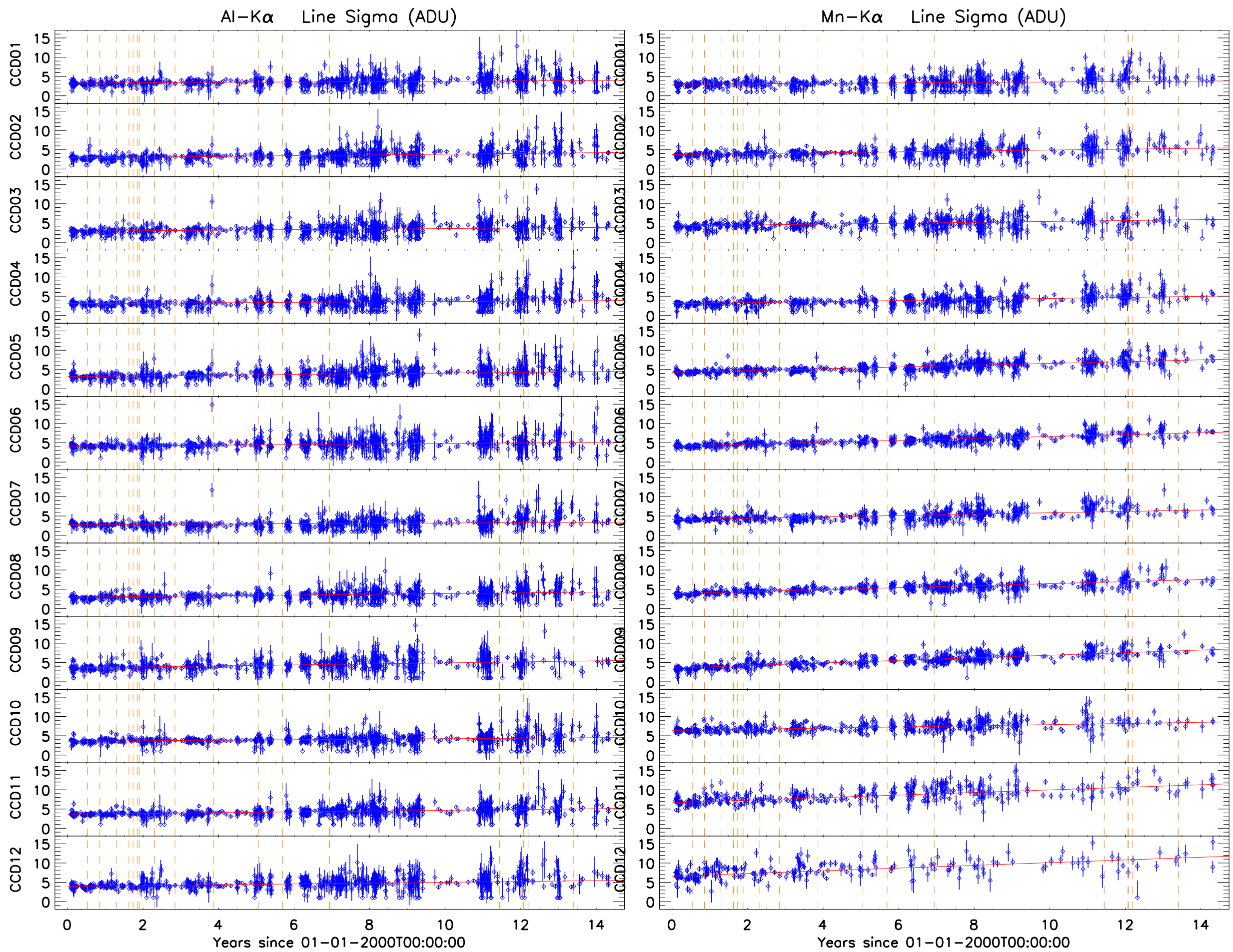

Figure 3: Al-K and Mn-K line widths (in ADU) versus time for each CCD, from FF mode, closed-cal data taken over the full CCD, after the application of this CCF update.

