Proceedings of the 6th European VLBI Network Symposium
Ros, E., Porcas, R.W., Lobanov, A.P., & Zensus, J.A. (eds.)
June 25th-28th 2002, Bonn, Germany

EVN and MERLIN observations of microquasar candidates

M. Ribó[1], E. Ros[2], J. M. Paredes[1], M. Massi[2], and J. Martí[3]

[1] Departament d'Astronomia i Meteorologia, Universitat de Barcelona, Av. Diagonal 647, 08028 Barcelona, Spain
[2] Max Planck Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany
[3] Departamento de Física, Escuela Politécnica Superior, Universidad de Jaén, Virgen de la Cabeza 2, 23071 Jaén, Spain

Abstract. In an attempt to increase the number of known microquasars, we have carried out a search for new Radio Emitting X-ray Binaries (REXBs). To this end, we have performed a cross-identification between the X-ray ROSAT all sky survey Bright Source Catalog (RBSC) and the radio NRAO VLA Sky Survey (NVSS) catalogs under very restrictive selection criteria for sources with $|b| < 5°$, and obtained a sample of 13 radio-emitting X-ray sources. Follow-up observations of 6 of these sources with the VLA have provided accurate coordinates, that have been used to discover optical counterparts for all of them. We have observed these six sources with the EVN and MERLIN at 5 GHz. Five of the six observed objects have been detected and imaged, presenting different morphologies: one source with a two-sided jet, three sources having a one-sided jet and a compact source. With all the available information up to now, we conclude that two of the sources are promising microquasar candidates in our Galaxy.

1. Introduction

Microquasars are X-ray binary systems, containing a neutron star or a black hole, with the ability to generate relativistic radio jets (see Mirabel & Rodríguez 1999 for a detailed review). These sources mimic, on smaller scales, many of the phenomena seen in AGNs and quasars, but in time scales several orders of magnitude shorter. This property allows to study, in a few minutes, the accretion/ejection processes that take place near galactic compact objects. Unfortunately, the population of microquasars is still very small, with 14 confirmed cases, of which SS 433, GRS 1915+105, GRO J1655−40 or Cyg X-3 are probably the better known examples. An interesting aspect of microquasars is the possibility of being related to unidentified high-energy γ-ray sources, as suggested by Paredes et al. (2000). Moreover, some parameters, like the jet velocity, seem to have a relationship with the mass of the compact object (i.e., with its potential well). Nevertheless, the lack of a meaningful statistical study because of the reduced population of microquasars with known jet velocities, prevents to be sure about statements of this kind. Therefore, it is worth to search for new microquasars in order to increase the known population.

2. Cross-identification between RBSC and NVSS catalogs and follow-up observations

In order to find new microquasar candidates, we have to find new REXBs. To this end, we have performed a cross-identification between the RBSC (Voges et al. 1999), which contains a total of 18 806 sources in the energy band 0.1–2.4 keV, and the NVSS (Condon et al. 1998), which covers the sky north of $\delta = -40°$ (82% of the celestial sphere) at a frequency of 1.4 GHz and contains over 1.8×10^6 sources stronger than its 2.5 mJy completeness limit. We have adopted the following selection criteria:

1. Absolute galactic latitude $< 5°$.
2. No screening flags about nearby sources contaminating measurements or problems with position determinations allowed in the RBSC.
3. Hardness ratios, $HR1 + \sigma(HR1)$, higher than 0.9.
4. NVSS sources within the 2σ error boxes of the RBSC sources.
5. Unresolved within the NVSS.

The sources selected with the RBSC/NVSS cross-identification, a total of 35, were then filtered with complementary optical information using the following criteria:

1. No extragalactic information within SIMBAD and NED.
2. No extended appearance in the Digitized Sky Survey, DSS1 and DSS2-red images.

Only 17 sources fulfilled all the selection criteria. The sample contained the well known REXB LS I +61 303 and the well known microquasars LS 5039, SS 433 and Cyg X-3, all of them being persistent high mass radio emitting X-ray binaries. The remaining unidentified sources where divided in two groups: 8 sources had offsets between the X-ray and radio positions within the 1σ RBSC position error (Group 1), and the other 5 had offsets between 1–2σ (Group 2). Unfortunately for our purposes, one of the sources belonging to Group 1 has been recently identified as a quasar (PMN J0724−0715 in the NED database). Nevertheless, we report here our observational results for this source, since it was a candidate when we performed the observations.

Follow up VLA A configuration observations of 6 of the Group 1 sources (listed in Table 1) provided accurate

Table 1. Observed sources selected from the RBSC/NVSS cross-identification. The object marked with '⋆' is a quasar.

