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AN APPARENTLY EXTENDED INFRARED COUNTERPART TO 1E 1740.7−2942

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ABSTRACT

We present the results of a revised search for the near-infrared counterpart to the microquasar 1E 1740.7−2942, which has eluded identification despite the many years elapsed since its discovery. By taking into account new astrometric information, we have been successful to identify a single near-infrared source, with apparent non-stellar morphology, whose position agrees well with that of the microquasar X-ray and radio-emitting core at the subarcsecond level. The possible implications of this finding with respect to the nature of 1E 1740.7−2942 are discussed.

Key words: galaxies: active – infrared: stars – ISM: jets and outflows – radio continuum: stars – X-rays: binaries

1. INTRODUCTION

The Galactic center (GC) region in hard X-rays/soft gamma rays is remarkably dominated by two strong persistent sources: 1E 1740.7−2942 and GRS 1758−258. They are located ∼50′ and ∼5° away from Sagittarius A, respectively. The first of them, 1E 1740.7−2942, was originally detected by the *Einstein* satellite (Hertz & Grindlay 1984) in soft X-rays and received strong attention in the early 1990s when possible evidence for an e^-–e^+ annihilation line was obtained by the French coded-mask telescope SIGMA on board the Russian satellite *Granat* (Bouchet et al. 1991). This instrument also detected GRS 1758−258 as another conspicuous high-energy emitter close to the GC direction (Goldwurm et al. 1994; Sunyaev et al. 1991). Searches for optical/infrared counterparts to both sources were attempted by several authors, but astrometric uncertainties and strong interstellar absorption rendered this a very difficult task and no conclusive results were obtained (Prince & Skinner 1991; Djorgovski et al. 1992; Mereghetti et al. 1992; Mirabel & Duc 1992; Martí et al. 1998, 2000; Eikenberry et al. 2001). Follow-up observations soon after discovery were most successful at radio wavelengths where the Galaxy is far more transparent. Interestingly, both 1E 1740.7−2942 and GRS 1758−258 turned out to display well-collimated arcminute radio jets terminating in bipolar lobes whose morphology is very reminiscent of Fanaroff–Riley type II (FR II) radio galaxies (Mirabel et al. 1992; Rodríguez et al. 1992). Despite this fact, the X-ray spectral properties of these sources appeared very similar to black hole candidates (BHCs) of stellar origin such as the historical system Cygnus X-1. Based on this similarity and the clear detection of radio jets, 1E 1740.7−2942 and GRS 1758−258 are currently understood as prototypical examples of microquasar X-ray binaries in the Galaxy (see Mirabel & Rodríguez 1999 for a classical review).

Despite nearly two decades of studies, the stellar nature of 1E 1740.7−2942 and GRS 1758−258 is not conclusively confirmed on the basis of optical/infrared photometry, or spectroscopy, in contrast to many other microquasar systems. Recently, a step forward has been achieved thanks to the identification of a serious optical/infrared counterpart candidate to GRS 1758−258 based on accurate astrometric coincidence with the radio core of the source (Muñoz-Arjonilla et al. 2010). The key points of this discovery were (1) a more accurate astrometric solution than the one that was feasible in the early 1990s and (2) a revision of the radio coordinates taking into account the improved positions of the interferometric calibrators now available. In this Letter, we perform a similar study devoted to the case of 1E 1740.7−2942 in the near-infrared wavelengths where interstellar extinction is significant but not as huge as in the optical domain ($A_V \sim 25$–50). As a result, a unique infrared counterpart candidate for this microquasar has been identified which is remarkably consistent with both the subarcsecond radio and X-ray positions also revised in this work. This object is one of the candidates previously reported by Martí et al. (2000) and Eikenberry et al. (2001) which exhibits hints of extended morphology.

2. ANALYSIS OF ARCHIVE DATA

The research reported here is mainly based on a revision of different archive data sets carried out as follows.

2.1. *The X-ray Position Revisited*

X-ray observations of 1E 1740.7−2942 are widely available in the literature. Given the goals of this work, we are mainly concerned with the location of the microquasar core which has been measured with subarcsecond accuracy by several authors using the *Chandra* X-ray satellite (Cui et al. 2001; Muno et al. 2009). Despite the fact that *Chandra* currently provides the best positional capabilities in X-rays, there is a small residual discrepancy between the X-ray and interferometric radio coordinates of 1E 1740.7−2942 as mentioned by Cui et al. (2001). We speculate that pileup problems or the source falling within the detector gaps may be behind this inconsistency.

