Modified Timing Mode of XMM-Newton

An Analysis of Cygnus X-1

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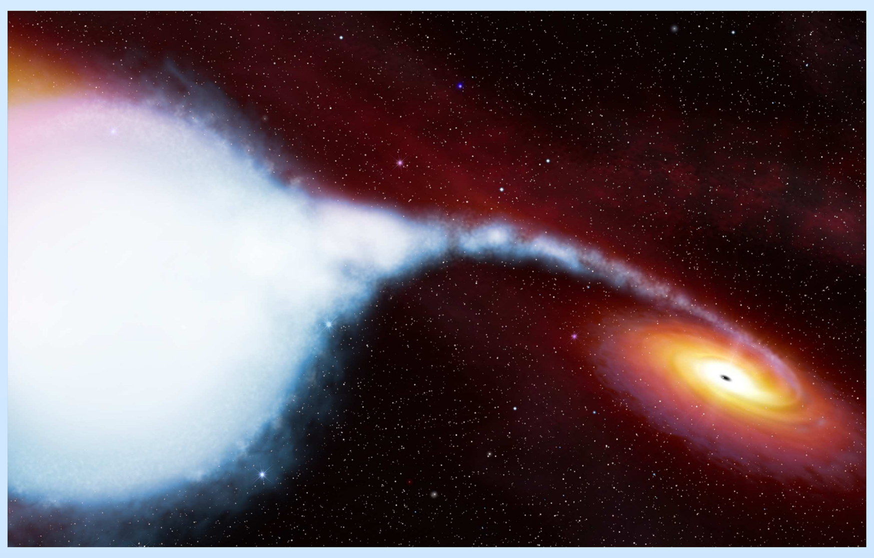


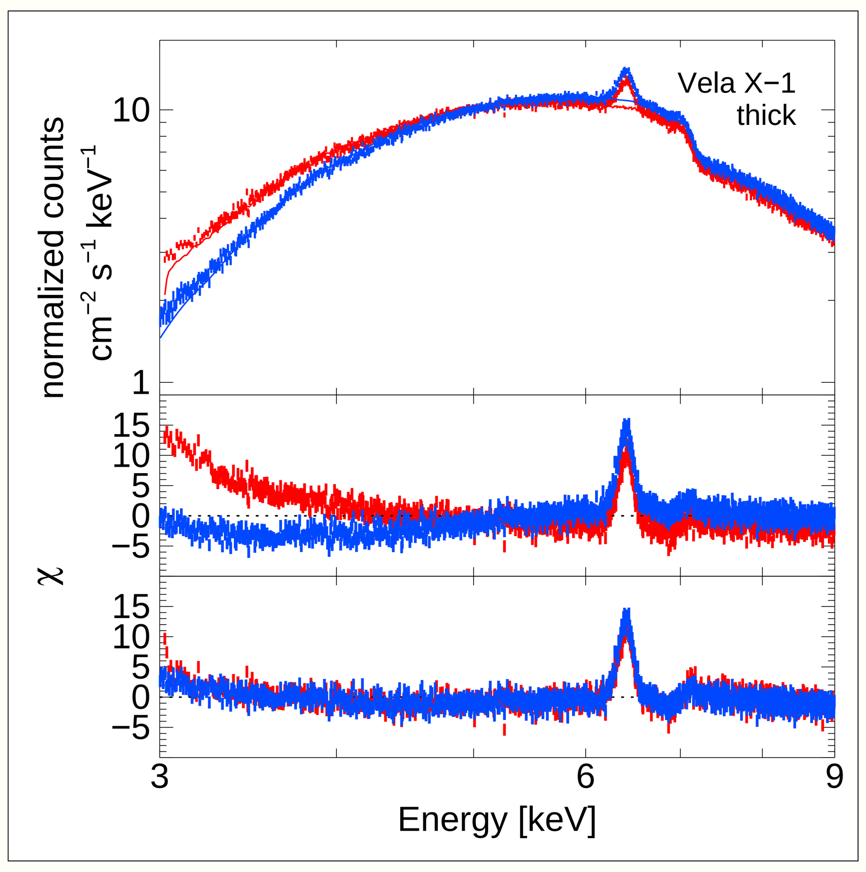
Abstract

We report on the development of the Modified Timing Mode of the *XMM-Newton* EPIC-pn camera. The Modified Timing Mode is a special version of the timing mode of the EPIC-pn camera on-board *XMM-Newton* which is especially well suited for bight source observations. Its major advantage is that it has a significantly higher efficiency than the usually applied burst mode, however, it requires a recalibration of the detector. Using the newest calibration, we present results on the broad iron line feature of the black hole binary system Cygnus X-1.

