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X-ray Spectroscopy of Cygnus X-3

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Abstract. We have analysed the X-ray spectra of the highly variable X-ray source Cygnus X-3 over a wide energy range from 5 keV to 150 keV using data selected from the RXTE archives. Separate analysis of the low and hard states show the presence of a hard powerlaw tail in both the states. Here we present the result of the wide band spectral study of the source.

Key words. Binaries: close—stars: individual: Cygnus X-3—X-rays: binaries.

1. Introduction

Cygnus X-3 is a high mass X-ray binary star system, comprising a compact object and a Wolf-Rayet type of star as the companion (vanKerkwijk *et al.* 1992). It is located at a distance of 9 kpc (Prehedl *et al.* 2000) in one of the Galactic arms. It is also very bright in the radio and the infra-red region of the electromagnetic spectrum. The soft X-ray, as well as the infra-red emission, exhibits a periodicity of 4.8 hours which is attributed to the orbital period of the binary system. In the radio band it shows flaring activity and exhibits radio jets analogous to the powerful radio galaxies and quasars during the burst phase.

The X-ray luminosity is highly variable with the source exhibiting two states, viz. low/hard and high/soft states. The X-ray high state is correlated with the major radio flares (with flux $>$ 1Jy) (Watanabe *et al.* 1994). The prominent features of the X-ray spectra are the three Fe lines at 6.37, 6.67, & 6.96 keV, respectively (resolved by ASCA observation (Kitamoto *et al.* 1994), and two absorption edges at $\sim$ 7.1keV (Rajeev *et al.* 1994) and at $\sim$9.1keV (Nakamura *et al.* 1993; Rajeev *et al.* 1994). Several models, comprising mostly of thermal (disc) blackbody, Comptonization of seed photons from a thermal multi-coloured accretion disk by a thermal Comptonizing plasma cloud (Sunyaev *et al.* 1980) and cutoff-powerlaw components, have been proposed to explain the continuum spectra of the source (Nakamura *et al.* 1993; Rajeev *et al.* 1994). The absorption of the soft X-ray due to the effective H column for this source is reported to be very high (Nakamura *et al.* 1993).

2. Data and analysis

To get a broad-band (5–150 keV) spectral picture we used 22 sets of the pointed observations of both the narrow field of view instruments aboard the RXTE: viz., PCA and the HEXTE. A systematic error of 2% was added to the PCA Standard 2 data (all

Table 1. The MJD of the pointed observations of RXTE along with the average flux obtained by ASM (2–10 keV), BATSE (20–600 keV) and GBI (radio–2.2 & 8.3 GHz.)

MJD	ASM[1]	BATSE[2]	GBI[3](2.2GHZ)	GBI[3](8.3GHZ)	Spectral state
50319	7.495	0.039	-	-	low/hard
50321	8.160	0.028	-	-	low/hard
50322	10.298	0.009	-	-	low/hard
50324	10.291	0.035	-	-	low/hard
50325	15.279	0.034	-	-	low/hard
50500	21.141	0.018	0.101	0.098	high/soft
50501	21.29	0.041	0.095	0.090	high/soft
50604	28.722		0.130	0.197	high/soft
50609	22.137	0.001	0.111	0.316	high/soft
50612	17.675	0.042	3.511	2.478	high/soft
50616	26.746	0.005	0.729	0.964	high/soft
50618	20.635	0.034	0.737	0.966	high/soft
50624	32.351	0.056	0.115	0.550	high/soft
50652	7.636	0.055	0.071	0.081	high/soft
50661	8.150	0.051	0.071	0.083	high/soft
50717	10.778	0.038	0.118	0.205	low/hard
50950	5.573	0.043	0.061	0.083	low/hard
50951	6.715	0.052	0.071	0.082	low/hard
50952	5.453	0.046	0.087	0.098	low/hard
50953	5.551	0.051	0.065	0.067	low/hard
50954	5.384	0.058	0.049	0.080	low/hard

Units: [1]counts s^{-1}; [2]photons cm^{-2} s^{-1}; [3]mJy.