RBSC				RBSC/NVSS	NVSS			Gal. coord.	
1RXS name	Pos. err. [″]	Count rate [10^{-2} s^{-1}]	$HR1$	Offset [″]	NVSS name	Pos. err. [″]	Flux density [mJy]	l [°]	b [°]
J001442.2+580201	9	8.5 ± 1.4	1.00 ± 0.12	3	J001441+580202	3	7.5 ± 0.6	118.07	−4.49
J013106.4+612035	7	25.0 ± 2.4	0.90 ± 0.05	6	J013107+612033	1	19.6 ± 0.7	127.67	−1.16
J042201.0+485610	14	5.1 ± 1.1	1.00 ± 0.24	4	J042200+485607	7	2.4 ± 0.5	154.41	−0.63
J062148.1+174736	8	8.8 ± 1.6	1.00 ± 0.13	4	J062147+174734	1	12.5 ± 0.6	193.78	+1.72
J072259.5−073131	8	17.4 ± 2.1	0.94 ± 0.05	6	J072259−073135	1	85.2 ± 3.1	223.24	+3.52
J072418.3−071508⋆	23	5.2 ± 1.2	1.00 ± 0.13	19	J072417−071519	1	331.0 ± 9.9	223.15	+3.93

Table 2. Effelsberg flux density measurements and EVN and MERLIN parameters of the images shown in Fig. 1.

1RXS name	Single dish $S_{\rm EB}$ [mJy]	Array[a] (taper FWHM) [Mλ]	beam size [mas] × [mas]	P.A. [°]	$S_{\rm tot}$ [mJy]	$S_{\rm peak}$ [mJy beam^{-1}]	$S_{\rm min}$ [mJy beam^{-1}]
J001442.2+580201	6.5 ± 0.5[b]	M	57×51	37	6.2	5.8	0.1
		E+M (10)	7.7×7.2	−4	10.1	9.9	0.18
		E	1.77×0.86	−20	11.5	7.0	0.15
J013106.4+612035	20.1 ± 0.6	M	71×39	−63	17.5	17.9	0.5
		E+M (15)	7.8×6.2	−75	19.2	18.7	0.8
		E	1.04×0.99	−1	17.6	11.6	0.4
J042201.0+485610	< 5	—	—	—	—	—	—
J062148.1+174736	7.1 ± 0.7[b]	M	88×39	24	5.8	5.6	0.2
		E+M (8)	13.1×11.1	−24	6.0	6.8	0.3
		E	8.8×4.1	47	7.0	6.4	0.3
J072259.5−073131	67.9 ± 1.1	M	115×66	4	66.0	62.9	0.7
		E+M (15)	9.5×7.3	−61	52.1	41.9	0.9
		E	5.74×1.12	11	46.9	36.2	0.9
J072418.3−071508	282.2 ± 4.1	M	120×64	8	301.0	285.7	0.9
		E+M (10)	11.7×9.8	−61	287.0	263.4	2.0
		E	5.73×1.02	11	248.0	184.8	0.7

[a] M: MERLIN. E+M: EVN+MERLIN, FWHM of the tapering function (weighting of visibilities) in parenthesis. E: EVN.
[b] Values with very low SNR in the Gaussian fits.

positions, as well as spectral and variability information. This allowed us to discover optical counterparts for all of them with probabilities of random coincidence below 0.3% after our own optical observations.

3. EVN and MERLIN observations and results

With the aim of revealing possible jet-like features at milliarcsecond scales, we observed the six sources listed in Table 1 with the EVN and MERLIN on February 29th/March 1st 2000 (23:30–23:05 UT) at 5 GHz using phase-referencing. The EVN observations were performed with EB, JB, CM, WB, MC, NT, SH, TR and ON, recording in MkIV mode with 2 bit sampling at 256 Mbps at left hand circular polarization. Single dish flux density measurements were carried out with the MPIfR 100 m antenna in Effelsberg, which are listed in Table 2, together with the EVN and MERLIN parameters of the obtained images, which are shown in Fig. 1.

1RXS J001442.2+580201. This source exhibits a two-sided radio jet at EVN scales. A model fitting to the core and to N1, N2, S2 and S1 components provides information on their position and flux density. Assuming relativistic beaming to explain the asymmetry in the brigthness of the components and in their distance to the core, we obtain $\beta > 0.20$ and $\theta < 78°$, where β is the velocity of the components and θ is the angle between the direction of motion of the ejecta and the line of sight. Overall, our results indicate that this source exhibits relativistic radio jets and, therefore, together with the VLA and optical results, we consider it as a very promising microquasar candidate.

