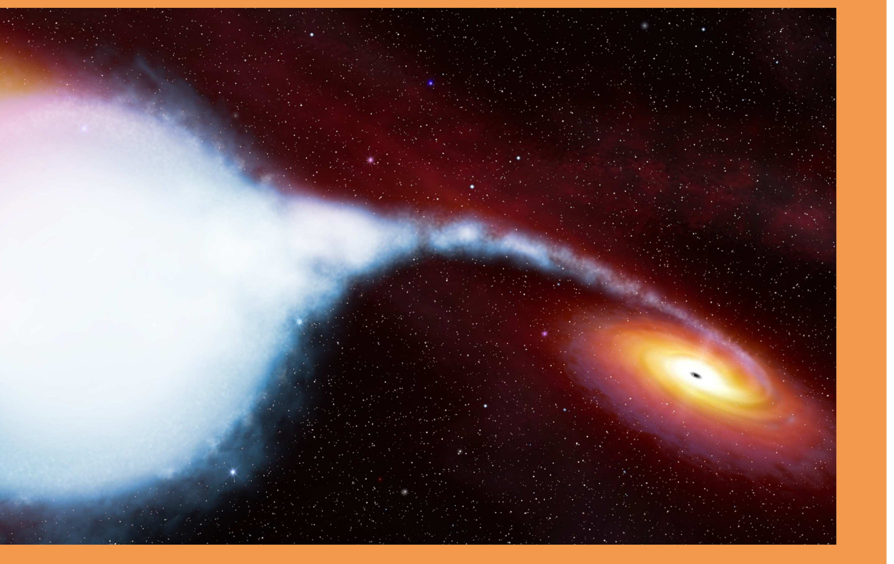
Modified Timing Mode of XMM-Newton



An Analysis of Cygnus X-1

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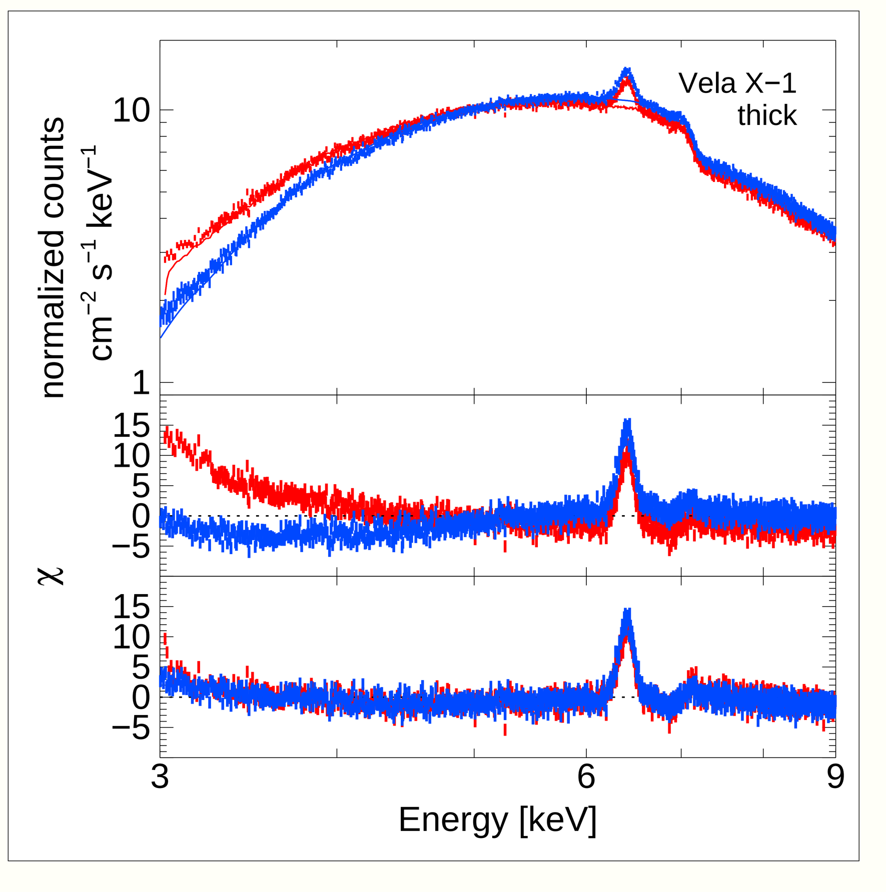
Abstract

