New facts about δ Velorum: fewer but larger components

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Summary. Interferometric observations of the nearby eclipsing binary δ Vel A were obtained with VLTI/VINCI and AMBER. The measurements, which for the first time resolve the two components, are analysed with non-linear least-square fitting methods and provide estimates of the orbital parameters and the stellar properties. We derive a system mass of $M_{Aa+Ab} = (4.05 \pm 0.30) M_{\odot}$ and an eccentric binary orbit ($e \approx 0.26$). The observations further indicate that the components' diameters are much larger than expected for main-sequence stars, implying that Aa and Ab are in evolved post main-sequence evolutionary phases.

1 A nearby (∼24pc) eclipsing binary system

An observer gazing at the southern sky constellation Vela will easily make out the bright star δ Velorum, since it is one of the 50 visually brightest stars on the sky. In the Cape Photographic Durchmusterung (1895-1900) δ Vel is listed with a photographic magnitude of 3.5 mag [1], while more modern measurements yield consistent values of V=1.9–2.0 mag (the *Hipparcos* magnitude is $H_p = 1.95$ mag). Already in 1847, Herschel [2] published the detection of two faint visual companions, δ Vel C and D, at $\sim 80''$ distance from δ Vel A. Even another companion, δ Vel B, had been discovered by Innes in 1895 [3]. The Washington Visual Double Star Catalogue [4] describes δ Vel as a quadruple stellar system: it reports that δ Vel consists of two pairs, AB (sep$\sim 2.6''$) and CD (sep$\sim 6''$), separated approximately by $70''$. Only recently, the most luminous component, component A, was discovered to be itself an eclipsing binary with a period of 45.15 days [5].

2 VLTI observations of the eclipsing binary

The eclipsing binary δ Vel A (components designated as Aa and Ab) was observed in April and May 2003 at four orbital phases using two siderostats and the K-band beam recombination instrument VINCI on the ESO Very Large Telescope Interferometer (VLTI). In February 2005, during the AMBER science demonstration phase, medium resolution ($\lambda/\Delta\lambda = 1500$) K-band data of

Aa+Ab were obtained, using three Unit Telescopes of the VLTI. The observations were combined with observations of HD63744, for calibration purposes. We used the data reduction routines described by [6] and [7] for VINCI and AMBER data reduction, and obtained as a result 26 squared visibilities (V^2) at 5 different orbital phases.

3 Results and discussion

3.1 Physical parameters of the close eclipsing binary (Aa+Ab)

The visibility measurements were fitted onto the model of a binary system made out of two uniformly bright circular disks, observed at K-band with filters of finite bandwidths. Five parameters of the binary model (stellar diameters D_1, D_2, position angle of the ascending node Ω, semi-major axis a, eccentricity e) were adjusted with non-linear least-squares fitting to best match the measured visibilities. Table 1 lists orbital and physical parameters corresponding to the best fit of the interferometric data, along with parameters estimated from other techniques.

Most interestingly, our results indicate stellar diameters for Aa and Ab of $6.1 \pm 0.4\ D_\odot$ and $3.5 \pm 0.6\ D_\odot$ respectively. Given the fact that many authors classify δ Vel A as A1V (e.g. [8]) much smaller diameters ($\sim 2D_\odot$) were expected. We further deduce a system's total mass of $M_{Aa+Ab} = (4.05 \pm 0.30)M_\odot$ based on the orbital period of 45.15 d and the size of the semi-major axis as constrained by our interferometric measurements.

The results need to be compared to predictions made by stellar evolutionary models. In Fig. 1 we plot the measured radii and absolute V magnitudes of δ Vel Aa and Ab against isochrones of evolutionary models published by Yi et al. [9]. The comparison suggests that the age of δ Vel is about $(0.9 \pm 0.1)10^9$yr. Separate masses of δ Vel Aa and Ab are then derived by tracing the relevant isochrones in the radius versus mass diagram, which yields $M_{Aa} = 2.23 \pm 0.10\ M_\odot, M_{Ab} = 2.15 \pm 0.10\ M_\odot$, and hence $M_{Aa+Ab} = 4.38 \pm 0.14\ M_\odot$, in agreement with the value above. Finally, the resulting locations of δ Vel Aa, Ab in the HR-diagram, assuming an age of $(0.9 \pm 0.1)10^9$yr, suggest that δ Vel Aa and δ Vel Ab are in evolved evolutionary states, i.e. have left the main-sequence.

3.2 On the physical association of δVel C and D

Since the observations of Herschel [2], δVel has been quoted as a visual multiple star, with δVel C and D representing the "outer" components. With apparent V magnitudes of 11.0 and 13.5 for C and D respectively [11], they should be of late spectral type, certainly no earlier than M, *if* they are at similar distance as δVel (Aa+Ab+B). To our knowledge, the only existing spectra of C and D were recorded during a survey of nearby M dwarfs [12].

Table 1. Parameters of δ Vel (Aa+Ab) involved in the analysis of the interferometric data. Second column: values estimated without the present interferometric measurements (References: [5, 10]). Last two columns: estimates derived from our measurements.

