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Research Note

VLT search for the infrared counterpart of 1E 1740.7–2942

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Abstract. We report the results of our search for the near infrared counterpart of the microquasar 1E 1740.7−2942 using the VLT[1]. For the first time, several counterpart candidates have been found in our Ks-band images that may be consistent with the best radio and X-ray positions available for 1E 1740.7−2942. However, the non-detection of variability between two observing epochs and the positional uncertainty still remaining at the $\lesssim 1''$ level prevent us from identifying an unambiguous counterpart. Alternatively, the VLT images set new upper limits significantly deeper than previously reported that constrain the binary companion to be later than B8 V or earlier than G5 III.

Key words: stars: individual: 1E 1740.7–2942 – Galaxy: center – infrared: stars – radio continuum: stars – X-rays: stars

1. Introduction

The Galactic Center (GC) in hard X-rays is dominated by the two bright sources 1E 1740.7−2942 and GRS 1758−258 (Sunyaev et al. 1991; Goldwurm et al. 1994). In spite of nearly one decade of observation, the true nature of these objects still remains a mystery. Nevertheless, from their likely radio counterparts with bipolar jets (Mirabel et al. 1992; Rodríguez et al. 1992) they are widely accepted to be microquasar systems with persistent activity at both X-ray and radio wavelengths. The reader is referred to the recent review by Mirabel & Rodríguez (1999) for an updated account.

Accepting the radio counterpart identification, the position of the two GC microquasars is known to better than one arcsecond thanks to the Very Large Array (VLA) interferometer in its most extended configurations. Even with this knowledge in hand the search for an optical/infrared counterpart in the 1E 1740.7−2942 case has proven to be virtually impossible. The best upper limits previously available were $z > 22$-23 (Mereghetti et al. 1992), $I > 21$ mag (Leahy et al. 1992) and $K > 17$–18 (Djorgovski et al. 1992; Chaty et al. 1998) Two circumstances conspire against a successful detection. First, the huge interstellar absorption ($A_V \geq 50$ mag) in the line of sight to 1E 1740.7−2942. Second, the richness of the field especially in the J and K-bands. These difficulties also yield most optical astrometric standards practically unrecognizable in infrared frames. The situation seems to be a little bit less severe for GRS 1758−258, where a few possible candidates close to the VLA position have been proposed (Martí et al. 1998).

In this note we present the Ks-band images of the 1E 1740.7−2942 field taken with the first 8.2 m unit (Antu) of the Very Large Telescope (VLT) of the European Southern Observatory (ESO). The VLT images are significantly deeper than the upper limits reported in previous infrared searches. For the first time, we are able to detect some counterpart candidates that may be consistent with the accurate radio and X-ray positions. Although an unambiguous identification is not yet possible, the first VLT images of the 1E 1740.7−2942 field represent a useful template against which future observations can be compared.

2. Observations

We observed 1E 1740.7−2942, in service mode, on two different epochs using the ISAAC instrument of the VLT in imaging mode (see Cuby 1999 for a description). In both occasions, the Ks filter centered at the 2.16 μm wavelength was used. The first epoch was on 1999 April 04 (JD 2451272.834), with a total exposure time of 3000 s under windy conditions. The second observation took place on 1999 May 02 (JD 2451300.873), with a total exposure time of 1400 s under a more quiet atmosphere. Both nights were considered of photometric quality, but the seeing in May 02 ($0\farcs5$) was much better than in April 04 ($0\farcs7$). The Julian dates given correspond to the middle of the observation. The data were reduced using the IRAF package, including sky background subtraction, flat field division and frame combination, and also photometry in crowded fields was performed

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[1] Based on observations collected at the European Southern Observatory, Chile (ESO No 63.H-0261).

thanks to the DAOPHOT package. The photometric zero point was determined using the magnitudes of several stars in the field that were known from many previous observing runs with different ESO telescopes in La Silla (Chaty 1998).