We report on the development of the Modified Timing Mode of the EPIC-pn camera on-board X-ray observatory *XMM-Newton*. This observing mode is a special version of the Timing mode, which is particularly well suited for bright-source observations. It is obtained by increasing the lower energy threshold to 2.8 keV, above which detected photons are transmitted to the ground. The major advantage of this mode is that it has a significantly higher efficiency than the usually applied Burst mode. However, the changed lower energy threshold necessitates a recalibration of the detector. We report on the calibration effort of the mode. We present an example for its use from the analysis of the broad iron line feature from the black hole binary system Cygnus X-1. Models which take into account the relativistic effects produced by the material's closeness to black hole, describe the broad feature very well. Nevertheless, we conclude that the best description is done by relativistic covolution of the reflected spectra. We also note that our current results do not give decisive answer to the value of angular momentum of the black hole, although it prefers higher and positive values.

The Modified Timing Mode and its Calibration

The EPIC-pn camera on-board *XMM-Newton* can operate in three different modes: *imaging*, *burst*, and *timing mode*. The last two are suitable for observing bright X-ray sources, with the difference that the burst mode gives a lower signal to noise (S/N) ratio as only 3% of all events are transmitted. The telemetry allocated to the EPIC-pn camera is restricted to a maximum rate of 40 kbps. It is thus not trivial to study bright sources such as Cygnus X-1 (which can have up to 3000 cps) with the maximum possible time resolution in combination with a satisfying S/N ratio.



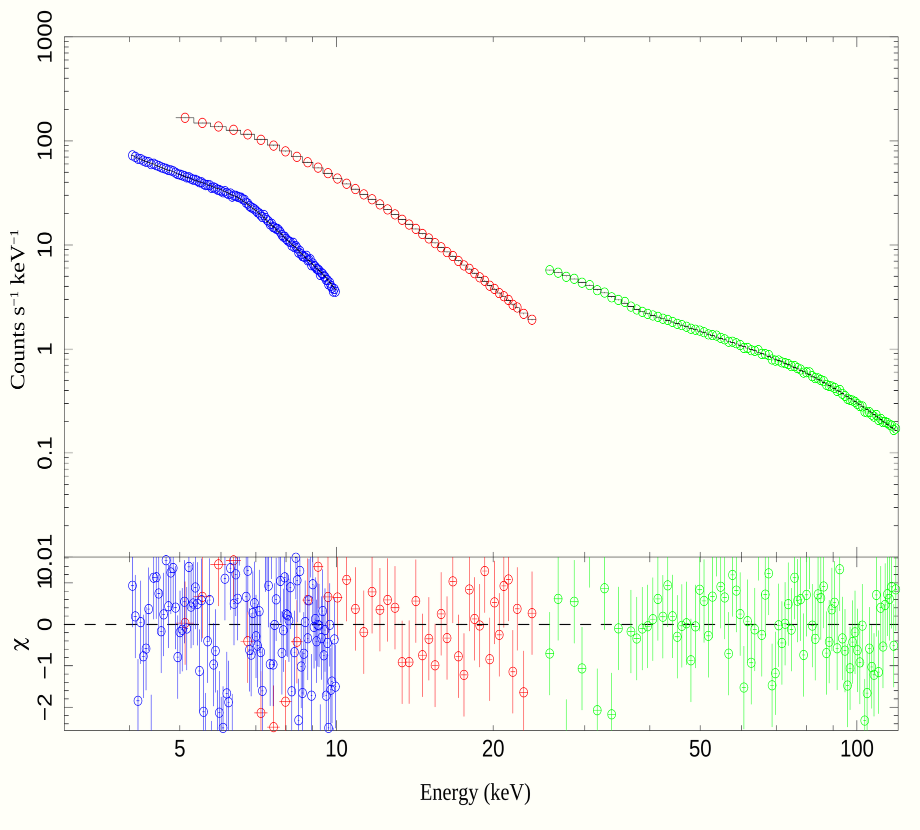
Top: Measured EPIC-pn timing mode spectrum of Vela X-1 (blue) and modified timing mode spectrum generated from these data (red). Both observations have been fitted with an absorbed power-law.
Middle: Residuals from fitting both data sets using the Timing Mode Response. The redistribution of events in the modified timing mode leads to an apparent soft excess.
Bottom: Using the new response matrix for the Modified Timing Mode fully describes the calibration of this mode.

