Low Frequency GMRT Observations of Microquasar V4641 Sgr

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We have observed the micro-quasar V4641 Sgr (SAX J1819.3-2525) at the time of flare during May 2002, using the Giant Metrewave Radio Telescope at low radio frequencies (244 and 610 MHz). This is the lowest frequency radio detection of the source. The source showed clear signature of spectral evolution from optically thick to thin state. We model the spectral evolution of the source to obtain some of the source parameters. Assuming the value of magnetic field strength to be in the range of 0.1 to 1 Gauss, we obtain the initial velocity of expansion of the jet to be in the range $\sim 0.45c$ to $0.25c$. This is consistent with the known expansion velocities of the jet with other microquasars.

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1. Introduction

The micro-quasar V4641 Sgr (XTE J1819-254/SAX J1819.3-2525) was discovered independently by proportional counter array in Rossi X-ray Timing Explorer (RXTE) [1] and wide field cameras on board BeppoSAX [2] in 1999. Optical spectroscopy and photometry showed that V4641 Sgr is a black hole candidate with a mass of $\sim 9.6 M_\odot$ in a binary system with a high mass companion [3]. The radio morphology of the source suggests that it is a relativistic jet source like SS433, GRS 1915+105 and Sco X-1 [4] and thus it is a microquasar. The object showed flaring events in past in X-ray [5], optical [6] and radio [4] wavelengths. From RXTE-PCA monitoring of galactic centre region on UT 17.6 and 20.9 May 2002, Markwardt and Swank [7] reported that the source had started flaring. Here we report low frequency radio observation of the source in 244 and 610 MHz using the Giant Meterwave Radio Telescope (GMRT) during the May 2002 outburst. In Section 2, we briefly describe the observation and data analysis and in Section 3 we discuss the results. The summary and conclusions are presented in Section 4.

2. Observation and Data Analysis

The present observation of V4641 Sgr is carried out at low radio frequencies of 244 and 610 MHz using the Giant Metrewave Radio Telescope (GMRT) [8] during the radio flare in May 2002. GMRT consists of 30 fully steerable parabolic antennas out of which 16 are distributed in a nearly 'Y' shaped array and the remaining 14 antennas are randomly distributed in the central 1 km region. The resolution at 244 and 610 MHz are $13''$ and $5''$ respectively. Details of GMRT specification can be found at GMRT home page `www.gmrt.ncra.tifr.res.in` . The bandwidths of the present observations were 6 MHz and 16 MHz at 244 and 610 MHz respectively in the spectral line mode with a total of 128 channels with channel width of 125 kHz per channel. For our observations,

Table 1: Observation Log and Fluxes

| Date 2002 May (UT)	MJD	Frequency (MHz)	Duration (sec)	Flux (mJy) V4641 Sgr	Flux (mJy) background source
23.99	52417.99	244	1680	57.8 ± 7.70	102.9 ± 6.3
24.89	52418.89	244	2700	81.8 ± 5.04	105.0 ± 8.2
27.85	52421.85	244	1800	§ < 19.9	105.8 ± 10.1
28.90	52422.90	244	1800	§ < 20.3	107.5 ± 13.6
24.03	52418.03	610	1920	101.8 ± 5.25	65.2 ± 3.39
25.02	52419.02	610	1500	102.5 ± 5.33	66.3 ± 3.44
25.92	52419.92	610	4500	47.8 ± 2.97	71.0 ± 3.66
26.92	52420.92	610	4800	14.4 ± 1.75	71.3 ± 3.68
28.01	52422.01	610	2700	7.6 ± 1.38	67.9 ± 3.51
29.76	52423.76	610	1680	1.4 ± 1.28	62.8 ± 3.20