VLT-ISAAC observations were also conducted at longer wavelengths using the L-band (3.78 μm) filter on two nights in 1999 June. Unfortunately, both L-band epochs suffered from either non-photometric conditions or too bad seeing and they appear to be of little use. Therefore, we will concentrate our analysis on the Ks images only.

3. Results and discussion

A wide view of the 1E 1740.7−2942 field in the Ks infrared band is presented in Fig. 1. This figure contains the Ks image of the second VLT epoch with the VLA 6 cm data overlayed on it for illustrative purposes. The radio contours display the appearance of the microquasar bipolar jets emanating from a central core against the near infrared background. No special increase, nor decrease, in the infrared star counts seems to be present in association with the arcminute extended radio lobes.

A close up view of the central arcseconds around the 1E 1740.7−2942 central core is presented in Figs. 2a and 2b for both the first and second epoch, respectively. The astrometric solution on these figures has been obtained by using 7 unsaturated USNO-A V2.0 stars, assumed to be reliably identified on the VLT frames. The corresponding residuals of the astrometric fit are about $\pm0\farcs20$, thus suggesting that the identification of the reference stars is indeed correct. Therefore, our astrometry should be reliable within a 3σ error of $\sim 0\farcs60$ when plotting X-ray or radio positions on the VLT grid. Such a conservative approach is justified given the difficulties of performing good astrometry in the crowded and heavily absorbed field of 1E 1740.7−2942. Several new infrared sources detected have been labelled from 1 to 8.

For detailed discussion purposes, an expanded view of our second epoch image is shown in Fig. 3. Here, the most accurate radio and X-ray positions available have been plotted according to our astrometry. At radio wavelengths we are using the VLA position $\alpha_{\rm J2000} = 17^h43^m54\fs83$ and $\delta_{\rm J2000} = -29^\circ44'42\farcs60$ with $\pm0\farcs1$ accuracy in each coordinate. This position is slightly different from that reported in Rodríguez et al. (1992) since it has been derived from the expanded VLA data set, as shown in Fig. 1. Haller & Melia (1994) have published a K-band image of the 1E 1740.7−2942 field with astrometric information, based on 8 reference stars, taken with the 2.3m telescope at the Steward Observatory (limiting magnitude $K = 16.5$). It is reassuring that the VLA position seems to be consistent in both cases with respect to nearby bright infrared sources.

In X-rays, the best source location currently available is provided by the Chandra X-Ray Observatory being $\alpha_{\rm J2000} = 17^h43^m54\fs876\pm0\fs004$ and $\delta_{\rm J2000} = -29^\circ44'42\farcs48\pm0\farcs04$, where the errors represent roughly 90% confidence limits (Cui et al. 2000). The Chandra position has a $0\farcs6$ offset from the VLA coordinates, which is within the uncertainty in the Chandra absolute aspect solutions (Cui et al. 2000).

