Chin. J. Astron. Astrophys. Vol. 5 (2005), **Suppl.**, 87–92
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Low Frequency Radio Observations of GRS 1915+105 with GMRT

C. H. Ishwara-Chandra[1] ⋆, A. Pramesh Rao[1], Mamta Pandey[2],
R. K. Manchanda[3] and Philippe Durouchoux[4]

[1] National Center for Radio Astrophysics, TIFR, P. B. No. 3, Ganeshkhind, Pune - 7, India
[2] Department of Physics, University of Mumbai, Mumbai - 400 078, India
[3] Tata Institute of Fundamental Research, Homi Bhaba Road, Mumbai - 400 005, India
[4] CEN Saclay, DSM, DAPNIA, Service d'Astrophysique, 91191 Gif sur Yvette, France

Abstract We present the first detailed low frequency radio measurements of the galactic microquasar GRS 1915+105 with GMRT. Simultaneous observations were carried out at 610 and 244 MHz. Our data does not show any signature of spectral turn over even at low radio frequency of 244 MHz. We propose that while the radio emission at high radio frequencies could predominantly come from compact jets, the emission at lower frequency originates in the lobes at the end of the jet which acts like a reservoir of low energy electrons.

Key words: stars: individual: GRS 1915+105 – radio continuum: stars – X-rays: binaries

1 INTRODUCTION

The Galactic X-ray transient source GRS 1915+105 was discovered in 1992 by the `GRANAT` satellite (Castro-Tirado et al. 1992). It has now been established as a black hole binary with the black hole mass of $14{\pm}4M_\odot$ and the companion K-M III star of mass $1.2{\pm}0.2M_\odot$ (Greiner et al. 2001). The source was shown to possess relativistic outflows during its radio outbursts (Mirabel & Rodríguez 1994). Extensive monitoring of GRS 1915+105 in the radio and X-ray band showed that the overall radio emission is correlated with its X-ray properties (eg: Harmon et al. 1997). The radio emission from the source can be broadly classified into three categories; (i) the relativistic superluminal radio jets of flux density ~ 1 Jy and above at cm wavelengths, with decay time-scales of several days (Fender et al. 1999), (ii) the baby jets of $20-40$ min durations with flux density of $20-200$ mJy both in infrared (IR) and radio (Pooley & Fender 1997; Eikenberry et al. 1998) and (iii) the plateau state with persistent radio emission of $20{-}100$ mJy for extended durations (Muno et al. 2001). In the case of superluminal jets, the radio emission has steep spectra and are observed at large distances ($400-5000$ AU) from the accretion disk (Fender et al. 1999; Dhawan et. al 2000). The radio emission at this distance is believed to be decoupled from the accretion disk. In contrast, the other two classes of radio emission has flat spectra and occur close to the accretion disk (within a few tens of AU; Muno et al. 2001). Even

⋆ E-mail: `ishwar@ncra.tifr.res.in`

Table 1 Some Useful Parameters of GMRT

Frequency (MHz)	151	235	325	610	1000 − 1450
Primary Beam (°)	3.8	2.5	1.8	0.9	0.56–0.4
Resolution (″)	20	13	9	5	2–3
RMS (mJy)/hour	??	2	1	0.5	0.1

though superluminal jets and baby jets are differentiated by their spectra, decay time scales, and the distance from the accretion disk at which the emission takes place; there is an evidence for the ejection of significant amount of relativistic material even during the baby jets (Fender et. al 1999). The radio emission is believed to be due to synchrotron emission from relativistic electrons and the dominant decay mechanism is the adiabatic expansion losses (Mirabel et. al 1998). The frequency corresponding to the peak radio flux in the source spectrum depends on the energy and spectral distribution of the electrons in the emitting volume. In the absence of in-situ acceleration, the energy of the electrons will decrease both by radiative and expansion losses and therefore, the peak flux will exhibit temporal evolution by shifting to lower frequencies. In the case of emission of baby jets from the GRS 1915+105, where there is evidence for ejection of significant amount of relativistic material, we expect low frequency ($<$ 1 GHz) radio emission from the "relic" electrons (Kaiser et al. 2004).

In this paper, we present the low frequency radio data taken simultaneously at two wavelengths and discuss the results in terms of the geometric model of the source.

2 OBSERVATIONS AND RESULTS

The radio observations of GRS 1915+105 were carried out at 610 and 244 MHz simultaneously with Giant Meterwave Radio Telescope (GMRT, Swarup et. al 1991). These observations are part of major programme to monitor microquasars with GMRT for extended duration (Pandey et al. 2004). The present data corresponds to two days of observations, viz, of June 21 and 22, 2003.

