THE BROAD BAND SPECTRUM OF CYG X-1

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ABSTRACT

We present first results on *INTEGRAL* and *RXTE* from our multi-mission observing campaign on Cygnus X-1. The black hole binary Cyg X-1 has been observed simultaneously by *INTEGRAL*, *RXTE*, and *XMM-Newton* for four times in 2004 November and December, when Cyg X-1 became first observable with *XMM-Newton* (see contribution by Wilms et al., these proceedings). One of the scientific aims of this campaign was the measurement of a high signal to noise spectrum of Cyg X-1 from 2.5 keV to >600 keV in order to constrain models for the hard spectral component. We show here first results of our ongoing analysis obtained by modeling the broad band spectrum with simple empirical models as well as with Comptonization models.

Key words: Interacting Binaries; Cyg X-1.

1. INTRODUCTION

Cyg X-1 has been observed by *INTEGRAL*, *RXTE*, and *XMM-Newton* simultaneously on 2004 November 14/15 (hereafter called obs1), 20/21 (obs2), 26/27 (obs3), and on December 2/3 (obs4). The total observation time was ∼320 ksec for the *INTEGRAL* observation and ∼152 ksec for *RXTE*. As Cyg X-1 is highly variable we decided to study the four observations independently. Our observation took place during one of the transitional states of Cyg X-1 between the hard and the soft state.

Here, we present first results of our ongoing analysis obtained with *INTEGRAL* and *RXTE*. For *RXTE* we used data from the *PCA* and *HEXTE*, covering an energy range from 3 keV to 120 keV. The *INTEGRAL* data comprises information of the three instruments *JEM-X*, *IBIS (ISGRI)* and *SPI*, including energies up to 1 MeV. The data extraction was done using HEASOFT 5.3.1 and *INTEGRAL* OSA 5.

2. FITTING THE BROAD BAND SPECTRUM

In order to compare our results of this long observation with results obtained during the *RXTE* monitoring campaign, we decided to fit our data with the same models used by Wilms et al. (2005, all correlations mentioned below refer to the data within this paper). In addition to the different continuum models we always included a Fe line at 6.4 keV and interstellar photo electric absorption. The aim of this first analysis was to check if the parameters found to fit the 3–120 keV energy range could also fit the data up to 1 MeV.

2.1. Broken Power Law Fits

The spectra of black hole candidates can be empirically described by an absorbed broken power law with an exponential cutoff (Nowak et al., 2005). The χ^2_{red} values obtained with this model range from 1.13 (obs1) to 0.94 (obs4). Broken power law fits can reproduce the spectrum equally well as the more complex `eqpair` model. The best fit parameters are $\Gamma_1 \approx 2.0$, $E_{\text{break}} \approx 10$ keV, $\Gamma_2 \approx 1.6$ and a folding energy ranging from 126 keV (obs1) to 149 keV (obs3). The values found for Γ_1 and Γ_2 agree very well with the strong linear correlation of this two parameters found in the *RXTE* monitoring campaign.

2.2. Fits using `compTT`

`compTT` (Titarchuk, 1994; Titarchuk & Lyubarskij, 1995; Titarchuk & Hua, 1995) is the first Comptonization model we used. The soft emission is modeled by adding a `diskbb` component which provides the seed photons for the Comptonization (therefore we set the temperature of the seed photons equal to kT_{in}, the temperature at the inner edge of the disk). This continuum is partly reflected off the accretion disk (*XSPEC*

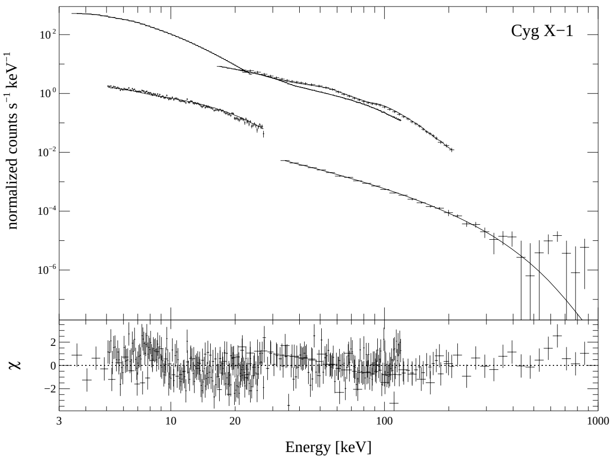

Figure 1. Best fit to the observation of 2004 November 20/21 (obs2) using the `eqpair` model. There are slight indications for a hard tail, but this could also be due to instrumental uncertainties.

model `reflect`). The parameters from this fit are in principle consistent with former results although the values for the electron temperature ($kT_\mathrm{e} \sim 69\,\mathrm{keV}$) and optical depth ($\tau \sim 0.7$) give a Compton-$y$ parameter $y = 4kT_\mathrm{e}/m_\mathrm{e}c^2 \max\left(\tau, \tau^2\right) \sim 0.35$ which differs from the value 0.5 found in the *RXTE* monitoring data for the hard state observations and is indicative for the transitional states. Consistent with this conclusion, the values for the reflection covering factor are slightly higher than in previous hard state results. The χ^2_red values of the `compTT` fits are very similar to those we get using the simple model, they range from 1.22 (obs3) to 0.96 (obs1).