§ 5σ upper limit
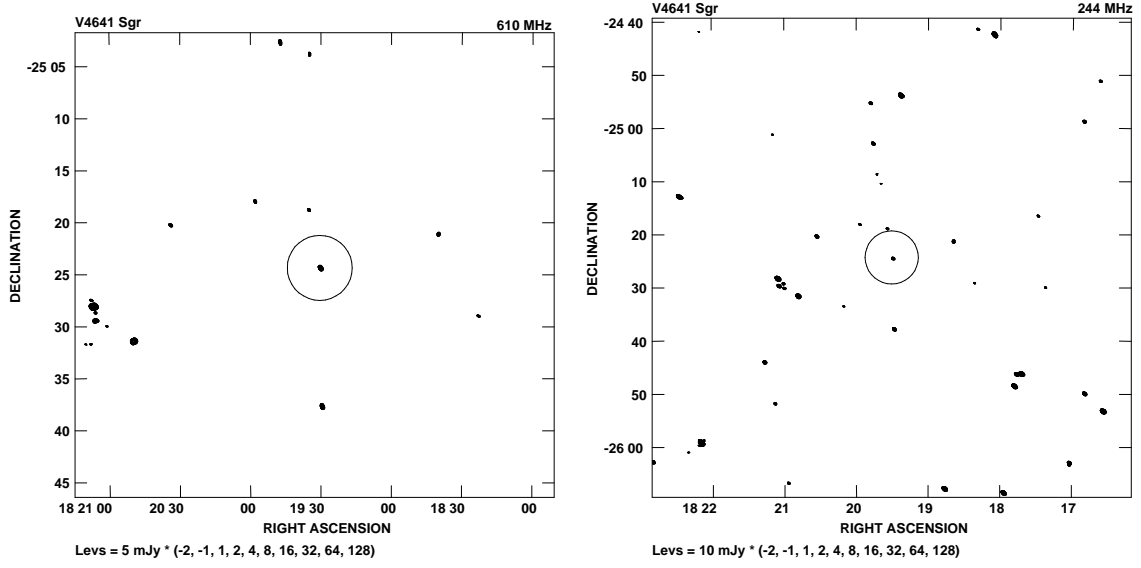
Figure 1: GMRT images of V4641 Sgr in 610 MHz (left) and 244 MHz (right). The circle drawn at the central region is only to help to locate the V4641 Sgr, which is at the center of this circle.

we used 16.9 second integration time. Presently, GMRT has a facility to observe simultaneously in 244 and 610 MHz but this facility was not available at the time of this observation. However, whenever possible, we have taken near simultaneous observation at 244 and 610 MHz. We have used 3C48 or 3C286 as flux and bandpass calibrator and 1626-298 as phase calibrator. The observation log and the measured flux of V4641 Sgr on different days are presented in Table 1. The flux of a background source J181929−253736 is also included in the Table, which exhibits constant flux.

We have also used the archival data of Very Large Array (VLA), observed between 23rd May and 31st May 2002 at 1.5, 4.9, 8.4, 15.0, 22.5 and 43.3 GHz. The array was in the AB configuration at that time. The data obtained from VLA is processed by using AIPS with standard procedures.

The data recorded with GMRT was converted to FITS format and then analyzed with the Astronomical Image Processing System (AIPS) using standard procedures. After editing the data, the data in 128 channels was collapsed into fewer channels by applying bandpass. To take care of bandwidth smearing, at 244 MHz, we have averaged each 8 channels. The flux measurements at 244 and 610 MHz were corrected for the increased sky background in the direction of V4641 Sgr.

