Infrared identification of 4U1323-619 revisited

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ABSTRACT

We re-examine the infrared counterpart of the dipping low-mass x-ray binary 4U1323-619. New X-ray data available from the XMM and Chandra observatories combined with archival IR observations from the ESO 3.6m New Technology Telescope allow us to define a new possible counterpart. We present here its photometric properties and compare them with a simple analytical model of an accretion disc illuminated by the hot central corona known to be present in the binary system.

Key words: X-rays: binaries – stars: individual: 4U1323-619

1 INTRODUCTION

4U1323-619 is a dipping low-mass x-ray binary detected by Uhuru and Ariel V (Forman et al. 1978; Warwick et al. 1981). It exhibits X-ray bursts and irregular intensity dips by periodic obscurations of the central X-ray emitting region by a structure located in the outer regions of the disc (White & Swank 1982). High interstellar matter column density (\(N_H \sim 4 \times 10^{22} \text{ cm}^{-2}\)) derived from X-ray spectral models (Parmar et al. 1989) suggests that this source possesses significant extinction of the order of \(A_V \sim 18 \text{ mag}\) and, thus, cannot be observed at optical wavelengths. Smale (1995) attempted to find its IR counterpart subject to much lower extinction and reported a candidate which demonstrated some variability of the IR flux (though at a low significance level).

Similarly to other sources, the dipping activity in 4U1323-619 attracted attention of researchers as a laboratory for studying the accretion disc corona (Balucinska-Church et al. 1990; Boirin et al. 2005; Church et al. 2005). These studies and other recent observational efforts produced new data available for this source in archives of X-ray missions and the European Southern Observatory (ESO). We have noticed a significant positional discrepancy between the Einstein coordinates of 4U1323-619 and its more recent XMM and Chandra observations. Having found the IR archival data for 4U1323-619 by the means of the Virtual Observatory, we decided to re-examine the IR candidate discovered by Smale (1995).

2 OBSERVATIONS AND RESULTS

2.1 X-ray observations

We have analysed Chandra observations performed on Sep 25, 2003 with a total exposure time about 40 ksec. The observations were aimed at high energy resolution spectroscopy and the telescope was equipped with gratings. Detectors were operating in the so-called Continuous-Clocking (CC) mode, when the information in one spatial direction is lost.

Therefore we have determined the source coordinates mainly in one direction (with the nominal Chandra localisation accuracy \(\sim 0.6 \text{ arcsec}\) at 90 per cent confidence). Orientation of the effective position “strip” depends on the orientation of the telescope during the observations. We represent the Chandra localisation by a wide ellipse in Fig. 1. The centre of the ellipse is at RA(J2000)=201.65397 deg, Dec(J2000)=−62.135403 deg, its positional angle is 156.6 deg, the ellipse is \(\sim 0.6 \text{ arcsec}\) wide in one direction and effectively infinitely long in another. In Fig. 1 we have limited the size by arbitrarily adopting a length of 5 arcsec.

XMM-Newton observed the source position two times, on Aug 17, 2001 and Jan 29, 2003, the observations spanning 26 ksec and 51 ksec, respectively. Data of the XMM-Newton EPIC-MOS cameras were analysed using the standard tasks of the Science Analysis Software (SAS) v9.0.0. Unfortunately, the source is sufficiently bright to have a non-negligible effect on the XMM/EPIC-MOS imaging capability because of pile-up. This depresses the brightness of central pixels, degrading the localisation accuracy, in spite of the possibility of cross-calibrating the absolute astrometry

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of XMM using optical sources within its field of view. Therefore, we would like to adopt some conservative uncertainty radius of the source position ~ 3 arcsec approximately corresponding to 90 per cent confidence, which without pileup might have been significantly improved. The source position was determined to be RA(J2000)=201.654870 deg, Dec(J2000)=−62.135985 deg.

2.2 IR observations

The infrared data analysed in this work were obtained on May 18, 2005 between 03:40 and 04:01 UT using the SOFI infrared spectrometer and imaging camera (Moorwood et al. 1993) at the ESO 3.6m NTT telescope under programme ID 075.D-0529(A). All scientific and calibration data were retrieved through the publicly available ESO observational archive.

