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Multi-frequency radio observations of Cygnus X-3 at the time of giant flare of May 2006

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We have carried out multi-frequency radio observation of the microquasar Cygnus X-3 during 2006 May-June, when Cygnus X-3 underwent one of the largest flare in its recorded history. We used the Giant Metrewave Radio Telescope (GMRT) at 244 and 614 MHz. We have also used archival Very Large Array (VLA) data at 8.43 and 43.3 GHz. Using these measurements and also using the published results from RATAN, we construct the radio spectrum during both rising and fading phases of the flare. The radio spectrum clearly shows the turn-over frequency shifting towards lower radio frequencies as the flare evolves. The two point spectral index from the simultaneous observations at 244 and 614 MHz shows clear variation from positive (optically thick) and negative (optically thin) values, which is consistent with the synchrotron self absorption. Applying the synchrotron self absorption model, we obtain the physical parameters such as the size of the emitting region, turn over frequency and corresponding peak flux. By obtaining the size of the emitting region at different epochs of the flare, we estimate the velocity of the expansion of the blob to be in the range 0.04c to 0.34c, assuming the magnetic field strength in the range 0.1 to 1 Gauss. This is in broad agreement with the known expansion velocities of other micro-quasars.

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Table 1: Observation log of Cyg X-3 using GMRT

Telescope	MJD (Date)	Observation Frequency (GHz)	Flux density (Jy)
GMRT	53866 (11May)	0.614	1.39
	53867 (12May)	0.614	4.16
	53868 (13May)	0.244	1.24
		0.614	7.46
	53869 (14May)	0.244	3.06
		0.614	7.15
	53870 (15May)	0.614	7.16
	53872 (17May)	0.614	5.95
	53873 (18May)	0.614	4.37
	53874 (19May)	0.614	3.50
	53875 (20May)	0.244	3.86
		0.614	2.97
	53876 (21May)	0.614	2.61
	53877 (22May)	0.244	5.3
		0.614	2.13
	53880 (25May)	0.614	1.61
	53889 (3June)	0.244	2.70
		0.614	4.27
	53900 (14June)	0.244	1.17
		0.614	5.30

1. Introduction

Cygnus X-3 is a micro-quasar, discovered in early '70s during a survey of Cygnus region [1] and has been studied extensively at different bands of electromagnetic spectrum since then. The source is highly variable in all bands and showed many major flaring events ranging from X-ray to radio in past [2, 3, 4, 5, 6]. In May-June 2006, it was reported to be in one of its strongest flare [7, 8, 9] in its recorded history. For microquasars, typically it takes only 1-3 days for the flare to rise to its peak and comparatively longer duration ($\sim$ month) to return to its pre-flare state. Therefore, due to scheduling constraints of most telescopes, it is difficult to carry out observations of the flare during its rising phase and most of the time large telescopes catch only the decaying phase of these flares. Here we report the multi-frequency radio observation of the flare using Giant Meterwave Radio Telescope (GMRT) in its both rising as well as the decaying phase. We have also analysed archival data from Very Large Array (VLA) during the same time. We also use published result from RATAN telescope [10] to study radio spectral evolution of the source at the time of flare.

2. Observations and data analysis

We have observed Cygnus X-3 using GMRT, simultaneously in 244 and 614 MHz frequencies from May 11 to June 14, 2006. GMRT consists of 30 fully steerable antennas, each of which are 45 meter in diameter. It spread over 25 km area, in western India, south-east of Mumbai. The details of the GMRT specification can be found in http://www.gmrt.ncra.tifr.res.in. In the Table 1, we have summarized all observations by GMRT, reported in this article. In the second column, the date of observations are given in MJD and in the next column the observing frequency in GHz is mentioned. In the last column, the measured flux densities are included. Each radio observations were of duration ranging from two to six hours. The flux quoted in the table corresponds to the average