3. Results and Discussion

3.1 Radio Light Curve and Spectral Evolution

The image of the field of V4641 Sgr at 244 and 610 MHz is presented in Figure 1. The source V4641 Sgr is indicated by a circle as on 24 May at 610 MHz and 244 MHz. The source is not resolved at any of these frequencies. There are many background sources in the field. The flux of these background sources is constant in all the days of observations within measurement errors. V4641 Sgr is clearly detected at 610 and 244 MHz over the first two days. While the flux remained
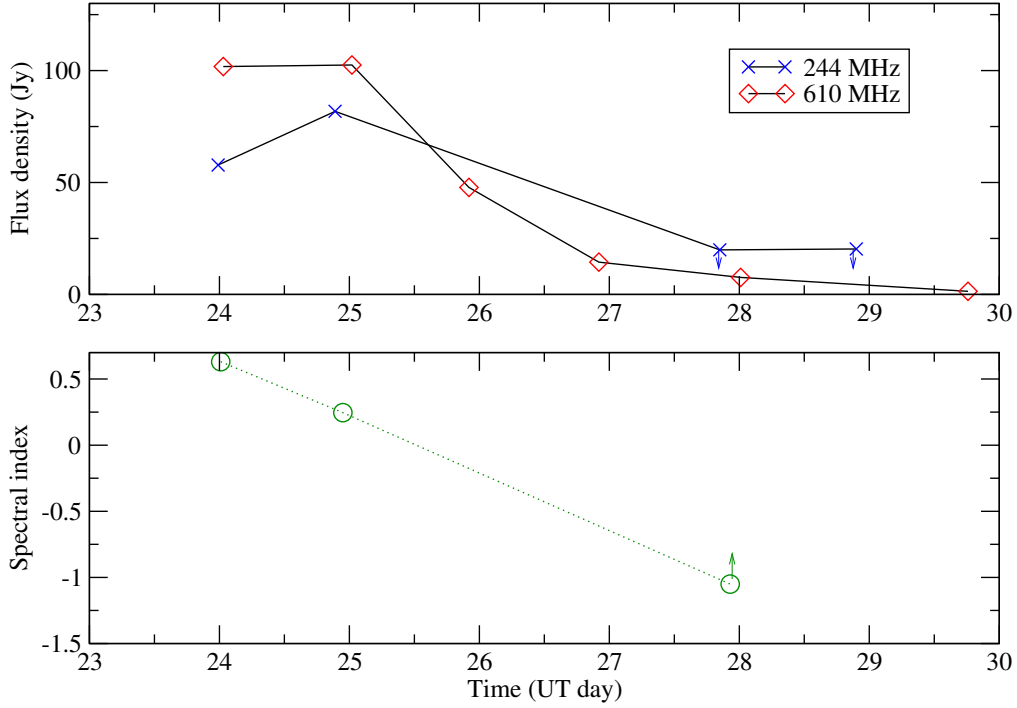
Figure 2: In the top panel, the radio light curve at 610 and 244 MHz is presented. The bottom panel shows the spectral index for the days where near simultaneous data was available between 610 and 244 MHz.

steady at 610 MHz on May 24 and 25, there was an increase in flux at 244 MHz over the same duration, indicating that the spectra has become optically thin on the second day. The radio light curve is presented in Figure 2. The source is seen to fade from 25 to 30 May 2002. The flux density is below 5σ limit of ~ 20 mJy on UT 27.85 May 2002 in 244 MHz, though it was still visible in 610 MHz with flux density of 7.6mJy (averaged over whole scan). The 5σ limit at 244 MHz is