The scientific data contain 21 three second exposures, each taken in Small Field imaging mode with pixel scale 0.144 arcsec pix−1 and seeing ~1.1 arcsec. Due to the specific nature of IR observations, i.e. a rapidly changing background and the techniques used to determine this, the reduction procedure is quite different from optical imaging observations. To get the data ready for scientific analysis we, therefore, used tools and recipes provided by ESO: GASGANO v2.3.0 for data organisation tasks and the SOFI data reduction recipes from the Common Pipeline Library v5.0.0 to correct for bias, flat field and frame jittering. After co-adding 21 reduced co-aligned frames (see Fig. 1), we performed aperture photometry measurements with the SExtractor software (Bertin & Arnouts 1996) and calibrated instrumental magnitudes using 2MASS Ks photometry of field stars. Our photometric errors therefore include calibration dependency uncertainties of 0.10 mag. The astrometric solution was obtained in the 2MASS reference frame with the SCAMP software (Bertin 2000) and had 0.2 arcsec calibration uncertainty. Infrared measurements of all sources of interest in the 4U1323-619 field are listed in Tab. 1.

2.3 Results

We overplotted positional uncertainties obtained from the XMM and Chandra data on the combined IR image (see Fig. 1), together with the Einstein error circle which, following Smale (1993), is centred at the X-ray position of Source D from Parmar et al. (1989), as measured by Einstein HRI: αJ2000 = 13h26m36.08s, δJ2000 = −62°08′10.2″, R = 2.5 arcsec (90 per cent confidence). In Fig. 1 we designated sources of the interest by a capital letters and measured their magnitudes and the astrometric positions which are given in Tab. 1. The single object within the Einstein error circle (source C in this work) was proposed by Smale (1993) as the IR counterpart of 4U1323-619 and can now be ruled out. This mis-identification was probably caused by the underestimation of the position uncertainty radius for the source, which is quite faint for Einstein/HRI. We propose the only source visible inside Chandra and XMM positional errors intersection down to a limiting magnitude Ks ~ 19.4 mag (3σ upper limit), source B, as a new counterpart for 4U1323-619.

3 DISCUSSION

We obtained simple estimations of optical luminosity of the accretion disc illuminated by the central isotropic spherical X-ray source with a 0.1-10 keV luminosity LX ~ 5.2 × 1036 erg s−1 (Boirin et al. 2005) assuming for convenience that its radius is ~ few × 10R⊙ which means that it is relatively small comparing to the accretion disc size. While it is known that the source has varied in luminosity over a 20 year period (Balucinska-Church et al. 2000) and an interpolation to the date of the IR observations gives ≃ 2.5 times smaller luminosity, we left mentioned LX value because the bolometric luminosity is expected to be the same factor higher. Given a system period P = 2.94 h and assuming a compact object to be a neutron star with MX = 1.4M⊙, one can estimate the mass of the secondary component from the mass-radius relation for main sequence stars and the constraint that the star fills its Roche lobe of size (Eggleton 1983):

\[
r/a = 0.49 \frac{q^{2/3} \ln(1 + q^{1/3})}{0.6 q^{2/3} + \ln(1 + q^{1/3})}
\]

where \( q = M_{\text{opt}}/M_X \) and \( a \) is the semi-major axis of the binary. This simple estimate gives \( M_{\text{opt}} \approx 0.25M_\odot \) and enables us to determine the accretion disc size using (Paczynski 1977):

\[
r_{\text{out}} \approx 0.51 a = 0.62 R_\odot \text{ for } \mu = M_{\text{opt}}/(M_{\text{opt}} + M_X) = 0.15.
\]

The effective temperature of an accretion disc with a height \( z_0 \propto r^{n} \) illuminated by a point source in its centre is approximated by (Shakura & Sunyaev 1973):

\[
\sigma T_{\text{eff}}^4 = \frac{L_X}{4\pi r^2 \cos \theta} = \frac{L_X}{4\pi r^2} (n-1) \frac{z_0}{r}
\]

where \( \eta \) is the absorbed fraction of the radiation impinging on the disc surface assumed to be \( \sim 0.5 \). Let us consider the situation when the illumination does not change much the structure of a standard \( \alpha \)-disc. We therefore adopt standard \( \alpha \)-disc parameters, \( n = 9/8, z_0 / r_{\text{out}} \approx 0.05, \) giving a temperature \( T_{\text{eff}, \text{out}} = 10500 \text{ K} \) at the outer disc radius \( r_{\text{out}} \).