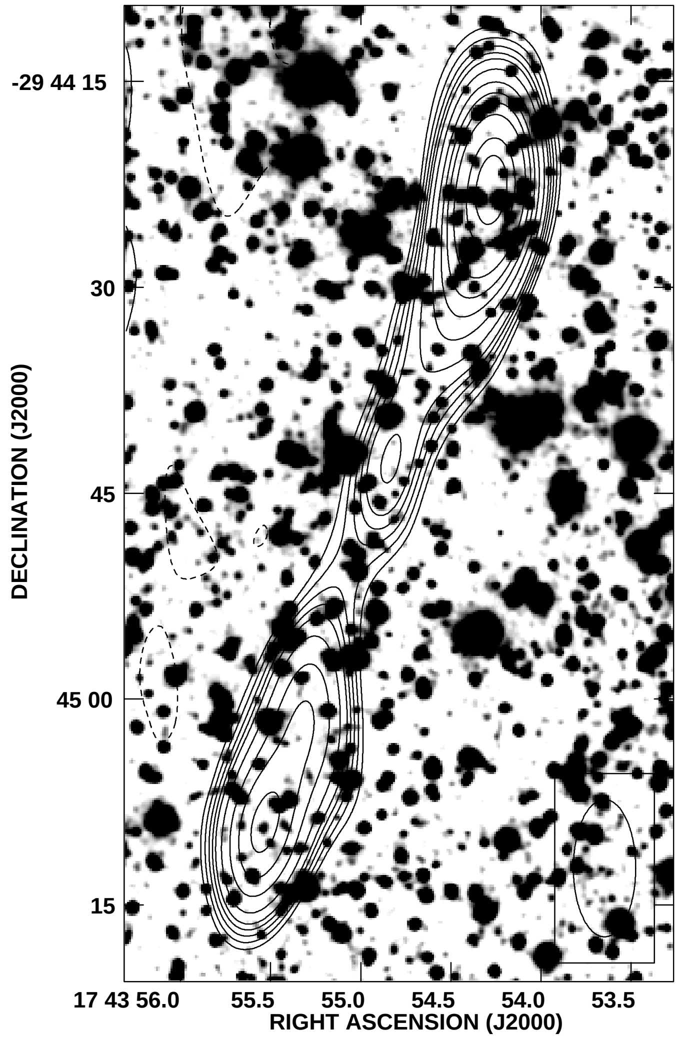

Fig. 1. VLT+ISAAC image of the 1E 1740.7−2942 field using the Ks filter. The solid contours represent the microquasar radio emission at 6 cm and they correspond to −3, 3, 4, 5, 6, 7, 9, 12, 15, 18, 22, 30 and 35 times 20 μJy beam^{-1}, the rms noise. The synthesized beam is shown as an ellipse at the bottom right corner measuring $10\farcs0 \times 4\farcs5$, with position angle $0\fdg0$.

By inspecting the VLT images, we detect at least 8 sources in the vicinity of the X-ray and radio position. We label them from 1 to 8 in Fig. 2b, the one with best seeing. Their Ks-band magnitudes are listed in Table 1. The magnitude for object 8 is very uncertain because of severe background contamination. Among these new sources, those labelled as 4, 6, 7 and 8 are the ones whose coincidence with the VLA and Chandra positions cannot at present be ruled out. This is because of the $\lesssim 1''$ uncertainties still remaining in the absolute positioning of the Chandra and VLA positions on the VLT image. Interestingly, source 4 looks slightly different than the seeing profile and may have extended appearance. No photometric variability above the quoted magnitude errors was observed between the two observing epochs. This fact, together with the presence of several candidates, still prevents us from proposing a reliable counterpart candidate based on present data.

