A study of the young quadruple system AO Vel with a ZAMS eclipsing BpSi primary and PMS companions

J. F. González[1], S. Hubrig[2], N. Nesvacil[2,3], and P. North[4]

[1] Complejo Astronómico El Leoncito, Casilla 467, 5400 San Juan, Argentina
fgonzalez@casleo.gov.ar

[2] European Southern Observatory, Casilla 19001, Santiago 19, Chile
shubrig@eso.org, nnesvaci@eso.org

[3] Department of Astronomy, University of Vienna, Türkenschanzstrasse 17, 1180 Vienna, Austria

[4] Ecole Polytechnique Fédérale de Lausanne (EPFL), Laboratoire d'Astrophysique, Observatoire, CH-1290 Sauverny, Switzerland
Pierre.North@obs.unige.ch

Summary. Using recent spectroscopic observations we discovered that the triple system AO Vel with an eclipsing BpSi primary is in fact a remarkable quadruple system formed by two double-lined spectroscopic binaries with ZAMS and PMS companions. For the first time, direct determinations of the radius and the mass have been obtained for a BpSi star.

1 Observations and RV measurements

We obtained five spectra of AO Vel with FEROS at the 2.2m telescope at La Silla (R = 48,000), and 6 additional spectra with the 2.1m telescope of the CASLEO and the echelle spectrograph REOSC (R=13,000). The spectral line profiles exhibit a variable and complex structure indicating four spectral companions identified here as A, B, C, and D. In order to obtain separate spectra for all four components of the system and to measure their radial velocities (RVs), we applied the iterative method described in [3], which was adapted here for multiple systems. RV curves are shown in Fig. 1.

2 Spectral analysis

For each component in the system, we calculated synthetic spectra using the SYNTH code [7], the VALD database [5] and ATLAS9 model atmospheres [6]. Comparing a variety of syntheses with different $T_{\rm eff}$ to our observations we determined the parameters that produced the best fits (Table 1). In order to reproduce the line intensities of the peculiar star A the abundances of He and Mg were decreased by 1.45 and 1.04 dex, respectively, while the Si abundance had to be increased by 0.5 dex relative to solar composition.

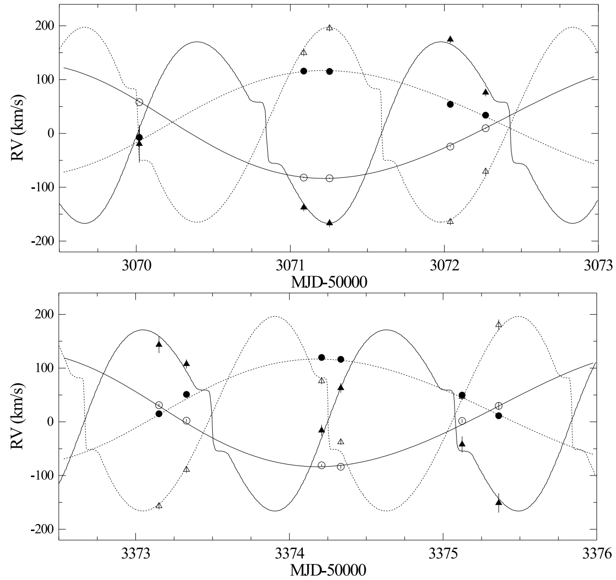

Fig. 1. Radial velocity curves for La Silla (up) and CASLEO (bottom) spectra. Filled and open symbols correspond to the primary and secondary component of each binary, respectively.

Table 1. Atmospheric parameters derived from comparison with synthetic spectra.

Star	$T_{\rm eff}$ [K]	$\log g$	$v \sin i$ [$\rm km\,s^{-1}$]
A	13700 (adopted)	4.3	65
B	$12500 \pm 250\,$K	4.3 ± 0.1	73
C	$10500 \pm 500\,$K	4.1 ± 0.2	40
D	$10000 \pm 500\,$K	4.2 ± 0.2	18

3 Orbital analysis

Spectroscopic orbits for the two binaries A+B and C+D were calculated using the 11 RV measurements of each star. In the case of the system A+B, we fitted the RV curves using the Wilson & Devinney program [9, 10] taking the inclination and relative radii from [2]. The resulting parameters are listed in Table 2. We recomputed the apsidal motion of the binary A+B and the wide orbit AB+CD from the analysis of the light-time effect over all the available times of minimum along with our spectroscopic observations. We calculated the orbital period of the eclipsing system to be $P_{AB} = 1.5846154 \pm 0.000002$ days. The value we found for the apsidal motion period (54.72 ± 0.45 yr) is indistinguishable from that found by previous works [2, 11]. However, the orbit AB+CD ($P_o = 41.0 \pm 0.2$ yr, $a_{o,1} \sin i_o = 11.15 \pm 0.07$ AU, $e_o = 0.291 \pm 0.005$) is essentially different.

Table 2. Spectroscopic orbits and stellar parameters of binary systems C+D and A+B.