PCUs added), which included all the 129 channel PHA data, and it was simultaneously fit with 64 channel data from only the cluster 0 of the HEXTE, to get a proper fit (Vadawale *et al.* 2001). Of these 22 sets of observation 13 are in the low/hard state and 9 are in the high/soft state, the details of which are given in Table 1. To get a proper idea of the spectral state during the pointed observations, in Table 1 we give the flux as observed by three more instruments: viz.,

(1) ASM aboard the RXTE, in the soft X-ray energy region (2–10 keV),
(2) BATSE aboard the CGRO, in the hard X-ray energy region (20–600 keV), and
(3) the Green Bank Interferometer (GBI) in the radio region, of the electromagnetic spectrum.

The background noise was removed from the source PHA file during the fit, and the background PHA file was generated from the model of background noise for the corresponding epoch of RXTE observation, as provided.

The resolution of the three Fe lines (Kitamoto *et al.* 1994) and the two absorption edges (Rajeev *et al.* 1994) are beyond the capability of the PCA, hence we fix the relative separation of line and edge energies as reported earlier (Nakamura *et al.* 1993; Rajeev *et al.* 1994; Kitamoto *et al.* 1994), and treat the edge energy at 7.1 keV and the normalization of all the lines and edges as the variable parameters in the fit. Throughout we fix the line width at 80 ev (reasonably accepted value as obtained from ASCA observations (Kitamoto *et al.* 1994). This mode of tying the line energies with one edge energy doesn't affect the continuum fitting, but brings the χ^2 value corrsponding to the best fit parameters within the acceptable limit. The spectra is fit separately for the

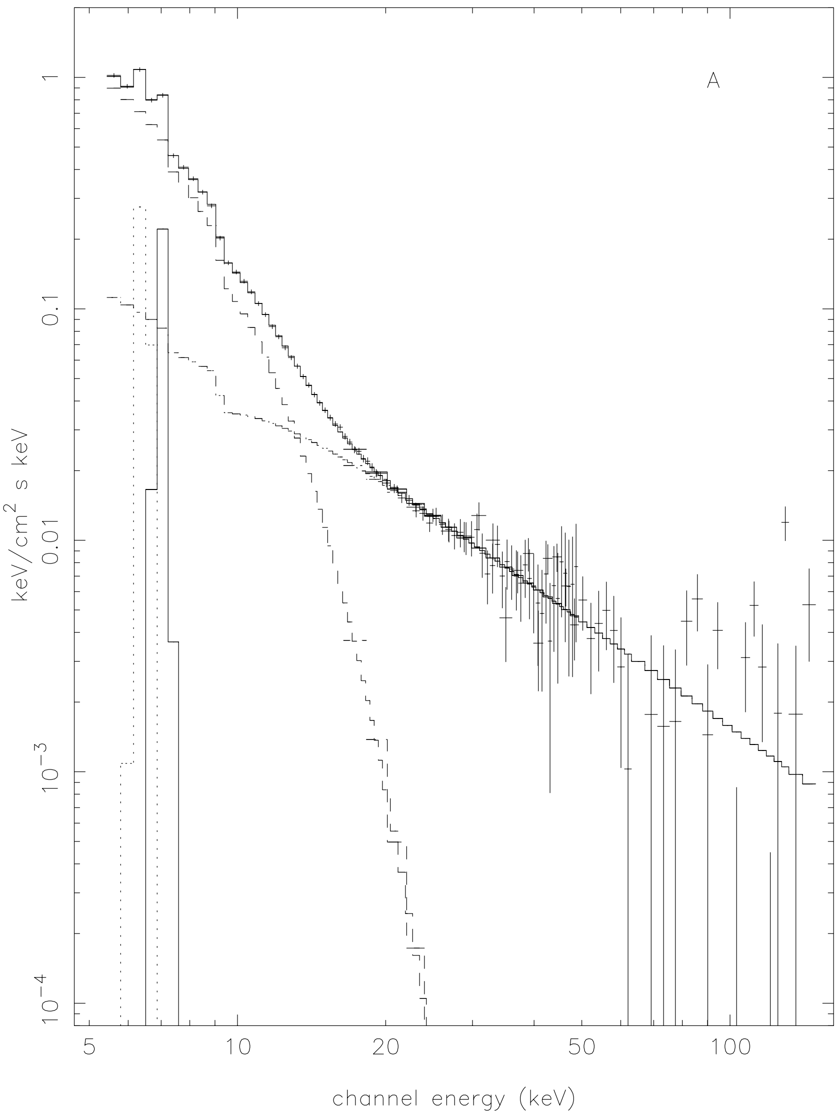

Figure 1(A). The spectra of observation on MJD 50616 showing all the components, viz., three Fe lines, two absorption edges, multicoloured disk blackbody and the powerlaw continuum.