Consultation of the *Chandra* archives yields an unpublished data set of 1E 1740.7−2942 with the High Resolution Camera (HRC-I) with 29.7 ks exposure time obtained by W. Heindl. This observation provides an excellent tool for measuring a very accurate X-ray position free from the problems quoted above. A standard pipeline analysis of the corresponding event file gives the following improved X-ray position (J2000.0): $\alpha = 17^{\rm h}43^{\rm m}54\overset{\rm s}{.}85$, $\delta = -29^\circ44'43\overset{''}{.}0$, and we conservatively adopt a 90% confidence radius of $0\overset{''}{.}6$ according to the *Chandra* absolute astrometric accuracy. As will be seen below, this new position now agrees with the radio coordinates of 1E 1740.7−2942 within their respective errors.

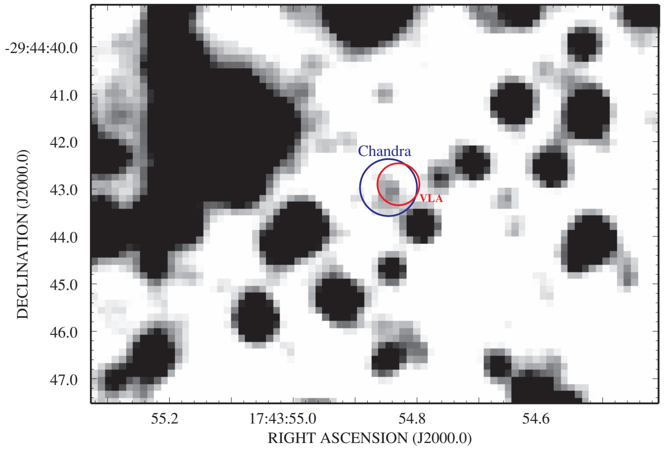

Figure 1. Zoom of the VLT image of 1E 1740.7−2942 by Martí et al. (2000) in the K_s band with the new 90% confidence error circles of the X-ray (blue) and radio (red) positions. Only one infrared source is consistent with both of them.

2.2. *The Radio Position Revisited*

The most accurate radio position for the 1E 1740.7−2942 core is the one reported by Martí et al. (2000) obtained with the Very Large Array (VLA) and with a $\pm 0''.1$ accuracy (1σ) in each coordinate. However, the position of the VLA phase calibrator 1751–253 that was used for astrometry has been revised since the observations were carried out more than a decade ago. In fact, the quality code of this object improved from C in the original data to B in the present version of the VLA Calibrator Manual. Basically, the 1751–253 position shifted as much as $0''.3$ toward the south, and we have consequently corrected the Martí et al. (2000) coordinates to the following J2000.0 values: $\alpha = 17^{\mathrm{h}}43^{\mathrm{m}}54^{\mathrm{s}}.83$, $\delta = -29^\circ44'42''.9$, also adopting the same $\pm 0''.1$ accuracy.

2.3. *Improved Astrometry on Near-infrared Frames*

The astrometric solutions in the early searches for optical/infrared counterparts by Martí et al. (2000) and Eikenberry et al. (2001) were based on merely a few reference stars in the field (7 and 3, respectively). This situation was due to the lack of astrometric standards in the near-infrared 10 years ago. Therefore, the scarce optical astrometric standards available had to be painfully identified in the hugely crowded infrared field of 1E 1740.7−2942. As a consequence, the reliability of the result can certainly be improved with the nowadays available star catalogues such as the Two Micron All Sky Survey (Skrutskie et al. 2006), hereafter 2MASS.

The astrometry in the Martí et al. (2000) Very Large Telescope (VLT) K_s-band images has been thus completely recomputed using 30 unsaturated reference stars with accurate coordinates retrieved from the 2MASS database. We refer the reader to the original paper for details about the observation procedure and data reduction. The residuals of the astrometric fit had an rms value of $\pm 0''.1$ in both right ascension and declination. Different astrometric tasks (based on custom software, AIPS and the IRAF packages) were tried with very similar outcome. The final result is presented in Figure 1 zooming around the vicinity of 1E 1740.7−2942. Here, we have also plotted the corresponding 90% confidence circles for the *Chandra* and VLA positions taking into account the combined astrometric uncertainty. A conservative estimate of $0''.15$ for possible systematic errors in 2MASS has been also included.