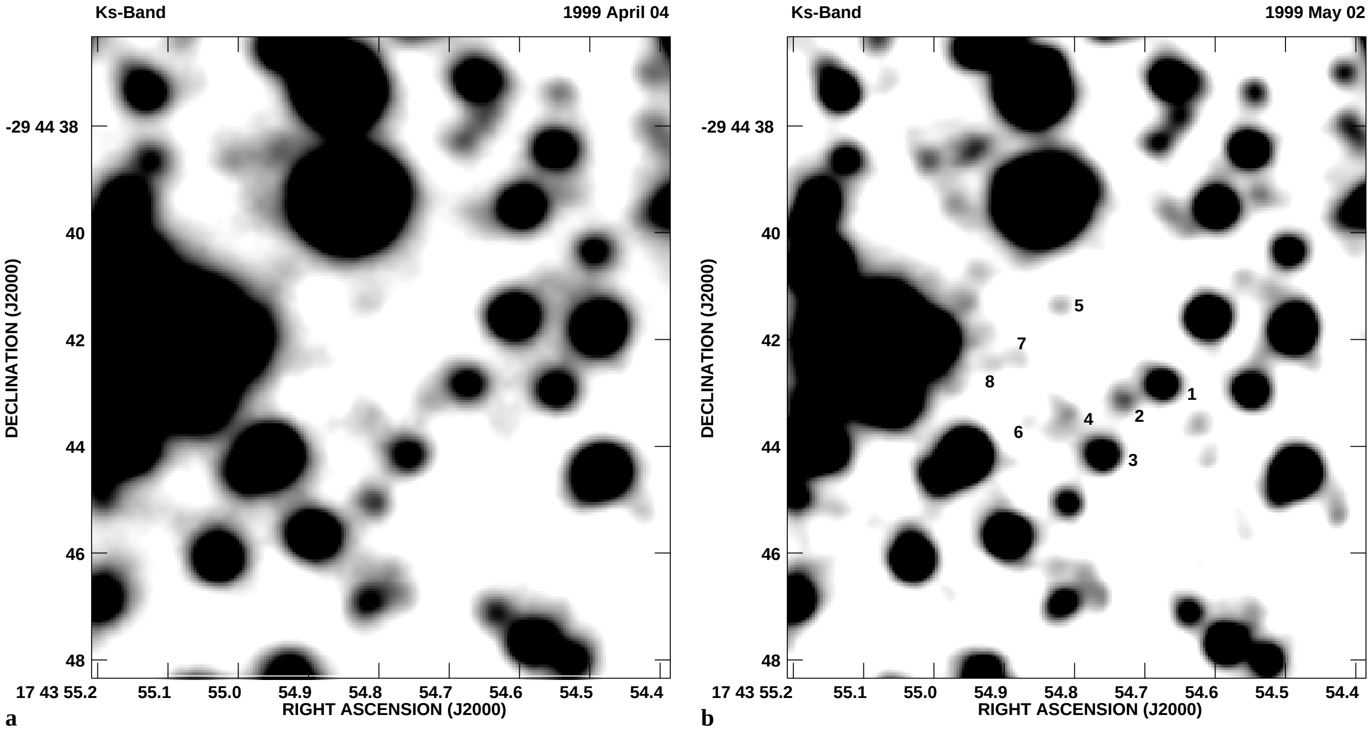

Fig. 2a and b. A close up view of the 1E 1740.7−2942 field, centered at the radio position, taken with the VLT+ISAAC on two different epochs at the 2.16 μm wavelength. The infrared sources newly detected in its vicinity are labelled from 1 to 8. The corresponding 3σ upper limit of both panels is $K = 19.5$ mag.

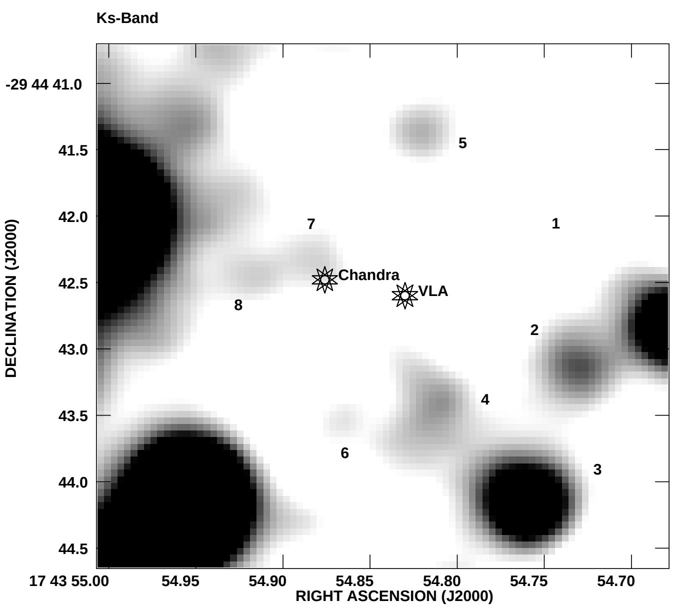

Fig. 3. Expanded view of the second epoch image. The VLA radio and Chandra X-ray positions have been plotted as star symbols whose size is comparable to their respective formal uncertainty. The residual 0.″6 offset between them is within the Chandra absolute positional error, as expected for both the X-ray and radio source being the same object.

