

Evolution of X-ray spectra of Cygnus X-3 with radio flares

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Abstract. Cygnus X-3, among the X-ray binaries, is one of the brightest in the radio band, repeatedly exhibiting huge radio flares. The X-ray spectra shows two definite states, low (correspondingly hard) and high (correspondingly soft). During the hard state the X-ray spectra shows a pivoting behaviour correlated to the radio emission. In the high state the X-ray spectra shows a gamut of behaviour which controls the radio flaring activity of the source. The complete evolution of the X-ray spectra along with the radio flaring activity is reported here, for the first time for this source.

INTRODUCTION

Cygnus X-3 is one of the most studied yet least understood source among the X-ray binaries. The nature of the compact object is still unresolved, although the X-ray spectral energy distribution (SED) suggests it to be a black hole candidate. Also, similar to the established black hole candidates, it shows two main states of X-ray emission, high (correspondingly 'soft') and low (correspondingly 'hard'), although these states can not be classified as the canonical black hole states as the individual spectral components during these states are not those pertaining to the classical black hole candidates, viz. Cygnus X-1 [1]. Cygnus X-3 is one of the brightest and persistent radio source among the X-ray binaries, exhibiting huge radio flares quite frequently. These flares occur during the X-ray high (and correspondingly soft) state.

General X-ray spectra

The X-ray SED of this source typically shows two different states, low (correspondingly hard) and high (correspondingly soft), see Figure 1. There is very high intrinsic absorption of the X-ray emission in this system, probably due to the dust originating from the winds of the Wolf-Rayet type companion star. As a result the disk black body component is not observable using the *RXTE-PCA* during the low state, and the spectra is best described by a comptonising component, CompST, and a power law. The high state is generally characterised by a thermal component, multi- coloured disk black body, plus a comptonising component (CompST) [2], except on a few cases when the disk black body component is replaced by a power law, analogous to the low state (see the following sections). Spectral analysis of the data ob-

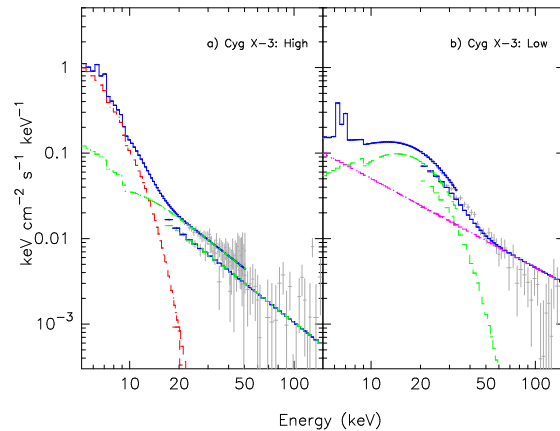


FIGURE 1. Typical X-ray spectral energy distribution of Cygnus X-3 during its high (correspondingly soft) and low (correspondingly hard) states, along with their continuum components. The high state is characterised by disk black body component and a comptonising component, (CompST). The low state is characterised by CompST and a power law.

tained from ASCA observatory also reveal three Fe emission lines at 6.36, 6.67 & 6.96 keV. These line features are more prominent during the low state (Figure 1).

LONG TERM MONITORING IN X-RAY AND RADIO BANDS

The *All Sky Monitor (ASM)* aboard the *RXTE* satellite observatory, the *Burst And Transient Sources Experiment (BATSE)* aboard the *CGRO* satellite observatory, and the *Green Bank Interferometer (GBI)* serendipitously monitored the source (quasi-)simultaneously in the soft X-ray (2-12 keV), hard X-ray (20-100 keV) and the radio (2.2

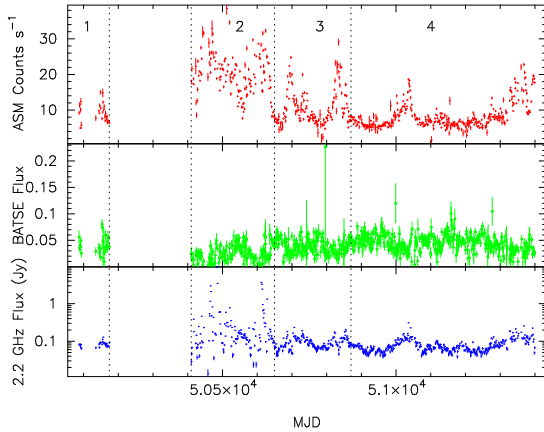


FIGURE 2. Soft X-ray (*RXTE-ASM*, 2-12 keV), hard X-ray (*CGRO-BATSE*, 20-100 keV) & radio (*GBI*, 2.2 GHz) monitoring of the source. Region 1, 3 & 4 correspond to the low state whereas region 2 correspond to the high state of the X-ray emission.

