Wolf-Rayet Stars
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Accurate parameters of massive binaries in the Danks clusters

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We present results from our near-infrared spectroscopy with VLT/ISAAC of four, massive eclipsing binary systems in the young, heavily reddened, massive Danks clusters. We derive accurate fundamental parameters and the distance to these massive systems, which comprise of OIf+, WR and O-type stars. Our goal is to increase the sample of well-studied WR stars and constrain their physics by comparison with evolutionary models.

1 Introduction

Eclipsing binaries (EBs) observed as double-lined spectroscopic binaries stand as unique tools to accurately derive fundamental parameters of stars (Andersen 1991). The majority of hot massive stars are known to form close binary systems (Sana et al. 2012) and hence, such systems constitute ideal tracers for the properties of young Galactic clusters (e.g. Koumpia & Bonanos 2012). In addition, they serve as anchors for the calibration of the extragalactic distance scale (e.g. Hilditch et al. 2005; Bonanos et al. 2006, 2011; Pietrzyński et al. 2013). We aim to explore the properties of massive stars located at the optically faint young, Danks clusters by studying three luminous EBs which are found to contain OIf+, WR and O-type stars.

2 Methodology

An optical variability survey of the Danks clusters was taken by Bonanos et al. (in prep), yielding a total of 21 EBs. Of these, five were observed with VLT/ISAAC in medium resolution ($R \sim 7500$) yielding K-band spectroscopy of S/N$\sim$ 150. Radial velocities were measured employing the near-infrared atlas of hot stars by Hanson et al. (2005) (for D2-EB) and the synthetic non-LTE stellar atmosphere codes FASTWIND (for D2-EB) and CMFGEN (for D1-EB1,2). The binary modeling was achieved proceeding simultaneously with the light curves and radial velocity curves using PHOEBE (Prša & Zwitter 2005) that implements the Wilson-Devinney code (Wilson & Devinney 1971). The genetic optimizer of ELC (Orosz & Hauschildt 2000) was also used, to assist the determination of the uncertainties for the parameters of D2-EB.

3 Results

3.1 D2-EB

D2-EB is a detached, double-lined system with a period of $\sim$ 3.37 days and a circular orbit. We generated a grid of FASTWIND templates assuming Galactic metallicity, at the temperature range $35-40$ kK, adopting surface gravity log$g \sim 3.9$ resulting from the binary modeling. We fit the Brγ (2.166 μm)/ He I (2.162 μm) blend and the He II (2.189 μm) feature, providing temperatures of 38 and 37 kK for the primary and the secondary component, respectively. In addition, the spectrum was also compared against the atlas by Hanson et al. (2005), providing an O6.5 spectral type for both components.

Radial velocities were measured selecting different K-band diagnostic lines such as the CIV at 2.08 μm, the blend of the CNO complex at 2.115 μm with He I at 2.112 μm and the He II line at 2.18852 μm. We found that the best-fit model is obtained with the use of the HeI/CNO blend, being the best tracer of the motion of the components. We derived masses and radii of $24.5 \pm 0.9 M_{\odot}$ and $9.2 \pm 0.1 R_{\odot}$ for the primary and $21.7 \pm 0.8 M_{\odot}$ and $8.7 \pm 0.1 R_{\odot}$ for the secondary component with an accuracy $\sim$3.8% for the masses and $\sim$1% for the radii. This best-fit model is displayed in Fig. 1.

We employed spectral energy distributions generated by FASTWIND using the modeled parameters and fit the available BVI_c photometry by Baume et al. (2009) and near-infrared photometry from 2MASS, as shown in Fig. 2. We derived a distance $d = 3.52 \pm 0.08$ kpc, with a precision of 2% and a visual extinction of $A_{5495} = 11.9 \pm 0.1$ mag. Based on the position of D2-EB on the mass-radius diagram, the system is found coeval to the Danks 2 cluster with an age of $\sim$5 Myr. The measured systemic velocity is inconsistent to that of the cluster, indicating that D2-EB was likely ejected from the cluster as a runaway binary in the recent past. A detailed analysis of the system is presented in Kourniotis et al. (2015).