significantly higher than the detected flux at 610 MHz, hence it is possible that the source is optically thin. In the Table 1 we have listed the flux of the source (averaged over whole scan) for different days in each frequencies and for comparison the flux density of a background source J181929−253736 is also given. The radio data at 610 MHz is roughly fitted with an empirical decay formula $\sim 0.92\nu_{MHz}^{0.51}(MJD - 52419)^{-0.37}$. In Figure 2 (bottom panel), we have plotted the variation of spectral index with time between 244 and 610 MHz, assuming $S_\nu \propto \nu^\alpha$. The plot clearly shows spectral evolution from optically thick to optically thin states. The spectral index α on May 24, 2002 was ~ 0.60 which changed to 0.24 on next day. The source showed high variability for each days of observation. In Figure 3, we show the variability of the source for the observation of four days at 610 MHz. No signature of any periodicity or quasi periodic oscillation is found from the fast Fourier transform of short scans of variable radio data.
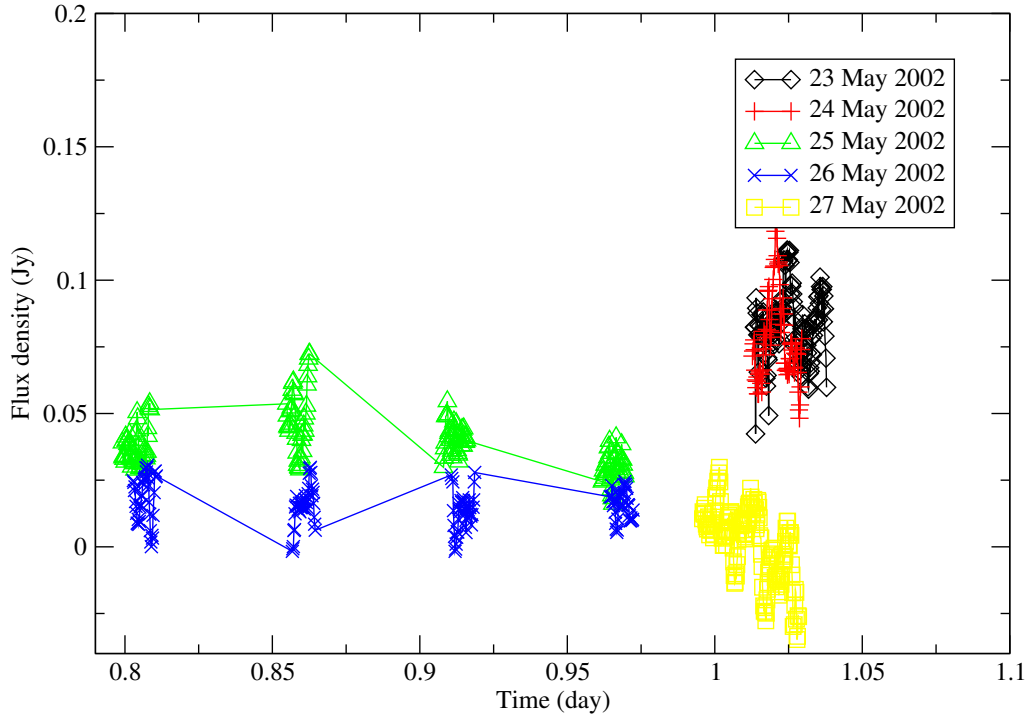
Figure 3: Variation of radio flux density at 610 MHz obtained on 24, 25, 26, 27 and 28 May 2002. Data is obtained using the Giant Meterwave Radio Telescope (GMRT).