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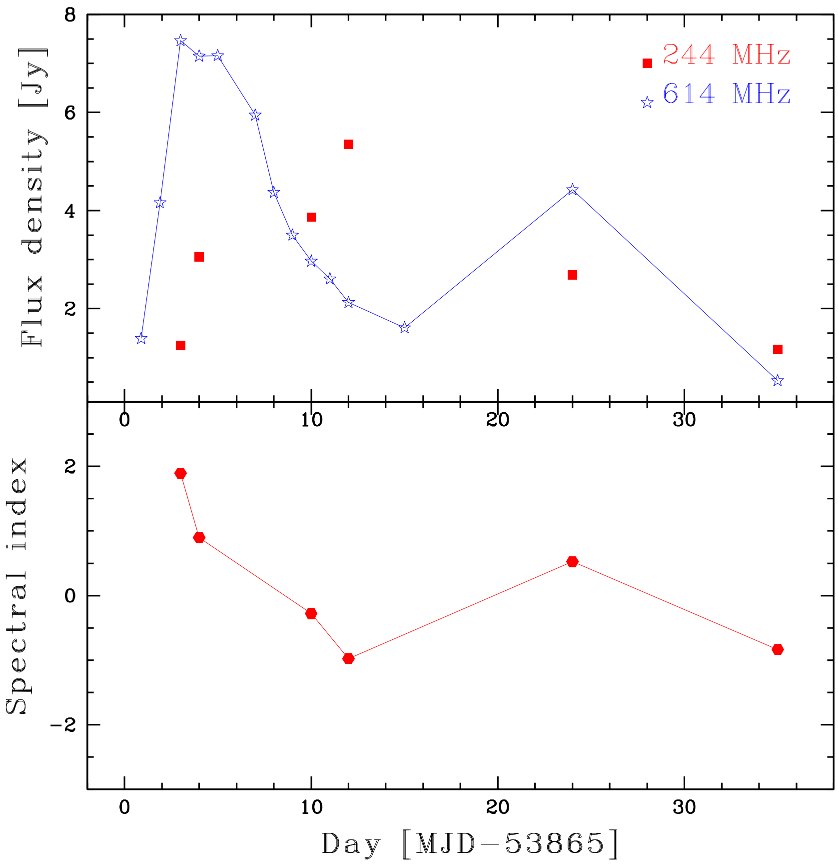

Figure 1: (*Upper panel*) Radio light curve of Cygnus X-3 during May-June 2006 flare using Giant Meter-wave Radio Telescope (GMRT). Data points correspond to 244 and 614 MHz observation are ploted. Two distinct flaring activities can be seen around 13th May and 3rd June 2006. (*Lower panel*) Variation of two point spectral index between 244 and 614 MHz for the same duration (assuming $F_\nu \propto \nu^\alpha$).

flux per observation. The data was analysed using Astronomical Image Processing System (AIPS) using standard procedure. 3C48 and 3C286 were used for both bandpass and flux calibration and 2052+365 for phase calibration. We have also analysed archival data from VLA in 8.43 and 43.5 GHz.

3. Radio light curve and spectral evolution

The radio light curve of the whole campaign is plotted in the upper panel of Figure 1. Two distinct flaring activities are observed around 13th May and 3rd June 2006. Using the simultaneous observation at 614 and 244 MHz, we have computed two point spectral index (α) and its variation over the period of observation which is shown in the lower panel of Figure 1 (we assume $F_\nu \propto \nu^\alpha$). The spectral index variation showed similar pattern for both of the flares. When the source was on the peak of the flare, on 13th May 2006, the measured spectral index was 1.89, and it gradually decreased to -0.98 on 22nd May 2006. During the second flare on 3rd June 2006, α was 0.52 at the peak which decreased to -0.83 on 14th June 2006. These behavior indicates that at the beginning

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of the flare the emitting region is compact and optically thick. As the flare progress, the emitting region expands and correspondingly spectral index shifts to negative and turn-over frequency shifts towards lower frequency region. Similar behavior of spectral index variation from optically thick to thin values, as the flare progresses, was observed earlier [11] in V4641 Sgr.

