TITLE
ASP Conference Series, Vol. **VOLUME**, **PUBLICATION YEAR**
EDITORS

OAO1657–415 : A 'Missing Link' in High Mass X-ray Binaries?

D.H. Maxwell, A.J. Norton

Department of Physics and Astronomy, The Open University, Walton Hall, Milton Keynes MK7 6AA, U.K.

P. Roche

Department of Physics and Astronomy, The University of Leicester, University Road, Leicester LE1 7RH, U.K.

Abstract. OAO1657–415 is only the seventh eclipsing X-ray pulsar known and therefore has the potential to yield only the seventh mass of a neutron star in an X-ray binary. Here we report photometric and spectroscopic observations of candidates for the optical counterpart to the system and identify a B5III or B6V star as a possible companion to the neutron star. We measure the observational parameters of the star and suggest reasons why OAO1657–415 may be unlike other high mass X-ray binaries.

1. Introduction

High mass X-ray binaries (XRBs) consist of a neutron star, usually an X-ray pulsar, in orbit around a supergiant or Be-type companion star. Supergiant XRBs are permanently bright X-ray sources – they lose mass by a roughly spherical wind which may be augmented by Roche lobe overflow. In contrast, Be star XRBs often exhibit transient X-ray outbursts which may or may not be correlated with periastron passage through a dense circumstellar disc. Using the radial velocity amplitude of the companion and the Doppler shift of the X-ray pulsar around its orbit, the mass of the neutron star can be unambiguously determined if the system is eclipsing.

OAO1657–415 is only the seventh eclipsing X-ray pulsar known and therefore only the seventh XRB in which the mass of the neutron star may potentially be measured. Originally detected by *Copernicus* (Polidan et al 1978) it was at first incorrectly identified with the massive binary V861 Scorpii, leading to speculation that it was a black hole system. A more precise source position, provided by *HEAO 1* and *Einstein*, established that V861 Sco was not the companion and detected 38.22s pulsations (White & Pravdo 1979; Parmar et al 1980). *BATSE* observations of the X-ray pulsar subsequently revealed a 10.4d orbit with a 1.7d eclipse by the stellar companion (Chakrabarty et al 1993). OAO1657–415 falls between recognised classes of object in the Corbet diagram (Figure 1); and no optical counterpart has been identified.

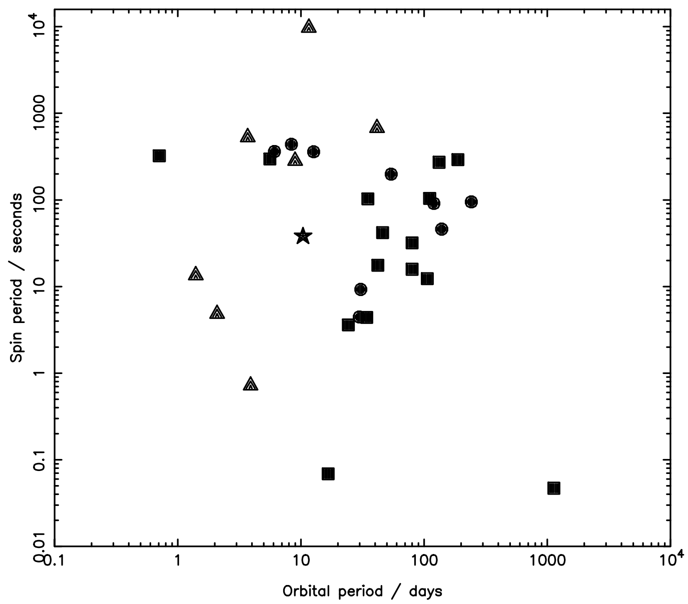

Figure 1. The Corbet diagram. Companion stars are shown as supergiants (triangles) or Be stars (squares) where spectroscopically identified. Other companions are shown as unidentified (circles). Be star XRBs cluster on the right of the diagram; supergiant XRBs lie in two regions: wind-fed systems lie at the top whilst Roche-lobe fed systems lie towards the left of the diagram. OAO1657–415 lies on its own, indicated by a star, in the centre of the diagram.