GHz) band, respectively, during the period MJD 50400 – 51500. Thereafter *CGRO-BATSE* stopped its operation while *GBI* and *RXTE-ASM* continued the simultaneous monitoring until *GBI* stopped its operation around MJD 51700.

Figure 2 shows the light curves of the source as observed by the three observatories. The regions 1, 3 & 4 correspond to the hard (as well as ‘low’) state of the X-ray emission, with correlated radio emission [3, 1]. The region 2 correspond to the high (correspondingly ‘soft’) state of the X-ray emission. Within the precincts of the hard (low) state of the X-ray emission, the soft X-ray (*RXTE-ASM*) and the radio (*GBI*) are highly correlated, while the hard X-ray (*CGRO-BATSE*) is anti-correlated to both the soft X-ray and the radio. This is due to the pivoting in the X-ray spectra, correlated to the radio emission. In the high (soft) state, we report the evidence of ejection of the central non-thermal Compton cloud, giving rise to very bright radio flares.

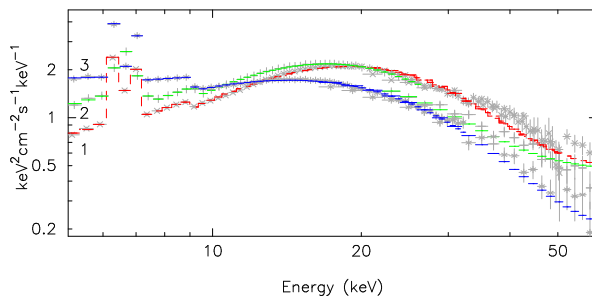


FIGURE 3. Pivoting of the X-ray spectra, correlated to the radio emission, in the low (correspondingly hard) state. The spectra becomes softer with increased radio emission.

LOW (HARD) STATE: PIVOTING OF NON-THERMAL SPECTRA

The low (as well as hard) state spectral energy distribution of the X-ray emission is generally non-thermal in nature (Figure 1). Figure 3 shows the pivoting of the X-ray spectra, which is correlated to the radio emission, in this state. The soft X-ray flux increases with the radio emission, inversely the hard X-ray flux spectra hardens with decrease in radio flux, with the pivot point lying in the region 10 – 20 keV [3, 1].

Assuming that the region of the Comptonization is confined to a small volume near the compact object, the pivoting of the spectra can be qualitatively explained by the Two Component Accretion Flow model of [4]. The Comptonisation component of the spectra originates from a region close to the compact object, confined within the Centrifugal Boundary Layer (CENBOL). At low accretion rate, the CENBOL is far away from the compact object and the spectrum is harder with lower outflow [5]. On increasing the accretion rate the CENBOL comes closer to the compact object with greater outflow, giving rise to increased radio emission and decreased non-thermal hard X-ray emission. The radio emission, from a core jet, is inversely proportional to the compression ratio which decreases as the spectra softens, in the low (hard) state.

HIGH (SOFT) STATE: X-RAY SPECTRAL EVOLUTION DRIVES THE RADIO EMISSION

The soft X-ray (*RXTE-ASM*, 2 – 12 keV) and the radio (*GBI*, 2.2 GHz) monitoring shows a more complicated evolution of the high energy emission with respect to the emission in the radio band (Figure 4), in the high (correspondingly soft) state of X-ray emission. The X-ray spectra in this state is generally dominated by the thermal multicoloured disk black body component, along with a hard component best described by a CompST model [6], except for the post flare phase, when the spectral shape hardens in the soft X-ray region. As shown in Figure 5, the salient features of the spectra are:-

The radio quiescent phase. The X-ray spectra has a strong disk black body and an equally strong Comptonising component.