high/soft and low/hard states. The unfolded spectra of an observation in high/soft state (MJD 50616) is shown in Fig. 1(A), and that of one of the low/hard states (MJD 50954) is shown in Fig. 1(B). The criteria of choosing these two as the representative of their respective states are: 1) exposure time, 2) quality of data, i.e., better background subtraction. Since the resolution of the PCA is poor in the lower energies and the absorption due to effective H column is a very sensitive parameter in this region, we neglect data below 5 keV and fix the height of H column to 1.6×10^{22} cm (low/hard state) and 5×10^{22} cm (high/soft state), as reported by Rajeev *et al.* (1994). The details of the best fit parameter values of the continuum components of the spectral modelling

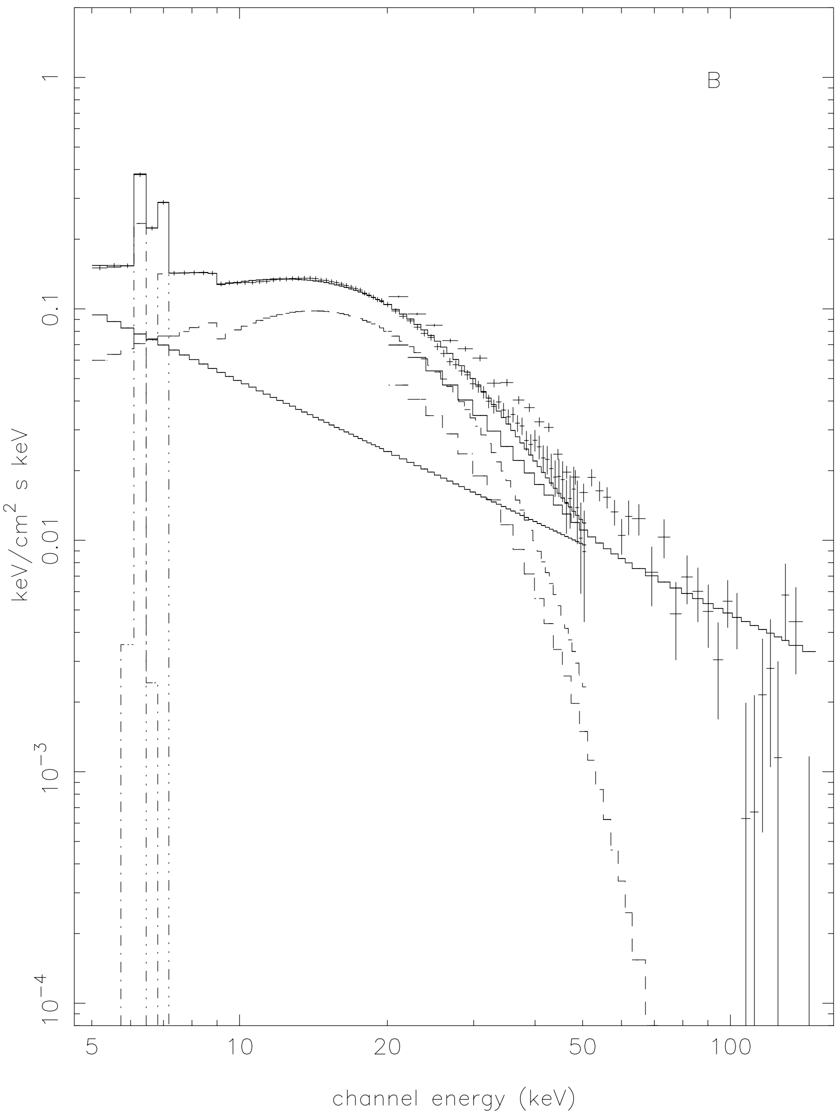

Figure 1(B). The spectra of observation on MJD 50954 showing all the components, viz., three Fe lines, two absorption edges, compST (Sunyaev & Titarchuk 1980) and the powerlaw continuum.

in the low/hard state is given in Table 2(A), and those in the high/soft state is given in Table 2(B).