GMRT is the world's largest radio telescope at meter-wavelengths and consists of 30 antennas, each of 45 metre diameter spread over about 25 km in the form of a compact central square and distributed Y-array. Some of the parameters of GMRT are given in Table 1, more details about the telescope can be found in `www.ncra.tifr.res.in`. GMRT has a built-in facility to observe simultaneously at 610 and 244 MHz, which was availed for the present observations. The flux density scale is set by observing the primary calibrator 3C286 or 3C48. A phase calibrator was observed before and after a 30 min scan on GRS 1915+105 for phase calibration. The integration time was 16 s. The data recorded from GMRT was converted to FITS and was analysed using Astronomical Image Processing System (`AIPS`). An iterative method of phase self calibration was performed to reduce the phase errors and to improve the image quality.

The radio images of GRS 1915+105 at 244 and 610 MHz are presented in Figure 1. The source is unresolved at both frequencies. In Figure 2, we have plotted the observed flux at different frequencies during the two observations. The present observations clearly demonstrate that GRS 1915+105 exhibits strong radio emission at 610 and 244 MHz and there is no evidence for spectral turnover up to 244 MHz. The flux densities at these frequencies have been corrected for the increased system temperature in the direction of GRS 1915+105. On June 21, 2003, the flux density of GRS 1915+105 at 610 MHz is 194.5±1.6 mJy and at 244 MHz is 756±58.7 mJy giving a spectral index of -1.46 ($S_\nu \propto \nu^\alpha$; Figure 2). On June 22, 2003, the flux density at 610 MHz is 156.2±1.5 mJy and that at 244 is 672±7.9 mJy, with a spectral index of -1.57 (Fig. 2), marginally steeper than the previous day. This marginal steepening is consistent with the expectation that the 244 MHz emission decays slower than 610 MHz. The observed spectral

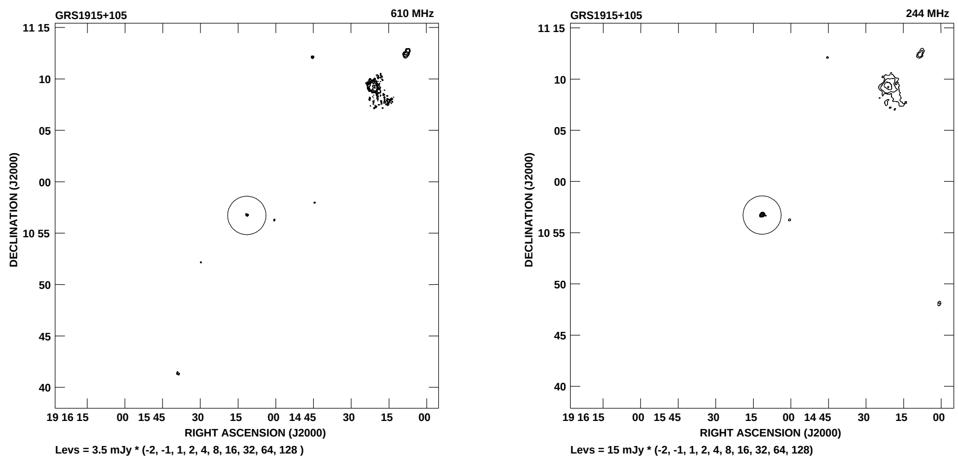

Fig. 1 Field of GRS 1915+105 at 610 (left) and 244 MHz (right). The circle drawn at the central region is only to help to locate the GRS 1915+105, which is at the center of this circle. The rest of the sources in the field are likely to be unrelated to GRS 1915+105.

indices on both days suggests that the radio emission at low frequencies arises in a optically thin medium.

3 DISCUSSION

The low frequency radio emission of microquasars are useful to understand and constrain several parameters such as compactness of the radio emitting plasma, the density of ambient medium. The radiative lifetimes of the electrons are also longer at these frequencies, thus the source will be visible for longer duration as compared to higher radio frequencies.

In the case of a compact radio emitting plasma, synchrotron self absorption will result in the spectral turn around at lower radio frequencies. In contrast, the extended diffused emission will result steep power-law spectra corresponding to a optically thin region. As seen in Figure 2, in the case of GRS 1915+105, the flux density seems to increase at lower frequencies suggesting a large population of low energy electrons in an optically thin plasma. The data suggest that source is not self-absorbed and the large flux value does indicate a separate region of large surface brightness in the source geometry.