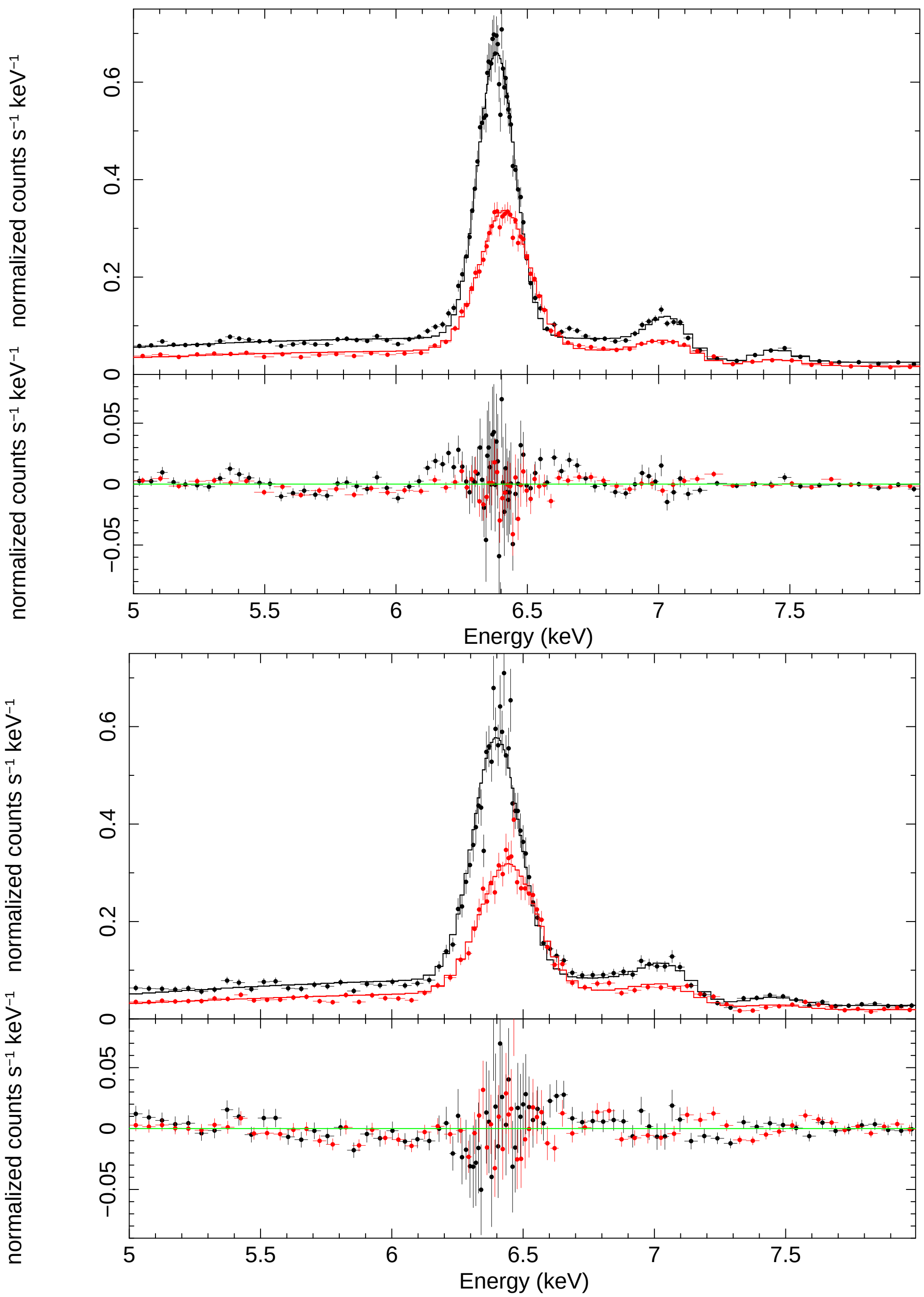

Figure 4: A fit of an absorbed power-law plus three narrow Gaussian functions to the 2001-08-06 (top) and 2014-03-01 (bottom) observations of the Circinus Galaxy, after the application of this CCF update.