In order to increase the Timing mode telemetry limit of EPIC-pn, we switch off the EPIC-MOS camera which changes the limit to 1050 counts s^{-1}. We also increase the lower energy threshold to 2.8 keV. For Cyg X-1, this approach reduces the count rate to 500–800 cps, well below the new telemetry limit.
In the EPIC-pn camera, the charge cloud produced by a photon is detected in either one, two, or more pixels. Information about each pixel is transferred to ground. Recombination of this information occurs on ground only. Increasing the lower energy threshold means that not all of this information is available, which necessitates a recalibration of the mode as the single-to-double ratio changes. This recalibration is easily done since available timing mode observations can be used (Fritz, 2008). Here, we present results using a matrix based on the newest EPIC-pn response matrix and all public available Timing mode observations (discarding all observations which are piled up). The data is extracted using SAS 9.0.0.
The Figure illustrates the quality of the recalibration by showing a Timing mode observation of Vela X-1 and a simulated modified Timing mode observation (produced by removing all events <2.8 keV in the raw data before recombining events).

An Analysis on Cygnus X-1 in its Intermediate State

We analyze an observation of Cygnus X-1 taken by *XMM-Newton* with the Modified Timing mode, using the new response matrix described above. The effects and results of a similar observation based on an earlier version of the response matrix are summarized by Wilms et al.(2006).
All spectral fits were performed with the Interactive Spectral Interpretation System (ISIS; Noble & Nowak, 2008, and therein). Based on earlier *Chandra*-observations (Hanke et al., 2009, Miller et al., 2002), we describe the line emission by the sum of a narrow Gaussian at 6.4 keV and a broad line feature, and the continuum by an absorbed power-law ($N_{\rm H} \sim \text{few} \cdot 10^{21}\,\text{cm}^{-2}$, i.e., absorption is negligable in the energy band considered).
For our analysis, we use the `relline` model (Dauser et al., 2010), as well as the standard `reflionx` convolved with relativistic `relconv` model. In order to better constrain the underlying continuum, we use parameter values extracted from the simultaneous fit to the XMM-Newton data and simultaneous RXTE observation, energy range from 4 keV to 120 keV. Overall normalization constants account for the cross-calibration uncertainties between the datasets.