Parameter	estimate based on light curves + astrometry	interferometry	evolutionary models
d: distance to δ Vel (Aa+Ab) [pc]	24.450±0.001		
T: orbital period [days]	45.150±0.001		
τ: fraction of orbital period from primary to secondary eclipse	0.435±0.005		
t_1: duration of primary eclipse [days]	0.51±0.05		
t_2: duration of secondary eclipse [days]	0.91±0.01		
e: eccentricity of orbit	0.300 ± 0.045	0.2581 ± 0.0004	
ω: angle of periastron [rad]	0.33±0.07	0.395 ± 0.001	
Ω: position angle of the ascending node [rad]		0.47±0.01	
a: semi-major axis [m]	$(6.0 \pm 0.4)10^{10}$	$(5.92 \pm 0.15)10^{10}$	
M_{Aa+Ab}: total mass of δ Vel (Aa+Ab) [$M_\odot$]	4.2 ± 0.7	4.05 ± 0.30	4.38 ± 0.14
M_{Aa}: mass of δ Vel Aa [$M_\odot$]			2.23 ± 0.10
M_{Aa}: mass of δ Vel Aa [$M_\odot$]			2.15 ± 0.10
$\phi = \frac{\phi_2}{\phi_1}$: surface intensity ratio	2.0±0.7		
D_1: diamater of Aa [$D_\odot$]		6.1 ± 0.4	
D_2: diameter of Ab [$D_\odot$]		3.5 ± 0.6	
Age of δ Vel [yr]			$(0.9 \pm 0.1)10^9$

While the limited range and resolution of the spectra precluded ready determination of the spectral types of C and D, they were nevertheless estimated as ~G8V and ~K0V. Therefore, given their apparent magnitudes, C and D must be at much further distances than δVel (Aa+Ab+B). We conclude, that δVel C and D are not physically associated and hence, δVel should be designated as a triple stellar system only.

4 Conclusions

New interferometric data of the eclipsing binary δVel A have been combined with existing photometric and spectroscopic observations in order to analyse the physical properties of this multiple system. One of our main results is that the eclipsing binary components show large radii that are incompatible with the general classification of δVel Aa, Ab as early A-type main-sequence stars. While fitting the interferometric data we also varied the stellar diameter values of δVel Aa, Ab within ranges more appropriate for main-sequence A-type stars, but it was impossible to achieve any acceptable solution this way. Our analysis therefore suggests that δVel Aa, Ab are in a post main-sequence phase of their evolution. The result is puzzling and certainly deserves further investigation. Our understanding would benefit from precise photometry during the eclipses in order to provide separate intensities of Aa and Ab and a confirmation of the ratio of their stellar diameters. Moreover, high resolution spectra of (Aa+Ab) during and out of the eclipses should enable a better determination the stars' effective temperatures and luminosity classes.

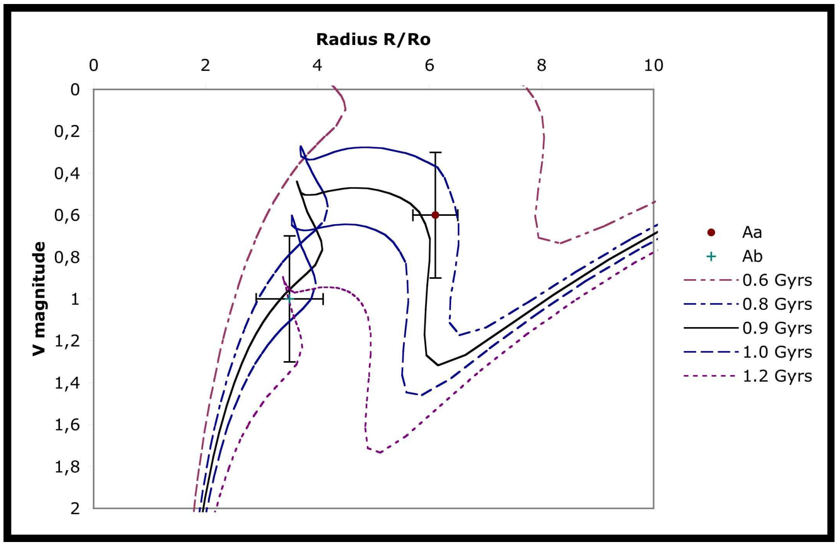

Fig. 1. Observations of δ Vel A compared to evolutionary models by [9], for solar chemical composition. The age of δ Vel A appears to be $(0.9 \pm 0.1)10^9$yr.

References

1. Gill D., Kapteyn J. C: Ann. Cape Obs. **5**, part III (1900)
2. Herschel, J.F.W.: QB **3**, H52, Smith, Elder and co. (publisher), London (1847)
3. Innes, R.T.A.: MNRAS **55**, 312 (1895)
4. Worley C.E., Douglass G.G.: A&AS **125**, 523 (1997)
5. Otero, S.A., Fieseler, P.D., Lloyd, C.: IBVS **4999**, 1 (2000)
6. Kervella, P., Thévenin, F., Ségransan, D. et al.: A&A **404**, 1087 (2003)
7. Millour, F., Tatulli, E., Chelli, A.E. et al.: SPIE **5491**, 1222 (2004)
8. Royer, F., Gerbaldi, M., Faraggiana, R., Gómez, A.E.: A&A **381**, 105 (2002)
9. Yi, S., Demarque, P., Kim, Y-C., Lee, Y-W. et al.: ApJS **136**, 417 (2001)
10. Argyle, R.W., Alzner, A., Horch, E.P.: A&A **384**, 171 (2002)
11. Jeffers, H.M. et al.: Publications of the Lick Observatory, icvd.book (1963)
12. Hawley, S.L., Gizis, J.E., Reid, I.N. Hawley: AJ **112**, 2799 (1996)