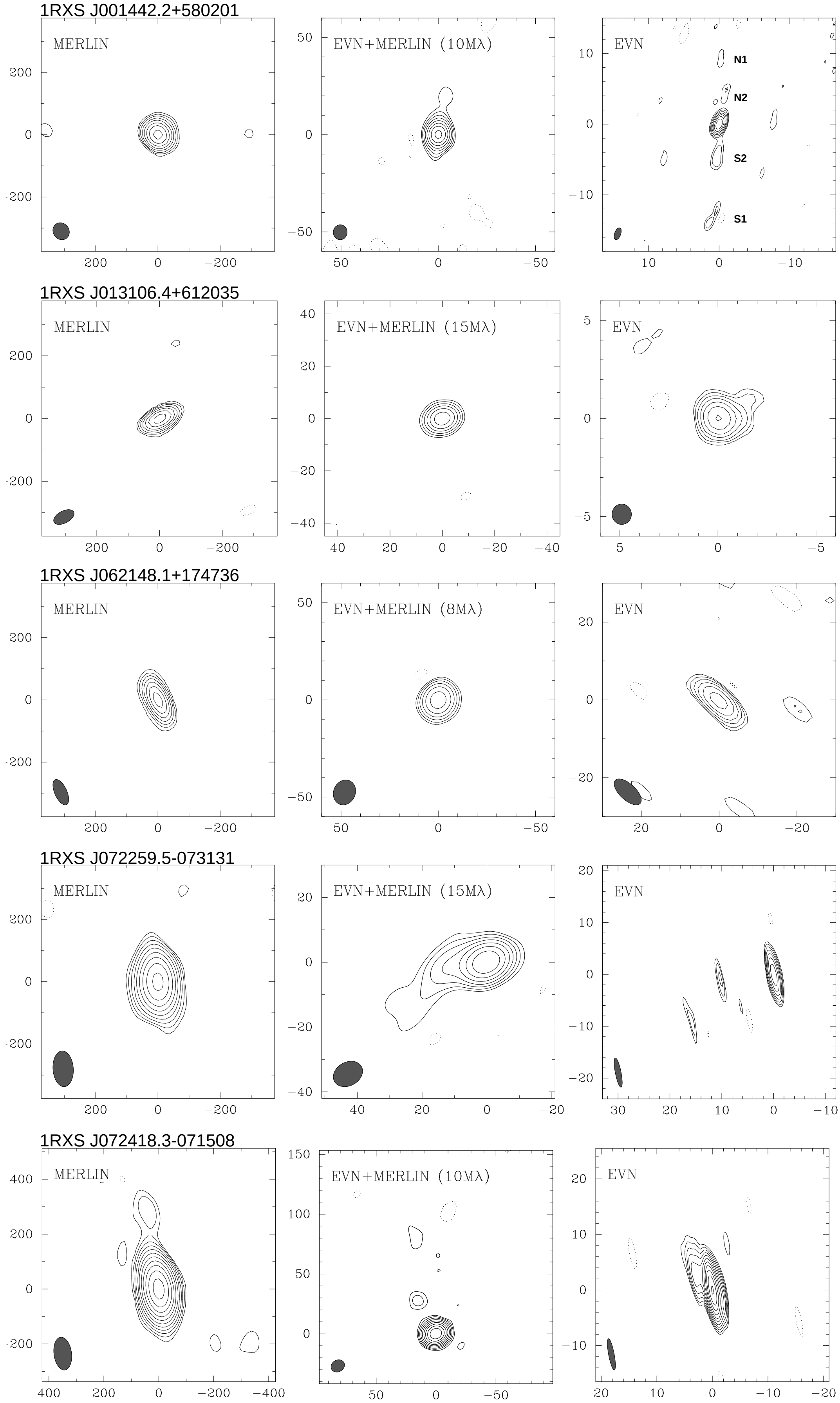

Fig. 1. MERLIN, EVN+MERLIN and EVN images of the five detected sources using the parameters given in Table 2.

Table 3. Summary of the obtained results after the VLA, optical and EVN+MERLIN observations. A '*' indicates a non-expected behavior for microquasars. Notes on the nature of the sources are listed in the last column.