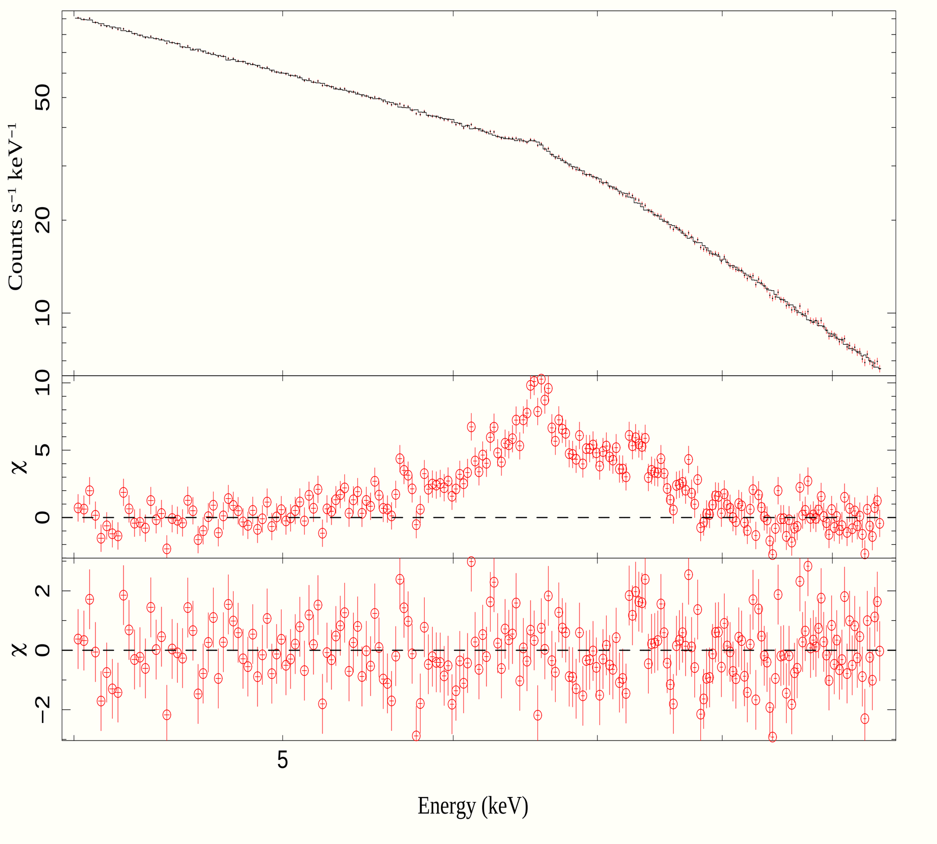
The relativistic line model describes the XMM-Newton data seemingly well, with $\chi^2_{red} \sim 1.8$. Nevertheless, the inclination angle tends to go towards unrealistically high values. Hence we introduce a second line, which would rise as an effect of the ionization state of the iron in the disk. χ^2_{red} improves towards ~ 1.3, but the inclination remains similar. The issue forces us to try to fit only reflection describing a state of higher ionized iron in the disk, convolved with the relativistic smearing. This is where we get the best description of the data, with $\chi^2_{red} \sim 1.3$(see Figures below), and with the inclination angle that points at $\sim 42°$, in excelent agreement with the optical analysis of the system (Ninkov et al.,1987).
The angular momentum of the black hole has wide confidence range, as seen from the simultaneous fitting. We note, however, that constraining $a = 0.998$ yields lower inclinations that are in line with those obtained from precessing disk models for the superorbital radio-period of the source (Ibragimov et al., 2007).



Results of spectral fitting to simultaneous datasets, EPIC-pn (blue), pca (red) and hexte (green).

Comparison of values extracted from XMM-Newton data. First column represents one line model, while the second column represents relativistically convolved reflection. The spin is set to maximum.

Parameter	One line	Convolved refl.
Γ	$1.74^{1.78}_{1.72}$	$1.77^{1.81}_{1.73}$
$E_{K\alpha,rel}$ [keV]	$6.42^{6.45}_{6.36}$	$6.56^{6.58}_{6.55}$
α	$2.1^{2.19}_{2.05}$	$2.55^{3.24}_{2.02}$
i[deg]	$60.2^{61.6}_{59.1}$	$47.6^{50.5}_{45.8}$
χ^2	1.84	1.30
χ^2_{red} / dof	403/219	286/219



Fits to the EPIC-pn data. The top residual plot shows a broad feature, while the next residual plot shows clear impovement of the fit using convolved reflection.

Acknowledgments

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References

Dauser, T., Reynolds C.S., Wilms, J., & Brennman, L.
Hanke, M., Wilms, J., Nowak, M.A., Pottschmidt, K., Schulz, N.S.,& Lee, J.C., 2009, ApJ **690**, 330
Ibragimov, A., Zdziarski, A.A., Poutanen, J. 2007, MNRAS **381**, 723
Miller, J.M., Fabian, A.C., & Wijnands, R., 2002, ApJ **578**, 348
Wilms, J., Kendziorra, E., Nowak, M. A., Pottschmidt, K., Haberl, F. W., Kirsch, M.,& Fritz, S. 2006, ESA-SP **604**, 217
Noble, M., Nowak, M.A., 2008, PASP **120**, 821
Fritz, S., Wilms, J, Pottschmidt, K., Nowak, M.A., Kendziorra,E., Kirsch, M.G., Kreykenbohm, I, Santangelo, A, 2007, ESA-SP **622**, 341
Ninkov, Z., Walker, G. A. H., & Yang, S. 1987, ApJ, **321**, 425

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