2.3. Fits using `eqpair`

The third model we used is the hybrid thermal/non-thermal Comptonization code `eqpair` by Coppi (1992) in which the temperature of the Comptonizing medium is computed self-consistently. The distribution of the seed photons is defined by a disk blackbody. An example of an `eqpair` fit can be seen in Fig. 1 which shows the best fit to obs2. Table 1 summarizes the best fit parameters for all our observations. The compactness ratio, $\ell_\mathrm{h}/\ell_\mathrm{s}$, and the optical depth, τ, which describe the hard spectral component, are in good agreement with the previous results. Our values for the compactness ratio also go very well with the correlations found between this parameter and the parameters of the broken power law fits in the *RXTE* monitoring.

3. SUMMARY

We modeled the broad band spectrum of Cyg X-1 with a simple power law model as well as with more physically motivated Comptonization models. All fits are in good agreement with former results of the *RXTE* monitoring campaign, the parameters describe the extended energy range equally well. Our data show indications of a spectral hardening above $\approx 300\,\mathrm{keV}$, which could possibly be a hard tail, but could also be due to instrumental uncertainties. The next step will be fitting the broad band spectrum with models taking the existence of the jet into account.

Table 1. Best fit parameters for the `eqpair` model.

	obs1	**obs2**	**obs3**	**obs4**
N_H [$10^{22}\mathrm{cm}^{-2}$]	$0^{+0.12}_{-0}$	$0^{+0.12}_{-0}$	$0^{+0.20}_{-0}$	$0^{+0.11}_{-0}$
T_in [keV]	$1.08^{+0.03}_{-0.02}$	$1.09^{+0.05}_{-0.08}$	$1.18^{+0.01}_{-0.03}$	$1.12^{+0.05}_{-0.10}$
norm	62^{+6}_{-4}	43^{+8}_{-4}	46^{+4}_{-2}	41^{+2}_{-2}
$E_{\mathrm{K}\alpha}$ [keV]	$6.41^{+0.03}_{-0.13}$	$6.27^{+0.05}_{-0.13}$	$6.34^{+0.05}_{-0.13}$	$6.25^{+0.05}_{-0.12}$
$\sigma_{\mathrm{K}\alpha}$ [keV]	$0.79^{+0.13}_{-0.04}$	$0.82^{+0.14}_{-0.07}$	$0.62^{+0.13}_{-0.06}$	$0.75^{+0.14}_{-0.05}$
$\ell_\mathrm{h}/\ell_\mathrm{s}$	$2.76^{+0.02}_{-0.01}$	$3.15^{+0.03}_{-0.03}$	$3.69^{+0.04}_{-0.02}$	$3.96^{+0.03}_{-0.03}$
τ	$1.19^{+0.01}_{-0.03}$	$1.19^{+0.03}_{-0.03}$	$1.45^{+0.02}_{-0.01}$	$1.44^{+0.01}_{-0.07}$
$\Omega/2\pi$	$0.33^{+0.01}_{-0.01}$	$0.30^{+0.01}_{-0.01}$	$0.27^{+0.01}_{-0.01}$	$0.27^{+0.01}_{-0.01}$
ξ	0^{+13}_{-0}	1^{+10}_{-1}	3^{+10}_{-3}	1^{+13}_{-1}
χ^2_red / dof	1.18 / 343	1.27 / 342	1.73 / 341	1.19 / 338

REFERENCES

Coppi, P. S. 1992, Mon. Not. R. Astron. Soc., 258, 657

Nowak, M. A., Wilms, J., Heinz, S., et al. 2005, Astrophys. J., 626, 1006

Titarchuk, L. 1994, Astrophys. J., 434, 570

Titarchuk, L. & Hua, X.-M. 1995, Astrophys. J., 452, 226

Titarchuk, L. & Lyubarskij, Y. 1995, Astrophys. J., 450, 876

Wilms, J., Nowak, M. A., Pottschmidt, K., Pooley, G. G., & Fritz, S. 2005, A&A in press