The observed flux (from a single side of the accretion disc as visible from Earth) at frequency \( \nu = 1.4 \times 10^{14} \text{ Hz} \) for the Ks filter is close to the Rayleigh-Jeans range and can be estimated as follows:

\[
Q_\nu = \frac{64}{49} \pi \cos \iota \frac{2\nu^2 k T_{\text{eff}, \text{out}} r_{\text{out}}^2}{c^2 d^2 f} e^{-r_\nu}
\]

Here the factor 64/49 accounts for the \( T_{\text{eff}}/r \propto r^{-15/32} \) dependency in the standard accretion disc, and \( f \approx 1 \) compensates for a non Rayleigh-Jeans law for a given

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1 http://archive.eso.org
by a factor of 1.0. Taking a moderate orbital plane inclination angle $i = 70\degree$, a source distance $d = 10$ kpc, and a typical extinction $A_K \approx 2.0$ mag ($\tau_v \approx 1.84$) derived from the 3D galactic extinction map in this direction (Marshall et al. 2004), gives $Q_v = 2.1 \times 10^{-29}$ erg cm$^{-2}$ s$^{-1}$ Hz$^{-1}$ which is an order of magnitude less than the observed flux (3.1...4.5) $\times 10^{-28}$ erg cm$^{-2}$ s$^{-1}$ Hz$^{-1}$ translated from the measured magnitude $K_s = 18.12 \pm 0.20$ mag and its uncertainty using zeropoints from Cohen et al. (2003).

We also estimated the observed flux in another limiting case for an illuminated disc with constant temperature along the $z$ coordinate (isothermal disc). Following equation (A5) from Vrtilek et al. (1990) with the same set of the system parameters used above, one gets $T_{eff, \text{out}} = 10000$ K. Use of $T_{eff}(r) \propto r^{-3/7}$ in integrating across the disc for isothermal model gives a factor of 14/11 instead of 64/49 in Eq. 2 and the observed flux $Q_v$ becomes a factor of 0.9 smaller than in the first case, considering also slightly different $T_{eff, \text{out}}$.

There are several possible explanations for this discrepancy between the observed and predicted fluxes. The existence of a hot ($2 \times 10^6$ K) atmosphere above the outer regions of a disc (Jimenez-Garate et al. 2002) can increase the observed flux at a given frequency $\nu = 1.4 \times 10^{14}$ Hz by a factor of 1.3...1.7 if we naively consider the effect of increased $z_0/r_{\text{out}} \approx 0.2$ ratio on Eq. 2. In such a hot atmosphere, the scattering of X-ray photons on free electrons with consequent penetration to sub-photosphere layers and thermalization takes place. This increases disc illumination and hence brightens the optical emission.

Also we assumed in the beginning the compact nature of the central X-ray source while it is now known that there exists extended accretion disc corona with the radius $\sim 30000$ km for adopted $L_X$ (Church & Bahcivanska-Church 2004, Bahcivanska-Church et al. 2009). This changes the illumination geometry of the outer regions of a disc, namely $\cos \theta \approx z_0/r$ in Eq. 2 and thus increases $T_{eff, \text{out}}$ and $Q_v$ by a factor of $(n-1)^{-1/4} \approx 1.7$, correspondingly.

Placing the object to the distance of 4–5 kpc instead of 10 kpc suggested by Parmar et al. (1989) on the basis of observed bursts being sub-Eddington would account for all inconsistency of predicted vs. observed fluxes because of significantly reduced extinction in this direction and the fact that $Q_v$ scales with distance as $d^{-3/2}$ for a fixed X-ray flux (which follows immediately from Eq. 2 since $Q_v \propto T_{eff, \text{out}}/d^2 \propto L_X/d^2$ while itself $L_X \propto d^2$ for the mentioned condition). We therefore might get $Q_v = 2.0 \times 10^{-28}$ erg cm$^{-2}$ s$^{-1}$ Hz$^{-1}$ in this case.

There is also a possibility of existence of a $\sim 2–3$ mag fainter object inside the combined XMM and Chandra error box which could be the actual counterpart of 4U1323-619.
but this cannot be ruled out on the basis of existing archival data and requires dedicated high spatial resolution X-ray observations and deeper phase-resolved follow-up IR observations, probably with adaptive optics in order to reduce field contamination by the source B. Discovery of the 2.94 h variability period in the IR source would allow to finally identify the 4U1323-619 counterpart.

4 CONCLUSIONS

On the basis of examination of archival ESO NTT data within the area of overlap of XMM and Chandra error regions, we have identified a probable candidate for the IR counterpart of 4U1323-619. Its observed $K_s$ magnitude significantly differs from that predicted by a simple analytical model of an accretion disc illuminated by a hot central spherical corona with a parameter set available in the literature. While putting the object to 4–5 kpc instead of assumed 10 kpc would explain the discrepancy, we encourage high spatial accuracy X-ray observations (e.g. using Chandra/HRC) and deeper phase-resolved follow-up observations inside the resulting error box listed here.

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