2. Observations

Optical photometry of the X-ray error circle and surrounding sky (Figure 2a) was obtained by service observations from the CTIO 1.5m in the BVRI bands on 12 Aug 1992. Infrared photometry was obtained by service observations from the AAT 3.9m using IRIS. Aperture photometry was performed on all the sources on and within the Einstein error circle, with the results shown in Figure 2b.

Spectra were obtained on 12-15 May 1997 using the RGO spectrograph on the AAT with the 1200B grating and 25cm camera. Spectra cover the wavelength range ~ 4100Å to 4900Å at a dispersion of 0.75 Å pixel^{-1}. Four different slit positions (see Figure 2a) were used to obtain spectra of 11 stars within the error circle. Only that of Star D (shown in Figure 3) corresponds to an early type star.

3. Results

Based on the relative strengths of the He I 4387Å, He I 4471Å and Mg II 4481Å lines, the spectrum of Star D corresponds to B5III or B6V, the low resolution precludes more refinement (Cananzi, Augarde & Lequeux, 1993). Furthermore the observed magnitudes of Star D are: U = 16.13 (A. Parmar, private commu-

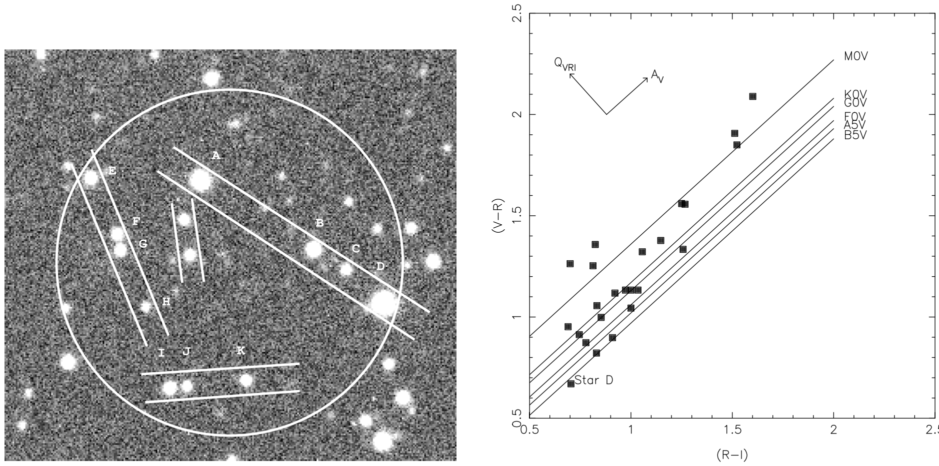

Figure 2. (Left) A CTIO V-band image of the field of OAO1657–415 illustrating the 30″ *Einstein* error circle centred at RA: $17^{\mathrm{h}}00^{\mathrm{m}}47.8^{\mathrm{s}}$, Dec: –41°39′14″(J2000). Straight lines show schematic outlines of the slit positions used for the AAT spectroscopy reported below. The candidate counterpart is Star D. (Right) A plot of $(V-R)$ versus $(R-I)$ shows lines of constant Q' for different spectral types, where $Q' = (V-R) - 0.91(R-I)$. Lines for luminosity classes III and V are similar.