3.2 D1-EB1 and D1-EB2

D1-EB1 is an eccentric ($e = 0.14$), detached system with a period of $\sim$ 5.97 days. The spectrum of D1-EB1 displays emission of the CIV/CNO/Brγ features while the 2.18852 μm HeII line shows a P-Cygni profile for the primary and absorption for the

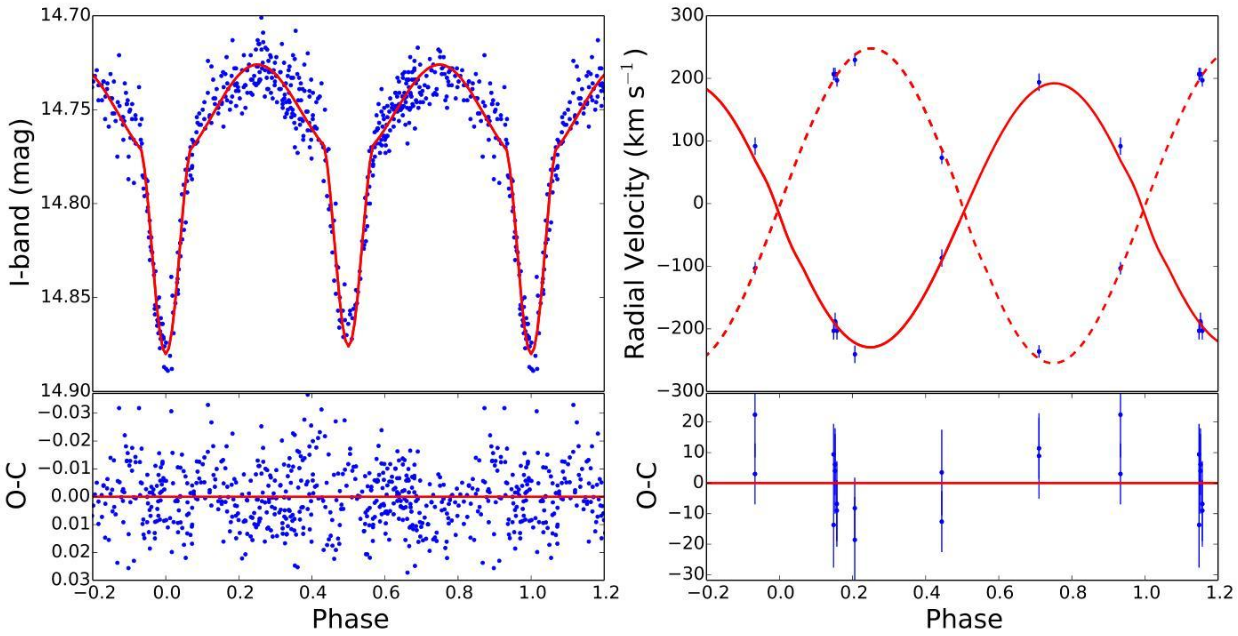

Fig. 1: The *left* panel shows the modeled light curve (red) and the I-band observations of Bonanos et al. (in prep). The *right* panel displays the radial velocities measurements from the ISAAC/VLT K-band spectra, and the overplotted modeled curves. Residuals of the fits are shown in the lower panels.

secondary. The system was modeled with the non-LTE atmosphere code CMFGEN and the best fit was achieved using an O5.5 − 6 If+ spectral type of $T_{\rm eff1} = 34.5\,{\rm kK}$ for the primary component and an O5 − 5.5 If spectral type of $T_{\rm eff2} = 36.5\,{\rm kK}$ for the secondary component. Radial velocities were measured using the HeI/CNO blend, which provided the best-fit curve, as in D2-EB. Our preliminary analysis has yielded masses of $\sim 75 M_{\odot}$ and $\sim 69 M_{\odot}$ for the primary and the secondary component, respectively.

The single-lined spectrum of D1-EB2 was classified by Davies et al. (2012) as a WNLh-type star which, based on its position on a near-infrared colour-magnitude diagram, is assigned an initial mass of $\sim 120 M_{\odot}$. We are the first to report D1-EB2 as an eclipsing system with a period of ~ 3.29 days. The light curve indicates overflow for the Roche lobe of the primary and/or the secondary component. The spectrum displays HeI/CNO/Brγ in emission and HeII in a P-Cygni profile. We employed the CMFGEN code to provide the best-fit model which corresponds to a hydrogen-rich WN star with $T_{\rm eff} = 34.5\,{\rm kK}$. Further analysis of the second quadrature of D1-EB2 may reveal the presence of the companion. Preliminary results based on the single radial velocity curve and an assumption for the mass of the primary from the range $60 - 120 M_{\odot}$ typical for hydrogen-rich WN stars, give rise to a double contact scenario and indicate an early O-type giant companion.

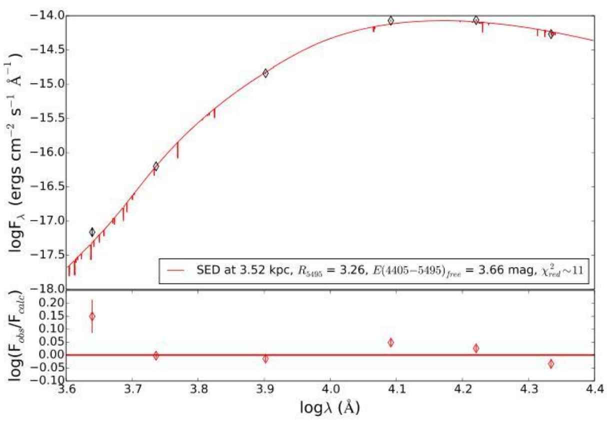

Fig. 2: Fit of the reddened, composite spectral energy distribution of D2-EB to the available BVI_cJHK_s photometry (points). We find a distance of 3.52 kpc, with a visual extinction of $A_{5495} = 11.9$ mag.