4. Radio spectrum evolution at the time of flare and jet expansion speed

The radio spectrum of the source on 11th May 2006, when the source was at the peak of the flare is shown in left panel of Figure 2 and in the right panel of Figure 2, radio spectrum of the source on 14th May 2006 is shown. The data points corresponding to 244 and 614 MHz were observed by GMRT and 8.43 and 43.3 GHz were observed by VLA and all other data points are taken from published result using RATAN [10]. On both of these days, absorption towards lower frequencies is seen indicating that the emission region is compact and optically thick at low radio frequencies. Between 11th May and 14th May, the turn-over frequency ν_t shifted from ~ 1.43 to ~ 0.78 GHz. The shifting of turn-over frequency towards lower frequency was also observed earlier for the case of other microquasar SS433 [12] and V4641 Sgr [11].

If we assume the turn-over to be due to synchrotron self-absorption, by equating the source function for the non-thermal emission with the observed flux, from the standard synchrotron-synchrotron self-absorption formula, $\theta^2 = 900 S_0 B^{1/2} F' \nu_t^{-2.5}$, where S_0 is the flux density at the turn-over frequency in Jy, θ is the angular size of the emitting region in arc seconds, ν_t is the turn-over frequency in MHz, F' is a function of power-law index $p = 2\alpha + 1$ and B is the magnetic field strength in Gauss. One can calculate $\theta/B^{1/4}$ as was previously done for the case of SS433 [12] and V4641 Sgr [11]. We find that $\theta/B^{1/4} \sim 5.44$ masGauss$^{-1/4}$ on 11th May and ~ 14.32 masGauss$^{-1/4}$ on 14th May 2006. One can obtain speed of expansion of the emitting region from the estimated size of the emitting region at different epochs for the same flare as has been done previously for the case of V4641 Sgr [11]. If we assume the distance to Cygnus X-3 to be ~ 10 kpc (viz. [13]) then the expansion velocity v is between $0.04c$ and $0.34c$ for magnetic field strength between 0.1 and 1 Gauss. This value of the expansion speed broadly agree with that of other known micro-quasars, such as V4641 Sgr [11].

Acknowledgments

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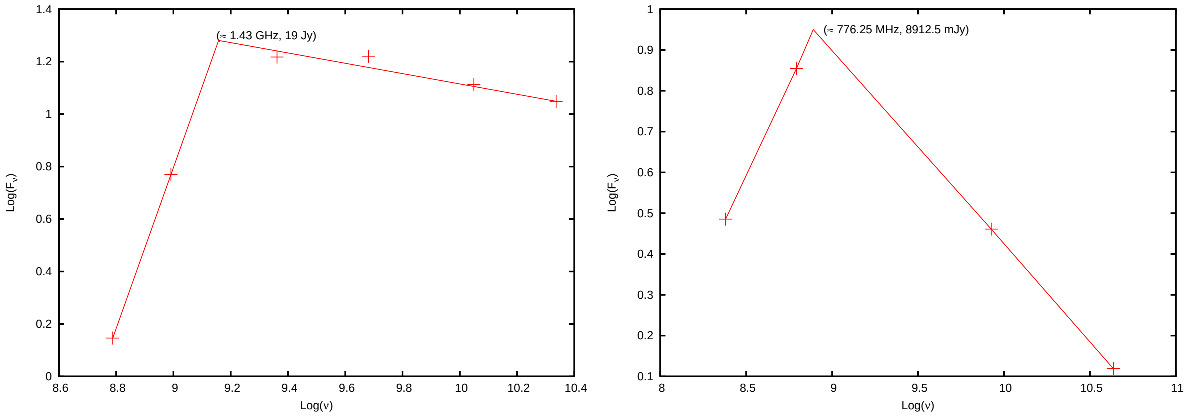

Figure 2: Radio spectrum of 11th May 2006 (*Left*) and 14th May 2006 (*Right*). Data points from 244 and 614 MHz are observed by GMRT and 8.43 and 43.3 GHz are observed by VLA. All other data points are taken from published results using RATAN [10].

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