In the following, we discuss the possible geometry of the emission and compare the radio properties of GRS 1915+105 with other well known microquasars.

3.1 Proposed geometry of emission region

The low frequency radio emission is unlikely to come from jet, since the geometry of a jet is compact and therefore, the low frequency radio emission would be self absorbed. In the standard model for the spherical radio emitting plasma, the higher frequency emission comes from the inner regions and the lower frequency comes from the outer layers due to increased optical depth for the inner layers (van der Laan, 1966; Hjellming and Johnston, 1988). Such a model is also referred as "onion model".

In the case of GRS 1915+105, the basic physical process will be similar to the onion model with a difference that geometrical nature of the emitting volume is not spherical, but a conical jet (Hjellming and Johnston, 1988). In this model, the infra-red emission occurs shortly after

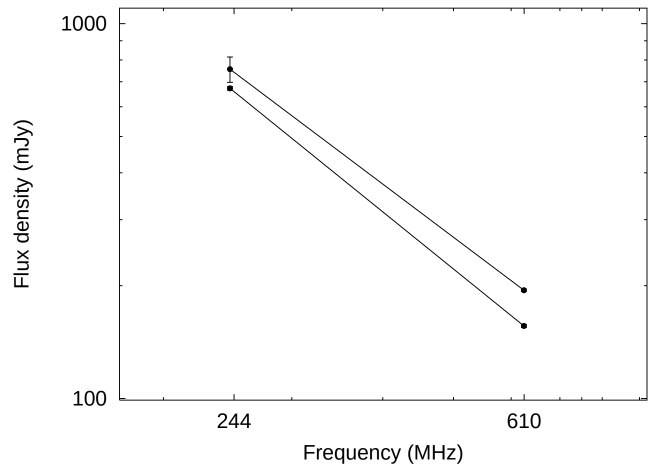

Fig. 2 Spectral index plot between 610 and 244 MHz for June 21 (upper line) and June 22, 2003 (lower line).

the ejection of the plasma from the accretion disk and radio emission follows with a time delay (Mirabel et al. 1998). As the plasma moves outwards along the jet, it also undergoes expansion and becomes optically thin. The peak of the emission moves progressively to lower frequencies. The plasma will continue to expand if the ambient medium is not dense enough to slow down or stop the expansion. Under such conditions, lobes will be formed at the end of the jet, similar to case of AGNs (Figure 3). Therefore no absorption effects will be visible and the spectra will continue to be optically thin.

3.2 Comparison with other microquasars

Eventhough GRS 1915+105 has been extensively observed over years in the radio wavelengths, nearly all the observations have been carried out at higher radio frequencies. In the absence of a spectral information of the source at lower frequencies, the true nature of the emission behavior is difficult to unravel, since the peak of the emission will evolve in to lower frequency domain and the knowledge of the spectral break is important. Some of the other known microquasars with strong radio emission exhibit spectral turn over at cm wavelengths (Cyg X-3: Miller-Jones et al. 2004; V4641 Sgr: Ishwara-Chandra and Pramesh Rao, this proceedings).

In the case of Cygnus X-3, the radio spectra is optically thin and steep above GHz frequencies whereas the spectra is flat or inverted at lower frequencies. The spectral turnover is understood as synchrotron self-absorption which suggests that the emitting region is compact. This is possible if the expansion of the jet is limited by the dense surrounding. Such clear spectral turn over at low radio frequencies give important information about the source and its ambiance. If the spectral turn over frequency is known, by applying the synchrotron self absorption models, it is possible to estimate the size and the magnetic field of the emitting region. Similarly, the microquasar V4641 Sgr also exhibits spectral turnover at low radio frequencies (Ishwara-Chandra and Pramesh Rao, this proceedings). However in the case of GRS 1915+105, the spectral turnover was not observed suggesting that the emitting region must be extended. In the present observations, GRS 1915+105 is unresolved at 610 MHz and at 244 MHz. The low frequency radio images are highly scatter broadened and scaling relation between the source size and frequency need to be used to obtain the true size. High resolution, high frequency

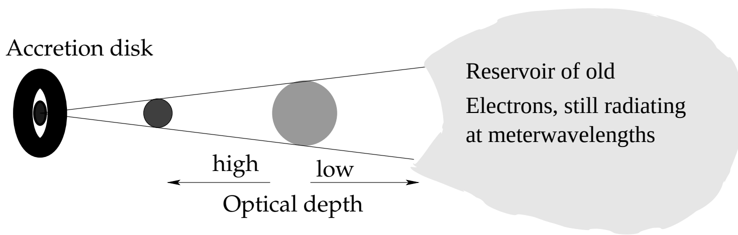

Fig. 3 Toy model to suggest the possible location for the low frequency radio emission.

imaging are required to obtain the scaling relation and to estimate the true size of emitting plasma at low radio frequencies.