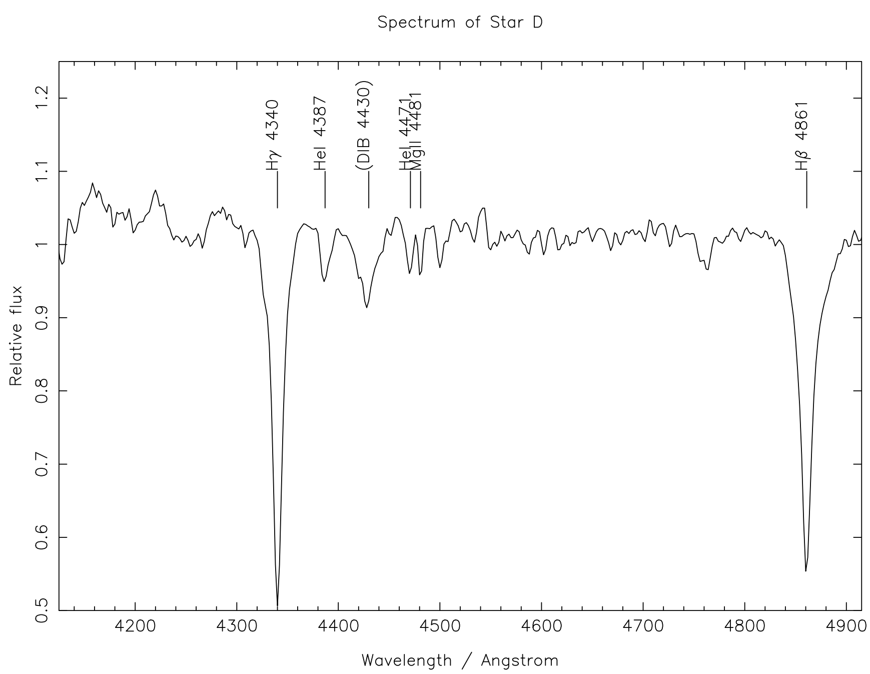

Figure 3. The spectrum of Star D

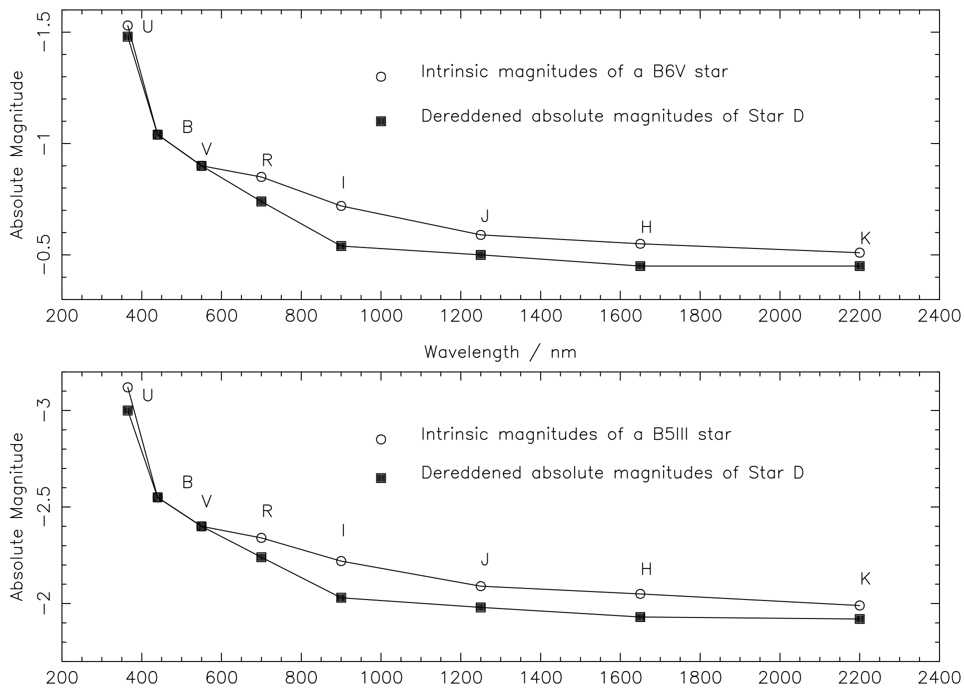

Figure 4. The de-reddened broad band spectrum of Star D compared with that of B6V and B5III stars. See text for reddening and distances.

nication) B = 15.84, V = 14.84, R = 14.17, I = 13.46, J = 12.59, H = 12.23, and K = 12.07.

The spectral classification is supported by the calculated reddening free Q-parameters. Defining $Q = (U - B) - 0.72(B - V)$, we have $Q_{\rm StarD} = -0.43$, $Q_{\rm B6V} = -0.39$ and $Q_{\rm B5III} = -0.46$. Alternatively, defining $Q' = (V - R) - 0.91(R - I)$, we have $Q'_{\rm StarD} = +0.03$, $Q'_{\rm B6V} = +0.05$ and $Q'_{\rm B5III} = +0.05$.

For a B6V/B5III star, $\rm M_V \sim -0.90/-2.40$ (Jaschek & Gomez 1998) and we use the colours of such a star from Wegner (1994) and Johnson (1966). So for Star D, the colour excess is $E(B - V) = 1.14/1.15$; and the extinction is $A_{\rm V} = 3.09E(B - V) = 3.52/3.55$ magnitudes.