We searched the 3XMM-Newton source catalogue for evidence of X-ray emission, reporting a bright source within 5" from D1-EB2, and a fainter source associated with D1-EB1 which, however, could be likely affected by the bright, nearby X-ray counterpart of WR48a. The X-ray spectrum of the single-lined D1-EB2 was fit with a soft component with $kT = 0.78\,{\rm keV}$ and a hard component with $kT = 3.33\,{\rm keV}$. Column density is found to be $n_{\rm H} = 2.30 \times 10^{22}{\rm cm}^{-2}$ and we derived the 0.5 − 8 keV X-ray luminosity of $\log L_{\mathrm{X}} \sim 33.72$. Comparing to the X-ray survey of colliding wind binaries by Gagné et al. (2012), the inferred X-ray luminosity that emerges from shocks in the wind collizion zone of D1-EB2, is typical for WR+O type systems. Nevertheless, the short period of D1-EB2 is unusual compared to the long periods that wide, X-ray bright systems typically have.

4 Acknowledgements

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References

Andersen, J. 1991, A&A Rev., 3, 91

Baume, G., Carraro, G., & Momany, Y. 2009, MNRAS, 398, 221

Bonanos, A. Z., Castro, N., Macri, L. M., & Kudritzki, R.-P. 2011, ApJ, 729, L9

Bonanos, A. Z., Stanek, K. Z., Kudritzki, R. P., et al. 2006, ApJ, 652, 313

Davies, B., Clark, J. S., Trombley, C., et al. 2012, MNRAS, 419, 1871

Gagné, M., Fehon, G., Savoy, M. R., et al. 2012, in Astronomical Society of the Pacific Conference Series, Vol. 465, Proceedings of a Scientific Meeting in Honor of Anthony F. J. Moffat, ed. L. Drissen, C. Robert, N. St-Louis, & A. F. J. Moffat, 301

Hanson, M. M., Kudritzki, R.-P., Kenworthy, M. A., Puls, J., & Tokunaga, A. T. 2005, ApJS, 161, 154

Hilditch, R. W., Howarth, I. D., & Harries, T. J. 2005, MNRAS, 357, 304

Koumpia, E. & Bonanos, A. Z. 2012, A&A, 547, A30

Kourniotis, M., Bonanos, A. Z., Williams, S., et al. 2015, A&A, submitted

Orosz, J. A. & Hauschildt, P. H. 2000, A&A, 364, 265

Pietrzyński, G., Gieren, W., Graczyk, D., et al. 2013, in IAU Symposium, Vol. 289, IAU Symposium, ed. R. de Grijs, 169–172

Prša, A. & Zwitter, T. 2005, ApJ, 628, 426

Sana, H., de Mink, S. E., de Koter, A., et al. 2012, Science, 337, 444

Wilson, R. E. & Devinney, E. J. 1971, ApJ, 166, 605

Philip Massey: Back in the olden days, Peter Conti and I did orbit solutions for a number of Of+Of systems, and often found that the gamma-velocities didn't agree. The reasons behind this make sense; the lines are formed in a region that is already part of the wind. Did you allow for this in your orbit solutions?

Michalis Kourniotis: I indeed report a discrepancy between systemic velocities modeled with different features. For instance, modeling the eccentric D1-EB1 using just the CNO complex, I got $\gamma \approx -110\,\mathrm{km/s}$ but using the He II instead, I got $\gamma \approx 0\,\mathrm{km/s}$. Taking this discrepancy into account, I proceeded into working with either feature separately. I found that the best-fit radial velocity curve was achieved with the use of the CNO/He I blend rather than the He II line. In general, I suggest that for such systems it is hard to claim membership to the cluster based on systemic velocities that are derived from K-band features.

Mike Corcoran: The high X-ray luminosity of the contact binary D1-EB2 is surprising, since in a contact system the winds near the line of centers do not collide at terminal velocities. Have you tried to fit the X-ray spectrum with colliding wind models of the emission?

Michalis Kourniotis: For the X-ray modelling, two-temperature models (apec) of thermal emission from collisionally ionized plasma were applied. The integrated flux corresponds to the range $0.5 - 8\,\mathrm{keV}$. To convert flux to luminosity, a distance of $3.8\,\mathrm{kpc}$ was employed, typical of the distance to the Danks 1 cluster.