Pre-radio flare. The Comptonising component vanishes, resulting in a flare. The flare may result in a time scale of a day or less.

Post-radio flare. The succession of radio flares, both minor as well as major, is stopped by the change in the X-ray spectrum, with the spectral shape harden-

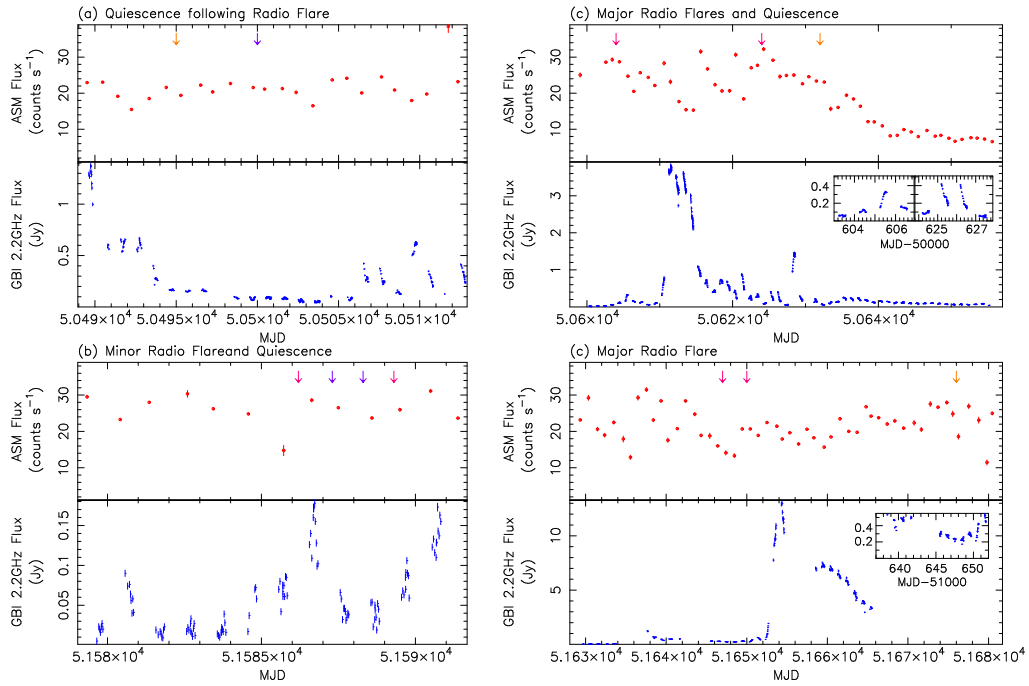


FIGURE 4. The soft X-ray (*RXTE-ASM*, 2–12 keV) and radio (*GBI*, 2.2GHz) monitoring of the source during the X-ray high state. The days for which the X-ray spectra obtained from the pointed observations using *RXTE-PCA* are reported here are indicated by arrows. The insets in the two right hand panels highlight the minor flares.