We analyze four Modified Timing mode, thick filter observations of Cygnus X-1 in its intermediate state. These observations are the highest signal to noise observations available which show a broad line in a Galactic source. The broad iron line feature is clearly present in the energy spectra. We present the results of fitting the line using the `kyrline`-model for the relativistic line shape and present our results on the angular momentum of the black hole, which cannot be constrained with these data.

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.



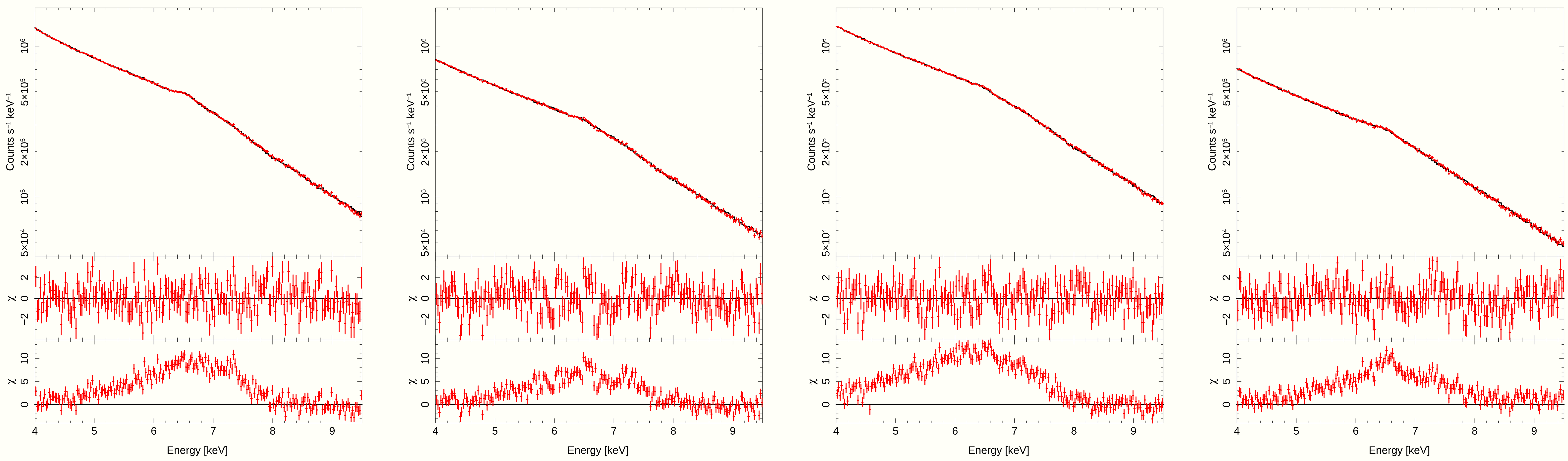
Top: Measured EPIC-pn timing mode spectrum of Vela X-1 (blue) and modified timing mode spectrum generated from these data (red). Both observations have been fitted with an absorbed power-law.
Middle: Residuals from fitting both data sets using the Timing Mode Response. The redistribution of events in 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 get below Timing mode telemetry limit of 250 cps, we switch off the EPIC-MOS camera which increases the count rate to 1050 counts s^{-1} and we 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 1050 cps limit.
In the EPIC-pn camera, the charge cloud produced by a photon is detected in 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 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 four observations of Cygnus X-1 taken by *XMM-Newton* with the Modified Timing mode, using the new response matrix as described above. Results based on an earlier version of the response matrix are summarized by Fritz et al. (2007) and Fritz (2008).
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 ($N_\mathrm{H} \sim \mathrm{few}\cdot 10^{21}\,\mathrm{cm}^{-2}$, i.e., absorption is negligable in the energy band considered).
For our analysis, we use the `kyrline` model (Dovčiak et al., 2004), as well as the standard `laor` and `diskline` models.

Fits with this simple model give reduced χ^2-values of around 2.0. We attribute this rather high χ^2 to the extremely high signal-to-noise ratio of the observations, due to which even small calibration uncertainties will dominate the resulting χ^2. A study of these uncertainties is currently underway. These uncertainties are already present in the standard Timing Mode, i.e., they are not introduced by the Modified Timing mode, and they are significantly smaller than in earlier versions of the Timing Mode calibration.
Despite these issues, however, the model describes the data and the line shape well (see Figures below). The continuum photon index ranged from 2.0 to 2.2, consistent with simultaneous pointed *RXTE* observations and indicative of the intermediate state (Fritz et al., 2007). Our best fit results point at an inclination ($i \sim 80°$) that is inconsistent with the inclination of the system ($i \sim 45°$). The angular momentum of the black hole cannot be constrained. 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 the four Modified Timing Mode observations of Cygnus X-1 from 2004 November 14, 2004 November 20, 2004 November 26, and 2004 December 02. Note the variations of the line profile.

Acknowledgments

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