Parameter	Units	Value
P_{CD}	days	4.15008 ± 0.00016
T_{CD}(periastron)	MJD	53074.059 ± 0.060
$V\gamma_{CD}$	km s^{-1}	21.2 ± 0.7
ω_{CD}	deg	60 ± 6
e_{CD}		0.047 ± 0.015
$M_C \sin^3 i_{CD}$	$M_\odot$	1.94 ± 0.07
$M_D \sin^3 i_{CD}$	$M_\odot$	1.77 ± 0.08
$V\gamma_{AB}$	km s^{-1}	8.9 ± 2.3
M_A	$M_\odot$	3.63 ± 0.18
M_B	$M_\odot$	3.38 ± 0.18
R_A	$R_\odot$	2.34 ± 0.08
R_B	$R_\odot$	2.11 ± 0.08

4 Physical parameters

The masses and radii calculated for the stellar components of the eclipsing binary are located near the ZAMS in the mass-radius diagram (Fig. 2). A lower limit to the masses of stars C and D can be obtained from the outer orbit between the two systems and the mass of the binary A+B, using the expression

$$\frac{(1+q_o)^2}{q_o^3} = (a_{o,1} \sin i_o)^{-3} \cdot P_o^2 \cdot M_{A+B} \cdot \sin^3 i_o,$$

where M_{A+B}, $(a_{o,1} \sin i_o)$, and P_o are known parameters. From the condition $i_o \leq 90°$ we obtain $M_C \geq 2.55 \pm 0.09$ $M_\odot$ and $M_D \geq 2.34 \pm 0.10$ $M_\odot$. Using the spectroscopic temperatures and the luminosity difference between the two binary systems, and assuming that the four stars are coeval, we found that the age of the system is about $10^{6.6}$-$10^{6.8}$ yr in the pre-main sequence grid of Bernasconi [1]. The fact that components C and D are still pre-main sequence stars, implies that stars A and B are just on the ZAMS. Specifically, the post-main sequence evolutionary age of the peculiar star A is only 1-2% of their main-sequence lifetime.

5 Conclusions

- AO Vel, the known triple system with an eclipsing BpSi primary, is in fact a remarkable quadruple system with ZAMS and PMS companions.
- It is formed by two spectroscopic binaries that move in a wide eccentric orbit (e=0.29) with a period of 41 yr.
- Absolute masses and radii are derived for stars A and B, and a lower limit to the masses of stars C and D has been established.
- The analysis of the stellar parameters reveals the extreme youth of all companions confirming our previous results that contrary to peculiar stars with masses below 3 $M_\odot$, stars of higher mass seem to fill the whole width of the main-sequence band in the H-R diagram [4].

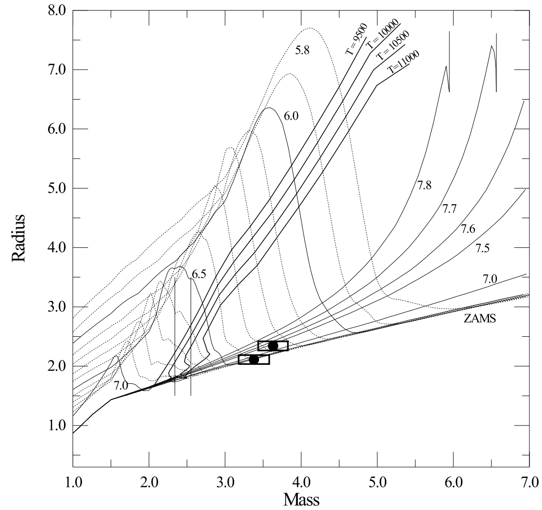

Fig. 2. Mass-radius diagram. Filled circles with error boxes are stars A and B belonging to the eclipsing system. Minimum masses for stars C and D are marked with vertical bars. Main sequence [8] (continuous lines) and pre-main sequence [1] (dotted lines) isochrones are plotted and labeled with log(age). Thick lines are isotherms interpolated for pre-main-sequence models.

References

1. Bernasconi, P. A.: A&AS, 120, 57 (1996)
2. Clausen, J. V., Giménez, A., & van Houten, C. J.: A&AS, 109, 425 (1995)
3. González, J. F., & Levato, H.: A&A, submitted (2005)
4. Hubrig, S., North, P., & Szeifert, T.: "Evolution of Magnetic Fields in Stars Across the Upper Main Sequence: Results from Recent Measurements with FORS 1 at the VLT," in *Astronomical Polarimetry: current status and future directions*, edited by A. Adamson, ASP Conf. Series, vol. 343, in press (2005).
5. Kupka F., Piskunov N., Ryabchikova T.A., Stempels H.C., Weiss W.W.: A&AS 138, 119 (1999)
6. Kurucz R.L.: CDROM13, SAO Cambridge (1993)
7. Piskunov N. E.: in "Stellar magnetism", eds. Yu.V.Glagolevskij & I.I. Romanyuk, Nauka, St. Petersburg, 92 (1992)
8. Schaller, G., Schaerer, D., Meynet, G., & Maeder, A.: A&AS, 96, 269 (1992)
9. Wilson, R. E., & Devinney, E. J.: ApJ, 166, 605 (1971)
10. Wilson R. E.: ApJ, 356, 613 (1990)
11. Wolf, M., & Zejda, M.: A&A, 437, 545 (2005)