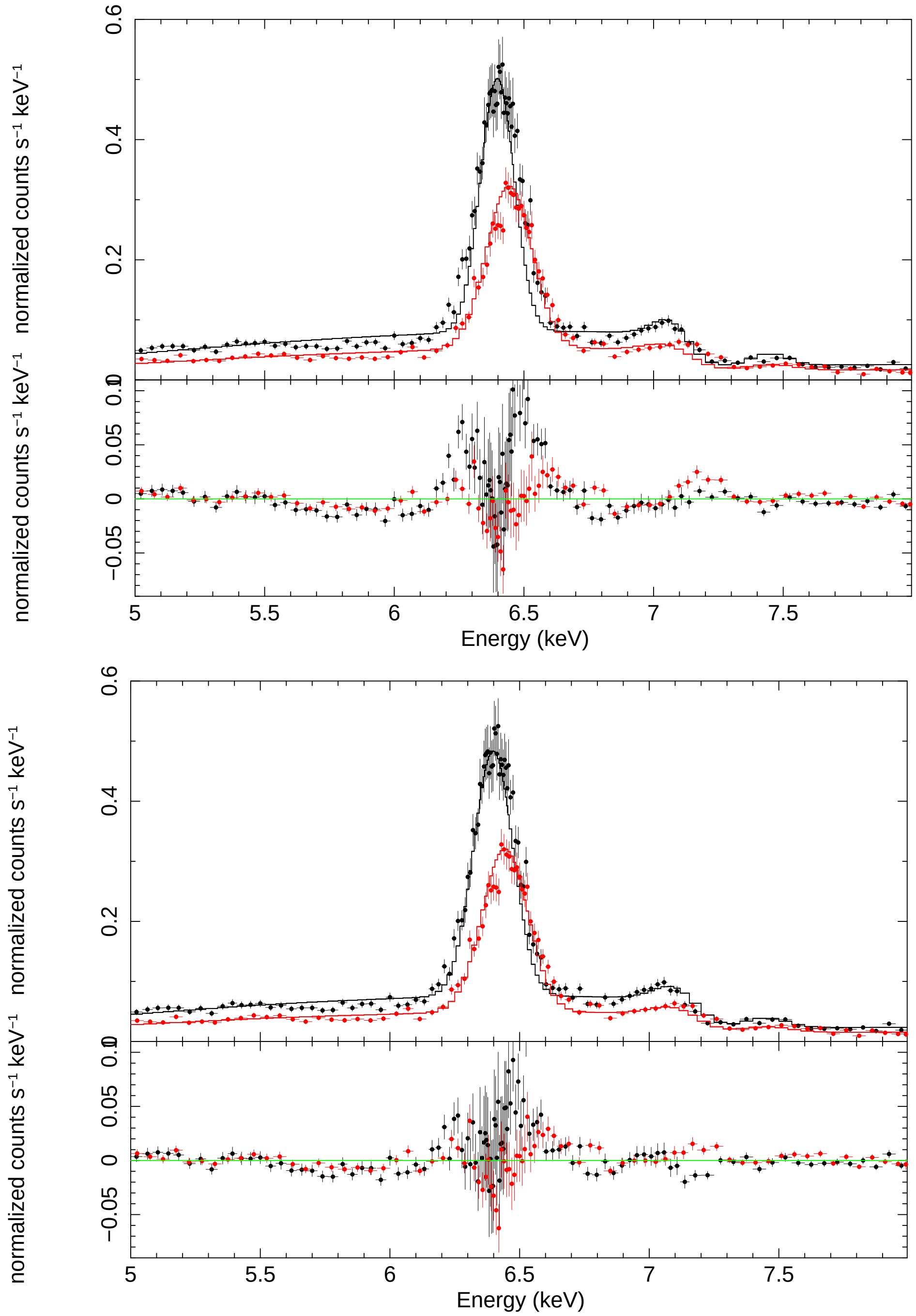

Figure 5: A fit of an absorbed power-law plus three narrow Gaussian functions to the 2013-02-03 observation of the Circinus Galaxy, which was made 4.5′ off-axis on CCD 4. Spectral fits have been made with the current CCF (upper panel) and after the application of this CCF update (lower panel).

5 Expected Updates

From the Circinus galaxy results it appears that more work is needed to solve the resolution problem for off-axis sources, observed later in the mission. Consideration should also be given to the introduction of a CCD by CCD response.

6 Test procedures

The response matrix generation task *rmfgen*, version 2.2, has been executed with EPN_REDIST_0012.CCF to produce the RMFs which have been used in the previous analysis. In addition, matrices have been created for early and late observations of another target. These response matrices show the expected increase in width with time, at ~ 6 keV.

In SAS 14, several changes have been made to the EPIC-pn event energy scale (Smith et al. 2014) which could have an effect on the measured line widths. As a further consistency check, spectra have been made for the three Circinus Galaxy observations using the full SAS 14 processing. These show good quality spectral fits, with line widths consistent with those shown in Tab. 2.

7 References

Guainazzi, M. et al. 1999, MNRAS, 310, 10.
Haberl, F., Saxton, R., Guainazzi M., Stuhlinger, M. 2010, CAL-SRN-0266.
Smith, M. et al., 2014, CAL-SRN-0323.