3.2 Jet Expansion Speed

If we assume the absorption in the optical thick region is due to synchrotron self absorption, it is possible to calculate the quantity $\theta/B^{1/4}$ (containing the size of the radio source θ and the magnetic field B) by equating the the observed flux with the source function for the non thermal emission (as done for the case of SS433 in Pal et al [9]). From the standard synchrotron synchrotron self-absorption formulae, [10]

$$\theta^2 \approx 900 S_s^* B^{1/2} F' v_s^{-2.5} \tag{3.1}$$

where θ is in seconds of arc, v_s is the turnover frequency in MHz, S_s^* is the flux density at the turnover frequency in Jy, F' is a function of the power-law index p $(= 2\alpha + 1)$ and B is the magnetic field in Gauss.

From Figure 4, where we have shown the radio spectrum of the source on 23rd May 2002 (UT 08h to 12h), the turnover frequency is approximately $v_s \sim 17$ GHz and the spectral index α between 22.5 and 43.3 GHz is -0.89 (assuming $S_v \propto v^\alpha$). This implies $\theta/B^{1/4} \sim 0.13$, where θ is in milli-arcsec and B in Gauss. If we assume $B \sim 100$ mG, the size of the radio source will be $\theta \sim 0.23$ mas.
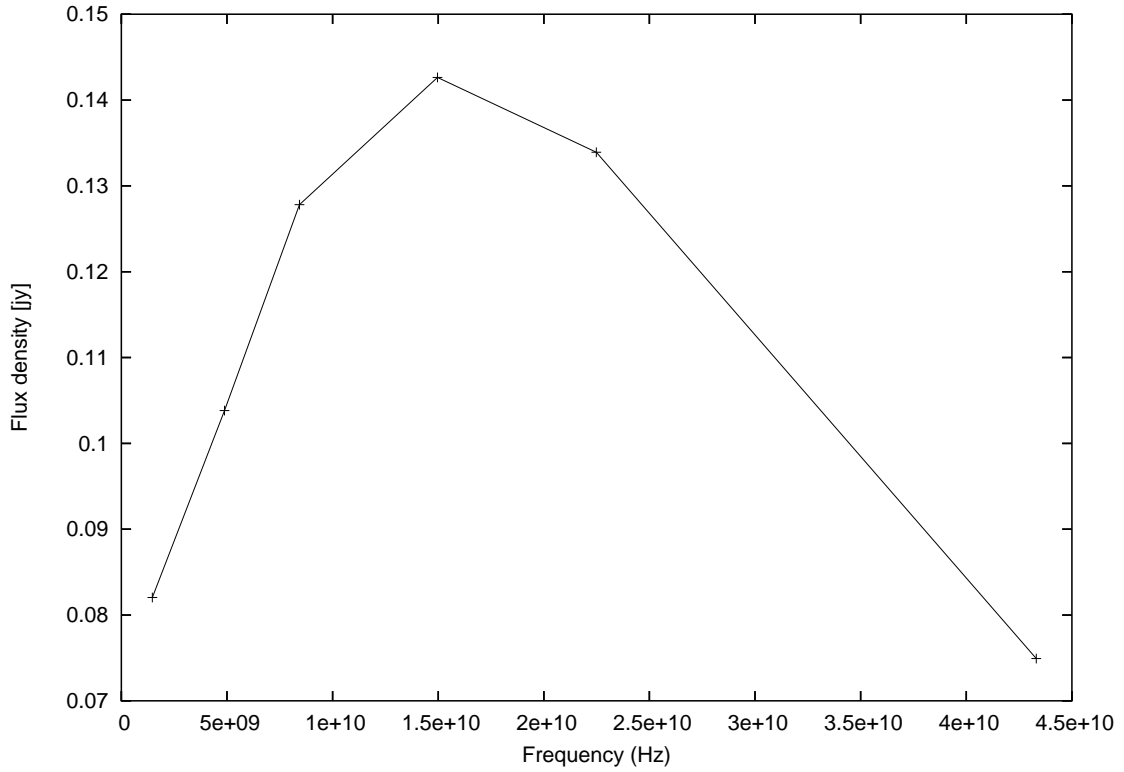
Figure 4: Radio spectrum of V4641 Sgr on 23rd May 2002 from VLA archival data.

The source has expanded since then and the spectra has become optically thin. The source is not detected in further VLA observations at GHz frequencies a few days later. From the GMRT light curve, the synchrotron turn over frequency did not cross below 610 MHz till 25th May. Unfortunately there is no measurement at 244 MHz on this day or on 26th May, but the examination of the light curve at 244 MHz suggests that the peak should have occurred after 25th May, but before 27th May. The time at which the 244 MHz emission would have peaked can be estimated using the adiabatic expansion models used to estimate the time delay for GRS1915+105 [11]. Assuming an optically thin spectral index of ~ 0.75, the application of the above model gives us a time delay of ~ 2.7 days between the peak at 17 GHz and 244 MHz. This means the 244 MHz emission would have peaked on May 26.1. This is broadly consistent with the light curve, where the peak at 244 MHz was expected after 25th May, but before 27th May, hence we use this time for further calculations. From the synchrotron self absorption equation, $\theta/B^{1/4} \sim 20$ if the turnover frequency and flux is 244 MHz and 100 mJy respectively. Assuming a magnetic field $B \sim 100$ mG, we get the size of the radio source to be $\theta \sim 35.7$ mas.

It should be noted that the size of the source depends weakly on the value of the magnetic field *B*. From the expansion between the days mentioned above, we can obtain the source expansion speed. Taking the distance of V4641 Sgr to be 6.1 kpc [12], the velocity of expansion comes out to be $\sim 0.45c$. If we assume the magnetic field to be 1 Gauss, the expansion speed is $\sim 0.25c$.

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4. Conclusion

We have shown for the first time that V4641 Sgr is active at meter wavelengths. This is the first detection of the source at the low frequency of 244 MHz. The source has shown considerable variability at 610 MHz. Synchrotron self absorption explains the behavior of the source in the optically thin limit with reasonable extent. Assuming the radio source is expanding spherically, we get the velocity of expansion of $\sim 0.45c$ to $0.25c$ for magnetic field values of 0.1 to 1 Gauss. This is broadly in agreement with the expansion speeds observed in some of the microquasars.

Acknowledgments

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