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EVN and MERLIN confirmation of the LS 5039 jets

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Abstract. The microquasar nature of LS 5039 was revealed by May 1999 VLBA+VLA observations showing a two-sided jet at milliarcsecond scales. Here we present follow-up interferometric observations carried out with the EVN and MERLIN at 5 GHz in March 2000. The obtained maps with both the EVN and MERLIN show a two-sided jet with a similar position angle to the previous VLBA+VLA map. The total length of the jet arms is ~ 60 mas in the EVN map and ~ 300 mas in the MERLIN map. A brightness and length asymmetry of the jets, compatible with the earlier observations, is also present in the maps. Overall, these observations confirm the existence of a two-sided jet structure in LS 5039 and seem to indicate their persistent nature.

1. Introduction

LS 5039 is a high mass X-ray binary system, with an optical magnitude $V = 11.2$ and spectral type O6.5V(f), located at a distance of ~ 2.9 kpc and close to the galactic plane ($l = 16.88°$, $b = -1.29°$). VLA observations carried out by Martí et al. (1998) found that the source was also a non-thermal radio emitter with moderate variability. Paredes et al. (2000) discovered that the system displays relativistic radio jets, revealing the microquasar nature of LS 5039, and proposed an association with the high energy γ-ray source 3EG J1824−1514. The population of microquasars is still a very reduced one, with the best representative examples being SS 433, GRS 1915+105, Cyg X-3 and GRO J1655−40 (Mirabel & Rodríguez 1999). McSwain et al. (2001) have recently obtained the radial velocity curve of the system, determining a period of $P \simeq 4.1$ days and a high eccentricity of $e \simeq 0.4$. Recently, Ribó et al. (2002) have found that LS 5039 is a runaway X-ray binary.

2. Observations and data reduction

We observed LS 5039 simultaneously with MERLIN and the EVN on March 1st 2000 (3:20–7:10 UT) at 5 GHz. Single dish flux density measurements were carried out with the MPIfR 100 m antenna in Effelsberg, Germany.

The EVN observations were performed with EB, JB, CM, WB, MC, NT, and TR, recording in MkIV mode with 2 bit sampling at 256 Mbps at left hand circular polarization, allowing a bandwidth of 64 MHz. The data were processed at the MkIV correlator at JIVE with an integration time of 4 s. Interferometer fringes for LS 5039 were detected in all baselines. A later fringe fitting of the residual delays and fringe rates was performed within AIPS for LS 5039. We averaged in frequency the data and exported them to be imaged and self-calibrated into DIFMAP. The final imaging was carried out on those data after editing and averaging of the visibilities in 32 s blocks.

The EVN and MERLIN arrays have one common baseline, from JB to CM. That allows to combine both data sets and find some redundancy in the data to map them together, reaching (u, v) resolution ranges from 0.015 Mλ (MK2-Tabley) to 26 Mλ (JB-NT) at 5 GHz.

3. Results and discussion

The flux density monitoring with the Effelsberg antenna was not reliable due to confusion to nearby sources. However, inspection of the shortest baselines of MERLIN reveals a constant flux density during the full observation. We present all the resulting maps in Fig. 1, and the parameters of each one in Table 1. These maps clearly show that LS 5039 is a source of bipolar jets emanating from a central core. There is some asymmetry in the jets, both in flux density and separation from the core, that may involve relativistic beaming. These results confirm the existence of bipolar radio jets in LS 5039 obtained in previous VLBA+VLA observations by Paredes et al. (2000). We must note that this source apparently does not show strong outbursts or, at least, have never been detected in the eleven-month monitoring carried out by the Green Bank Interferometer. This suggests that the jets could be steady, as seem to indicate the VLBI maps obtained up to now. The total size of the jets in the EVN map is ∼180 AU and ∼900 AU in the MERLIN map. Hence, the jets extend to larger distances than those typically imaged with the VLBA+VLA observations, of ∼18 AU. All of them have similar position angles, being at a P.A. of $\sim 125°$ at VLBA scales, P.A. $\sim 140°$ at EVN scales and P.A. $\sim 150°$ at MERLIN scales, suggesting a bending of the jets with increasing distance from the core and/or precession. From the EVN map, we obtain for the approaching component (southeast) a flux density of 1.8 mJy and a