3. Discussion

The high/soft state continuum emission spectra is fit by the combination of multi-coloured disk blackbody and powerlaw components. Powerlaw is needed to fit hard X-ray continuum and incorporation of any extra component viz., compST doesn't improve the quality of the fit. The low hard state continuum emission spectra is best fit

Table 2. Best fit X-ray spectral parameters of Cygnus X-3

A. Low/hard state. Best fit parameters for CompST + power law							
MJD	kT_e (keV)	Γ_X	χ^2_ν(d.o.f.)	MJD	kT_e (keV)	Γ_X	χ^2_ν(d.o.f.)
50319	4.45	2.47	1.26(86)	50321	4.39	2.51	0.90(108)
50321*	4.47	2.61	1.18(108)	50322	4.91	2.51	1.08(108)
50322*	4.36	2.70	0.92(108)	50324	4.17	2.67	0.77(108)
50325	5.58	2.45	0.60(108)	50717	5.09	2.55	0.74(86)
50950	4.97	2.10	1.26(88)	50951	4.74	2.08	1.34(89)
50952	5.02	2.03	1.43(86)	50953	5.06	2.02	1.45(91)
50954	4.87	2.01	1.42(108)				
B. High/soft state. Best fit parameters for diskbb + power law							
MJD	kT_B (keV)	Γ_X	χ^2_ν(d.o.f.)	MJD	kT_B (keV)	Γ_X	χ^2_ν(d.o.f.)
50604	1.49	2.55	0.53(109)	50609	1.59	2.21	1.19(109)
50612	1.62	2.25	1.22(109)	50616	1.55	2.53	0.65(109)
50618	1.53	2.34	0.83(109)	50624	1.52	2.63	0.60(109)
50500	1.74	2.98	0.55(109)	50501	2.91	3.06	0.54(109)
50501*	2.56	2.98	0.59(109)				

*Extended observation.

by a combination of compST (Sunyaev *et al.* 1980) and a powerlaw. Incorporation of multicoloured blackbody doesn't improve the fit. Fe line features, although significant in both states, are more prominent in the low/hard state. Absorption edges also form very important spectral features in both the states.

Hard powerlaw tail is present in both the states. This tail extends beyond 150 keV. The presence of this tail suggests thermal/non-thermal Comptonization (Zdziarski *et al.* 2001; Gierlinski *et al.* 1999) occurring in the source. Hard powerlaw tail in the high/soft state is being reported for the first time in this source, which might suggest that the compact object might be a blackhole candidate.

Cygnus X-3 is an unusually compact binary with a Wolf-Rayet companion, the wind obscuring the disc blackbody component of the soft X-ray, especially in the low/hard state, when the 10–30 keV bump (Fig. 1B), due to Comptonization, is more prominent. The high/soft state is characterised by enhanced thermal emission from the disc, changing the shape of the spectra. Therefore two different fits for the two different states are needed.

References

Gierlinski, M., Zdziarski, A. A., Poutanen, J., *et al.* 1999, *MNRAS*, **309,** 496.
Kitamoto. S., Kawashima, K., Negoro, H., *et al.* 1994, *PASJ*, **46,** L105.
Nakamura H., Matsuoka, M., Kawai, N. *et al.* 1993, *MNRAS*, **261,**. 353.
Prehedl, P., Burwitz, V., Paerels, F. *et al.* 2000, *A&A*, **357,** L25.
Rajeev, M. R., Chitnis, V. R., Rao, A. R. *et al.* 1994, *Ap. J.*, **424,** 376.
Sunyaev, R. A., Titarchuk, L. G. 1980, *A&A*, **86,** 121.
Vadawale, S. V., Rao, A. R., Chakrabarti, S. K. 2001, *A&A*, **370,** L17.
vanKerkwijk, M. H., Charles, P. A., Gebale, T. R., *et al.* 1992, *Nat*, **355,** 703.
Watanabe, H., Kitamoto, S., Miyamoto, S., *et al.* 1994, *Ap. J.*, **433,** 350.
Zdziarski, A. A., Grove, E., Poutanen, J., *et al.* 2001, *Ap. J.*, **554,** L45.