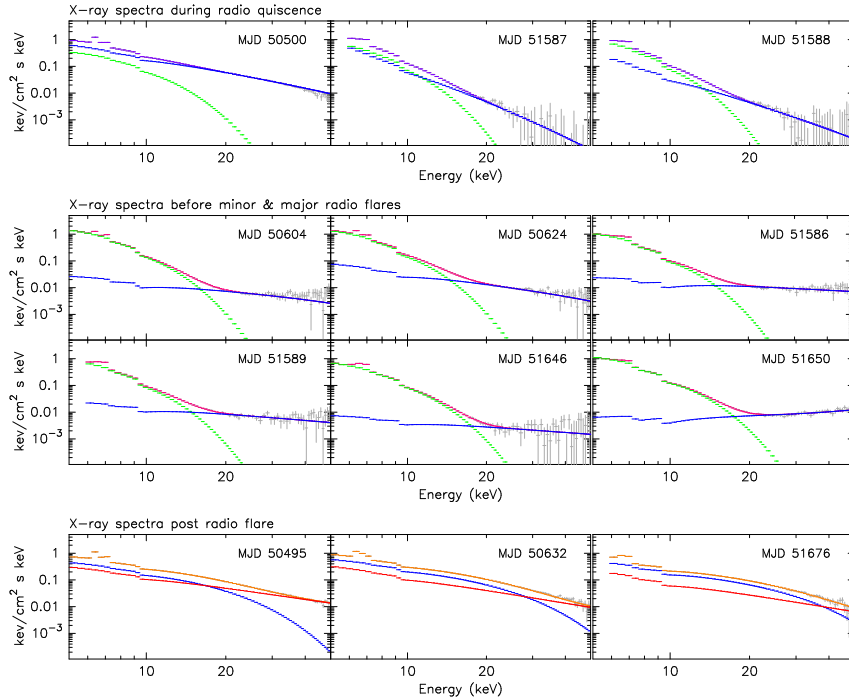


FIGURE 5. The X-ray spectral energy distribution (SED) and the individual continuum components, during the radio quiescent, pre-radio flare & post-radio flare phases. The quiescent phase has disk black body and Comptonising component at near equal ratio, the pre-radio flare has vanishingly small Comptonising component, and the post-radio flare has the disk black body component replaced by a simple power law.

TABLE 1. Model parameters of the continuum components and their flux contributions of the X-ray SED

Quiescent Radio Emission									
MJD	Total Flux	Disk Black Body			CompST				
		kT_{in} (keV)	Flux	% of Total Flux	kT_E (keV)	τ	Flux	% of Total Flux	
50500	7.9	1.8	1.9	24.05	23.93	2.22	6.0	75.95	
51587	6.6	1.44	3.4	51.51	13.39	1.59	3.2	48.49	
51588	5.1	1.42	3.7	72.55	21.69	1.39	1.4	27.45	

Pre-Radio Flare									
MJD	Total Flux	Disk Black Body			CompST				
		kT_{in} (keV)	Flux	% of Total Flux	kT_E (keV)	τ	Flux	% of Total Flux	
50604	6.6	1.53	6.0	90.91	18.27	4.07	0.6	9.09	
50624	6.9	1.55	5.9	85.51	18.34	3.31	1.0	14.49	
51586	5.3	1.56	4.4	83.02	42.31	3.41	0.9	16.98	
51589	4.5	1.53	3.8	84.44	53.53	2.40	0.7	15.56	
51646	3.6	1.63	3.3	91.67	54.33	2.53	0.3	8.33	
51650	5.8	1.70	5.0	86.21	80.79	9.91	0.8	13.79	

Post-Radio Flare									
MJD	Total Flux	Power law			CompST				
		Γ	Flux	% of Total Flux	kT_E (keV)	τ	Flux	% of Total Flux	
50495	8.5	2.43	4.2	49.41	4.03	8.12	4.3	50.59	
50632	9.9	2.62	4.0	40.40	5.12	7.05	5.9	59.60	
51676	7.9	2.62	2.7	34.18	6.18	6.36	5.2	65.82	

ing in the soft X-ray region. During this phase the disk black body component becomes insignificant, the spectral shape is explained by the similar combination of non-thermal components, viz. CompST and power law.

The evolution of the X-ray spectral changes with respect to the radio emission can be explained as follows:-

1. The radio quiescent emission is marked by the radio emission (2.2 GHz) bordering around 110 mJy and below. The X-ray spectra has strong CompST component with the amounting 75% – 25% of the total flux.
2. The vanishing of the CompST component (flux going below 15%) always precedes a minor flare, with the radio flux around $\approx 150 - 800$ mJy, suggesting the ejection of the central Compton cloud resulting in the flare. The stronger the ejection, the louder the flare.
3. The minor flare may be followed by the filling of the central Compton cloud, i.e. increase in CompST flux, causing the radio emission to become quiescent. Otherwise, if the continuous accretion persists with the central cloud unfilled, i.e. the CompST flux remains low, a major radio flare (2.2 GHz, flux > 1 Jy) follows.

4. The continuing series of minor and major flares come to an end only with the change in the X-ray spectra, i.e. hardening of the soft X-ray band, with the flux level remaining high. This is the most interesting state of the X-ray spectra with the shape being best fit by the model of the low (correspondingly hard) state, i.e. power law and CompST, although the soft X-ray flux remains high. This change in the X-ray spectra puts a brake in the episodes of radio flaring.

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