If one of the astrometrically selected sources is indeed the correct 1E 1740.7−2942 counterpart, we can adopt $K = 18.5$-19.0 for the infrared magnitude of the system. Given the similarity in hard X-rays of 1E 1740.7−2942 and the classical black hole candidate Cygnus X-1, it is instructive to derive which is the interstellar absorption required for both objects having the same infrared luminosity. The absolute K-band magnitude of Cygnus X-1 is $K = -5.8 \pm 0.2$ (Beall et al. 1984). At the Galactic Center distance of 8.5 kpc, a Cygnus X-1 system would appear with the magnitudes observed for the candidates, provided that an absorption of $A_K = 9.7$-10.2 magnitudes exists. According to usual extinction laws (Rieke & Lebofsky 1985; Predehl & Schmitt 1995) this implies a visual absorption of $A_V = 86$-91 magnitudes, equivalent to a hydrogen column density of $N_H = (1.5$-$1.6) \times 10^{23}$ cm^{-2}. This value is perfectly consistent with the interstellar absorption from X-ray spectral fits, that provide $N_H > 8 \times 10^{22}$ cm^{-2} (Churazov et al. 1996; Sheth et al. 1996).

Table 1. Photometry of the candidate counterparts

Object	Ks (mag)	Remarks
1	16.7 ± 0.1	
2	18.2 ± 0.2	
3	16.6 ± 0.1	
4	18.0 ± 0.1	Possibly extended
5	18.4 ± 0.3	
6	19.2 ± 0.3	
7	18.7 ± 0.3	
8	19 ± 1	Uncertain background

If none of sources 4, 6, 7 and 8 is the true 1E 1740.7−2942 counterpart, the 3σ limiting magnitude of our best image ($Ks = 19.5$) implies that the absolute magnitude is $K > -0.1$. In this case, the stellar types allowed would be main sequence stars later than about B8 V or giants earlier than G5 III.

In any case, further observations will be necessary to finally detect the 1E 1740.7−2942 counterpart and establish its true nature.

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References

Beall J.H., Knight F.K., Smith H.A., et al., 1984, ApJ 284, 745
Chaty S., 1998, Ph.D. Thesis, University of Paris Sud XI
Churazov E., Gilfanov M., Sunyaev R., 1996, ApJ 464, L71
Cuby J.G., 1999, ISAAC User Manual. ESO
Cui W., Schulz, N.S., Baganoff F.K., et al., 2000, ApJ (submitted)
Djorgovski, S., Thompson D., Mazzarella J., Klemola A., 1992, IAU Circ. 5596
Goldwurm A., Cordier B., Paul J., et al., 1994, Nat 371, 58
Haller J.W., Melia F., 1994, ApJ 423, L109
Leahy D.A., Langill P., Kwok S., 1992, A&A 259, 209
Martí J., Mereghetti S., Chaty S., Mirabel I.F., Rodríguez L.F., 1998, A&A 338, L95
Mereghetti S., Caraveo P., Bignami G.F., Belloni T., 1992, A&A 259, 205
Mirabel I.F., Rodríguez L.F., Cordier B., Paul J., Lebrun F., 1992, Nat 358, 215
Mirabel I.F., Rodríguez L.F., 1999, ARA&A 37, 409
Predehl P., Schmitt J., 1995, A&A 293, 889
Rieke G., Lebofsky M., 1985, ApJ 288, 618
Rodríguez L.F., Mirabel I.F., Martí J., 1992, ApJ 401, L15
Sidoli L., Mereghetti S., Israel G.L., et al., 1999, ApJ 525, 215
Sheth S., Liang E., Luo C., et al., 1996, ApJ 468, 755
Sunyaev R.A., Churazov E., Gilfanov M., et al., 1991, A&A 247, L29