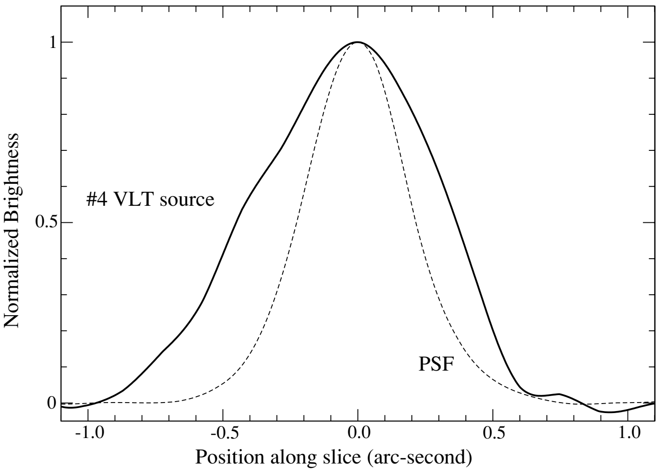

Figure 2. Continuous line corresponds to the clearly extended brightness profile of the proposed 1E 1740.7−2942 counterpart candidate, sliced along the north–south direction, as it appears in the VLT K_s-band image by Martí et al. (2000, source #4 in their paper). For comparison purposes, the dashed line shows a typical point-spread-function (PSF) profile obtained when a nearby stellar-like object in the field is sliced along the same direction.

3. DISCUSSION AND CONCLUSIONS

It is clear from Figure 1 that only one infrared source is consistent with both the X-ray and radio positions at the 90% confidence level. Its J2000.0 position based on 2MASS astrometric standards is found to be: $\alpha = 17^{\mathrm{h}}43^{\mathrm{m}}54^{\mathrm{s}}.84$, $\delta = -29^\circ44'43''.1$, with $\pm 0''.18$ combined error in both axes (1σ). This finding rules out seven of the eight counterpart candidates proposed by Martí et al. (2000) and Eikenberry et al. (2001) based on VLT and Keck observations, respectively. The object that we point as the infrared counterpart to 1E 1740.7−2942 coincides with their source #4. Its magnitude was consistently measured as $K_s = 18.0 \pm 0.1$ (VLT data) and $K_s = 18.2 \pm 0.1$ (Keck data) with a time baseline of one year. No apparent long-term variability is observed, and this is also true when comparing images separated by monthly timescales. Moreover, this source exhibits an apparently extended morphology obvious in Figure 2 as already noted in these previous works. In contrast, the rejected counterpart candidates are all consistent with being point-like sources. Although source #4's diffuse appearance could be due to the overlap of several faint stellar images (Eikenberry et al. 2001), we cannot exclude that it is actually intrinsic to it.

The near-infrared field around 1E 1740.7−2942 is highly crowded since we are close to the GC. From VLT source counts, we estimate an average surface density of about 0.34 stars arcsec^{-2} brighter than $K_s = 18$. Given that the VLA 90% confidence radius in Figure 1 amounts to $0''.44$, the probability of having a chance coincidence with a normal background/foreground star is about 20%. This number is low but clearly not negligible a priori for a single star. However, here we may be dealing with the superposition of at least three stars or with a truly extended source. In the first case, the expected probability is $\leqslant 0.2^3$ (i.e., less than 1%). In the second case, the probability of a chance coincidence is also expected to be very low given the scarce surface density of extended infrared sources in this region as compared to stars. Thus, in either case, source #4 seems likely to be the true physical counterpart to 1E 1740.7−2942.

An extended infrared counterpart with a non-stellar appearance, suggestive of a radio galaxy nature instead of a microquasar, would conflict with the traditional interpretation of 1E 1740.7−2942 as a galactic BHC based on its X-ray behavior.

Alternatively, if the proposed counterpart turns out to be of stellar origin, its observed brightness translates into an absolute magnitude of about $K_s = -4.2$ when assuming an 8.5 kpc distance for the GC and the interstellar absorption due to the $N_{\rm H} = 1.2 \times 10^{23}$ cm^{-2} column density toward 1E 1740.7−2942 (Gallo & Fender 2002). The extinction law of Rieke & Lebofsky (1985) has been used for this estimate yielding an extinction of $A_K = 7.5$ mag. The resulting absolute magnitude is consistent with a main-sequence O star or a late M-type giant star.

To conclude, for the first time we have been able to unambiguously identify the likely infrared counterpart to 1E 1740.7−2942 and with a remarkable apparent extended morphology. If further observations (e.g., with adaptive optics) reveal that this is an intrinsic feature of the source, then an FR II radio galaxy scenario would emerge as the most likely one. In such a case, the microquasar context believed to apply during decades would need to be revised. On the other hand, if the counterpart we propose here is actually stellar, the observed magnitude and interstellar extinction points to a high-mass X-ray binary seen through a very high obscuration.

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