Using, $m_{\rm V} = 14.84$, $M_{\rm V} = -0.90/-2.40$ and $A_{\rm V} = 3.52/3.55$ yields a distance for star D of 2.78 kpc assuming it is B6V or 5.47 kpc assuming it is B5III. Dereddening its colours using the extinction law of Wegner (1994) and using these distances, we calculate the absolute magnitudes of Star D as shown in Figure 4, where they are compared with those of B6V and B5III stars.

4. Discussion

Based on the X-ray eclipse properties, Chakrabarty et al (1993) state the optical counterpart to OAO1657–415 must have a mass of 14–18$\rm M_\odot$ and a radius of 25–32$\rm R_\odot$, indicating a spectral type of B0-6Ia, and implying $M_{\rm V} \sim -6.3$ and $Q_{\rm B0-6I} = -0.92$ to -0.66. No object with these colours is seen in the photometry. Assuming an extinction rate of 1.3 mag per kpc (as for Star D if it is B6V), a star with $M_{\rm V} = -6.3$ would be visible out to $\sim$ 10kpc in the V and R bands. Alternatively, assuming an extinction rate of 0.65 mag per kpc (as for Star D if it is B5III), a star with $M_{\rm V} = -6.3$ would be visible out to $\sim$ 20kpc in the V and R bands. Chakrabarty et al (1993) state that OAO1657–415 must lie at a distance of at least 10 kpc, based on the accretion torque during spin up. If this is the case it rules out our candidate for the counterpart, and suggests that the true counterpart must be fainter than $m_{\rm V} \sim 20$.

Clearly there are problems reconciling our possible counterpart with the predictions of Chakrabarty et al (1993). Nonetheless, Star D *is* the most likely counterpart amongst the stars visible in the X-ray error circle and we reiterate the fact that OAO1657–415 is unusual both in its position in the Corbet diagram and in its X-ray properties. The system does not behave like a typical SGXRB or BeXRB, so we may expect its optical counterpart to have unusual parameters too. If Star D *is* the counterpart, we suggest the following explanation.

OAO1657–415 is a transient X-ray source and may therefore be a Be star system – the circumstellar material having dissipated at the time of our spectroscopy, so yielding a conventional spectrum. Disc loss events in BeXRBs have been observed on timescales of $\sim$ 1 year (e.g. Telting et al 1998) so this is feasible. Furthermore, it is possible to reproduce the wide eclipse required by the BATSE observations with a disc which is optically thick to hard X-rays out to a radius of $\sim 25{\rm R}_\odot$ from the centre of the star or $\sim 2.5\times$ the radius of a B5III star. If the disc in OAO1657–415 had similar unusual density properties to that in X Per (i.e. $\rho_0 = 1.5 \times 10^{-10}$ g cm^{-3} and $\rho(r) = \rho_0 (r/R_*)^{-4.73}$, Telting et al 1998) then N_H is $\sim 10^{27}$ atoms cm^{-2} along a line of sight at $\sim 25{\rm R}_\odot$ from the centre of the star, which is sufficient to absorb hard X-rays. The giant classification (rather than supergiant or main sequence Be) may also account for the anomalous position of OAO1657–415 in the Corbet diagram.

As of 2000 October, we have just obtained further spectroscopy of Star D from the SAAO 1.9m telescope, spread over several weeks during a campaign to observe SMC X-1. We will use these spectra to search for the expected $\sim$ 20 km s^{-1} radial velocity shifts of the companion star in OAO1657–415. If this is confirmed, we will construct a preliminary radial velocity curve of the companion and so obtain a first estimate of the neutron star mass in this system.

References

Cananzi K., Augarde, R., & Lequeux, J. 1993, A&AS, 101, 599

Chakrabarty, D., et al, 1993, ApJ, 403, L33

Jaschek, C., & Gomez, A. E. 1998, A&A, 330, 619

Johnson, H. L. 1966, ARA&A, 4, 193

Parmar, A. N., et al, 1980, MNRAS, 193, 49P

Polidan, R. S., et al, 1978, Nature, 275, 296

Telting, J.H., et al., 1998, MNRAS, 296, 785

Wegner, W. 1994, MNRAS, 270, 229

White, N.E., & Pravdo, S. H. 1979, ApJ, 233, L121