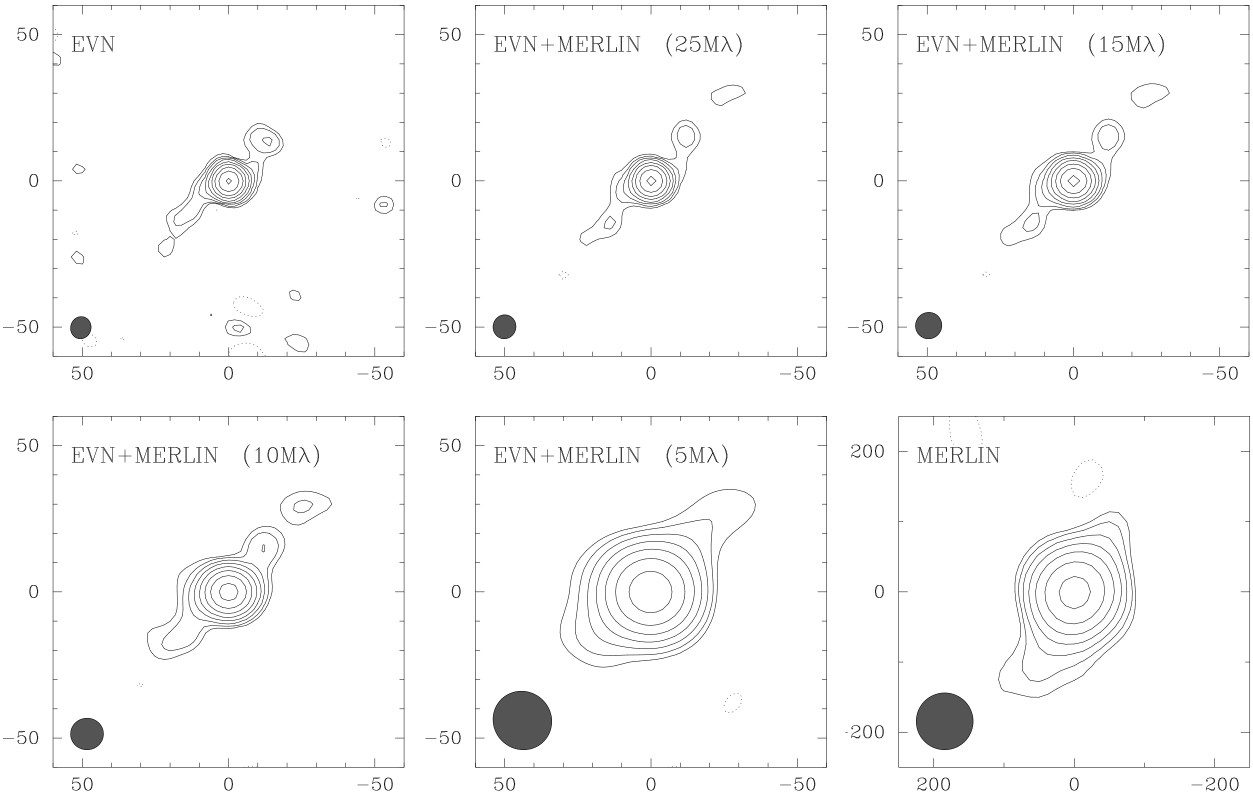

Fig. 1. Self-calibrated maps of LS 5039 at 5 GHz obtained on March 1, 2000, from higher to lower resolutions. Contours are those listed as $S_{\rm min}$ in Table 1 and scaled with $\sqrt{3}$. Note that the map scale is different at the bottom right panel (MERLIN data).

total distance from the core of 34 mas. For the receding component (northwest) the values are 1.5 mJy and 24 mas. Using these values, and assuming that the length asymmetry is due to Doppler boosting, we estimate lower limit of the jet speed of $\beta > 0.17 \pm 0.05$ and an upper limit for the viewing angle of the jet of $\theta < 80° \pm 3°$. These values are similar to those found in the VLBA+VLA map. A detailed analysis can be found in Paredes et al. (in preparation).

Table 1. Image parameters in Fig. 1

Array	beam size [mas]×[mas]	P.A. [°]	$S_{\rm peak}$ [mJy]	$S_{\rm min}$ [mJy]
EVN	7.60×6.96	−14	26.6	0.3
EVN+MERLIN (25 Mλ)	8.21×7.80	−14	26.8	0.5
EVN+MERLIN (15 Mλ)	9.08×8.93	−39	26.7	0.5
EVN+MERLIN (10 Mλ)	11.2×10.8	−87	26.5	0.45
EVN+MERLIN (5 Mλ)	20.4×19.7	47	26.7	0.7
MERLIN	81.0×81.0[a]	0	33.4	1.0

[a] This is a circular beam, equivalent to the interferometric synthesized beam of 142×46 mas (P.A. −47°).

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References

Martí, J., Paredes, J. M., & Ribó, M. 1998, A&A, 338, L71
McSwain, M. V., Gies, D. R., Riddle, R. L., Wang, Z., & Wingert, D. W. 2001, ApJ, 558, L43
Mirabel, I. F., & Rodríguez, L. F. 1999, ARA&A, 37, 409
Paredes, J. M., Martí, J., Ribó, M., & Massi, M. 2000, Science, 288, 2340
Ribó, M., Paredes, J. M., Romero, G. E., et al. 2002, A&A, 384, 954