1RXS name	VLA obs.		Optical obs.		EVN+MERLIN obs.			Notes
	Structure	α	Structure	I mag.	Structure	β	$\theta[°]$	
J001442.2+580201	compact	−0.2	point-like	19.9	two-sided jet	> 0.20	< 78	Promising microquasar
J013106.4+612035	compact	−0.1	point-like	17.9	one-sided jet	> 0.09	< 85	Promising microquasar
J042201.0+485610	compact	+1.5*	extended*	17.5	not detected*	—	—	Thermal source ?
J062148.1+174736	compact	+0.1	extended*	17.6	compact	—	—	Galaxy ?
J072259.5−073131	one-sided jet*	−0.2	point-like	16.8	bent one-sided jet*	> 0.05	< 87	Blazar ?
J072418.3−071508	compact	+0.1	point-like	17.2	bent one-sided jet*	> 0.29	< 73	Quasar (FSRQ)

1RXS J013106.4+612035. This radio source presents a one-sided jet morphology at EVN scales, that can be explained assuming relativistic beaming, which leads to $\beta > 0.09$ and $\theta < 85°$. Hence, our results point towards relativistic radio jets as the origin of the elongated radio emission present in the EVN map. As in the previous source, our results are indicative of relativistic radio jets and, since the VLA and optical results are within the expected ones for a microquasar, we also classify this source as a promising microquasar candidate.

1RXS J042201.0+485610. This source was not detected, and the obtained VLA and optical data seem to indicate a thermal radio source slightly extended in the optical.

1RXS J062148.1+174736. This radio source is compact at all scales. Although the compactness of the source is not indicative of a galactic or extragalactic nature, the extended optical counterpart suggests an extragalactic origin for this source.

1RXS J072259.5−073131. This source exhibits a bent one-sided jet. Assuming relativistic beaming to explain this behavior, we obtain $\beta > 0.05$ and $\theta < 87°$, which are not extreme values. The bending of the jet at such small angular scales resembles the ones seen in blazars. In fact, a one-sided arcsecond scale jet is also present in our VLA A configuration observations at 1.4 GHz, a non usual feature in the already known microquasars.

1RXS J072418.3−071508. This quasar shows a bent one-sided jet, that can be explained with $\beta > 0.29$ and $\theta < 73°$.

4. Conclusions

We have presented EVN and MERLIN observations of six microquasar candidates at low galactic latitudes. After a detailed analysis of the obtained data, we show in Table 3 a summary of the results obtained after the VLA and optical observations (Paredes et al. 2002), and the EVN+MERLIN observations (Ribó et al. 2002). As can be seen, the first two sources, 1RXS J001442.2+580201 and 1RXS J013106.4+612035, are promising microquasar candidates. 1RXS J042201.0+485610 has probably a thermal nature due to the highly inverted spectrum at high radio frequencies, while 1RXS J062148.1+174736 is probably an extragalactic object due to the extended nature of the optical counterpart. 1RXS J072259.5−073131 shows properties common to blazars, while 1RXS J072418.3−071508 is an already identified quasar. Nevertheless, optical spectroscopic observations of the first five sources are in progress, to clearly unveil their galactic or extragalactic nature.

A detailed discussion on the cross-identification method and follow-up VLA and optical observations will be reported in Paredes et al. (2002), while a careful analysis of the EVN and MERLIN observations will be presented in Ribó et al. (2002).

Acknowledgements. The European VLBI Network is a joint facility of European and Chinese radio astronomy institutes funded by their national research councils. This research was supported by the European Commission's TMR and IHP Programme "Access to Large-scale Facilities", under contract No. ERBFMGECT950012 and HPRI-CT-1999-00045, respectively. We acknowledge the support of the European Community - Access to Research Infrastructure action of the Improving Human Potential Programme. M. R., J. M. P., and J. M. acknowledge partial support by DGI of the Ministerio de Ciencia y Tecnología (Spain) under grant AYA2001-3092, as well as partial support by the European Regional Development Fund (ERDF/FEDER). M. R. is supported by a fellowship from CIRIT (Generalitat de Catalunya, ref. 1999 FI 00199). J. M. is partially supported by the Junta de Andalucía and has also been aided in this work by an Henri Chrétien International Research Grant administered by the American Astronomical Society.

References

Condon, J. J., Cotton, W. D., Greisen, E. W., et al. 1998, AJ, 115, 1693
Mirabel, I. F., & Rodríguez, L. F. 1999, ARA&A, 37, 409
Paredes, J. M., Martí, J., Ribó, M., & Massi, M. 2000, Science, 288, 2340
Paredes, J. M., Ribó, M., & Martí, J. 2002, A&A, submitted
Ribó, M., Ros, E., Paredes, J. M., Massi, M., & Martí, J. 2002, A&A, submitted
Voges, W., Aschenbach, B., Boller, Th., et al. 1999, A&A, 349, 389