3.3 Is this unique to GRS 1915+105?

The related question to be addressed is whether the extended low frequency radio emission in GRS 1915+105 is present at times when there are no flares at higher frequencies. Even in the case of baby jets and plateau state where high frequency radio emission is coupled to the activities of the accretion disk, the plasmon will expand outwards and will eventually decouple. These plasmons are expected to radiate at lower radio frequencies with longer lifetimes by virtue of the low energy of the electrons and slower expansion rate. Hence it is important to monitor GRS 1915+105 at 610 and 244 MHz even in the radio quite state. As a part of our ongoing project, GRS 1915+105 has been observed at 610 and 244 MHz even when there are no flares at high frequencies. The data analysis is in progress and the results will be published elsewhere.

4 SUMMARY

We have presented for the first time, detailed low frequency radio observations of the galactic microquasar GRS 1915+105 with GMRT. The observations have been carried out at 610 and 244 MHz simultaneously. Our results suggest that there is no spectral turn over even at low radio frequencies of 244 MHz. We suggest that while the radio emission at high radio frequencies could predominantly come from compact jets, the lower frequency emission is likely to come from regions far from the accretion disk. The relativistic plasma which was ejected from the accretion disk will move outwards and in this process, it will loose energy both by radiation and by expansion and will form the lobe, similar to the case of AGNs. This reservoir of low energy electrons is likely to be the origin for optically thin low frequency radio emission.

Acknowledgements GMRT is run by the National Centre for Radio Astrophysics of the Tata Institute of Fundamental Research. This research has made use of NASA's Astrophysics Data System and of the SIMBAD database, operated at CDS, Strasbourg, France.

References

Castro-Tirado A. J., Brandt S., Lund N., 1992, IAUC, 5590

Dhawan V., Mirabel I. F., Rodriǵuez L. F., 2000, ApJ, 543, 373

Eikenberry S. S., Matthews K., Morgan E. H., Remillard R. A., Nelson R. W.,1998, ApJ, 494, L61 (E98)

Fender R. P., Pooley G. G., 1998, MNRAS, 300, 573 (F98)

Fender R. P., Garrington S. T., McKay D. J., Muxlow T. W. B., Pooley G. G., Spencer R. E., Stirling A. M., Waltman E. B., 1999, MNRAS, 304, 865

Greiner J., Cuby J. G., McCaughrean M. J., 2001, Nature, 414, 522

Harmon B. A., Deal K. J., Paciesas W. S., Zhang S. N., Robinson C. R., Gerad E., Rodriguez L. F., Mirabel I. F., 1997, ApJ, 477, L85

Hjellming R. M., Johnston K. J., 1988, ApJ, 328, 600

Kaiser C. R., Gunn K. F., Brocksopp C., Sokoloski J. L., astro-ph/0405206

Miller-Jones J. C. A., Blundell K. M., Rupen M. P., Mioduszewski A. M., Duffy P., Beasley A. J., 2004, ApJ, 600, 368

Mirabel I. F., Rodriǵuez L. F., 1994, Nature, 371, 46

Mirabel I. F., Dhawan V., Chaty S., Rodriǵuez L. F., Marti J., Robinson C. R., Swank J., Geballe T., 1998, A&A, 330, L9 (M98)

Muno M. P., Remillard R. A., Morgan E. H., Waltman E. B., Dhawan V., Hjellming R. M., Pooley G. G., 2001, ApJ, 556, 515

Pandey M. D., Durouchoux P., Manchanda R. K., Rao A. P., Ishwara-Chandra C. H., Pooley G., 2004, in Proceedings of *Fifth INTEGRAL workshop*, Munich 16-20 February 2004

Pooley G. G., Fender R. P., 1997, MNRAS, 292, 925

Swarup G., Ananthakrishnan S., Kapahi V. K., Rao A. P., Subrahmanya C. R., Kulkarni V. K., 1991, Curr. Sci., 60, 95

van der Laan H., 1966, Nature, 211, 1131