Physical properties of the Algol-type eclipsing binary AO Ser

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Abstract.
We present the results of a combined analysis of photometric time series and spectroscopic observations for the semi-detached eclipsing binary AO Ser aimed to study physical parameters of the system. New CCD photometric light curves in the B and V bands and radial velocities of AO Ser are presented. The Wilson-Devinney technique was used to simultaneously analyze the light and radial velocity curves for determining a new set of the system's parameters. The solution shows that AO Ser is a semi-detached eclipsing binary system with a mass ratio of 0.183 $\pm$ 0.003, an inclination of 89.42 $\pm$ 0.04 degrees and a secondary star's temperature of 4900 K.

1. Introduction

The Algol-type binary is a semi-detached system of stars whose less massive component transfers mass to the more massive component due to filling its Roche lobe, causing mass and angular momentum loss. The period variations may be one of the main parameters for understanding the dynamics of binaries and possibly their stellar structure and evolution. Therefore, a series of observations and study of Algol-type binaries are still interesting.

AO Ser ($RA_{J2000}=15^h58^m18^s$, $Dec_{J2000}=+17°16'09''$ [1]) is an eclipsing binary with a pulsating component. It is a faint star with magnitudes B=11.^{m}26, V=11.^{m}04 [1], J=10.^{m}287, H=10.^{m}093, and K=10.^{m}031 [2]. The first light curve of AO Ser was published by Hoffmeister [3] and classified as an Algol-type eclipsing binary (EA) without accurate knowledge of the orbital period. There were several endeavors to derive the orbital period of the system, e.g. [4] and [5]. The orbital period was derived by Koch [4]. Kim *et al.* [6] discovered that AO Ser is an oEA binary which is an Algol type eclipsing binary with a pulsating component [7]. The periodic of the oscillations of AO Ser is less than 0.05 days and the small amplitude is $\Delta B \sim 0.^m02$. The first multiband photometry of AO Ser was presented by Yang *et al.* [8] and they reported the spectral type of A2. The results revealed that it is low mass ratio system, whose secondary components fill their Roche lobes. Hambalek [9] presented a new determination of physical parameters of the binary components, the mass ratio q = 0.396 and the distance to AO Ser d = 671 pc. They also confirmed pulsations of the primary component and derived its more accurate period $P_{puls} = 0.040$ d. No radial velocity curves have been published. Therefore, we decided to study AO Ser both photometrically and spectroscopically to obtain a more accurate set of physical parameters.

2. Observations and data reduction

We conducted imaging observations of AO Ser in B and V bands during 13 nights between 15th March and 29th May 2007 at the Beersel Hills Observatory (BHO), Beersel, Belgium with a 40-cm f4.9 Newton telescope equipped with a ST10XME camera, field of view 17.2×25.5 arcmin. A total of 546 images was obtained in the V band and 577 images were obtained in the B band. The differential photometry was applied to the data. We collected spectroscopic data between 23rd May 2011 and 5th May 2016 using the 1.2-m semi-robotic Mercator telescope (www.mercator.iac.es) at the Roque de los Muchachos Observatory on the island of La Palma, Spain. The telescope was equipped with the High Efficiency and Resolution Mercator Echelle Spectrograph (HERMES) [10] which is a high-resolution spectrograph. In high-resolution fiber (HRF) mode, spectral resolving power $R = \Delta\lambda/\lambda = 85000$ (3.5 km/s). Moreover, we used 10 spectra additional radial velocity measurements for AO Ser components determined by Hoffmann [11], spectra were collected between 24th May 2008 and 6th June 2009 using the 3.5-m telescope equipped with the Dual Imaging Spectrograph (DIS) instrument and one spectrum from the Echelle instrument at the Apache Point Observatory.

3. Data analysis and results

Epochs from data collected in 2007 of primary light minima along with others compiled from the literature [8] were used to find the new ephemeris. By using the least squares fitting method, the new linear ephemeris is

$$Min.I(HJD) = 2454175.5429 + 0.879349(\pm 0.000002)E \quad (1)$$

We obtained the phase diagrams in B and V bands as shown in Fig 1. In the search of binary model, the system's parameters were calculated using the Wilson-Devinney code with Kurucz models of atmosphere [12]. We applied the fixed parameters: the temperature for Star 1 of T_1, the bolometric and monochromatic limb-darkening coefficients of x_1 and x_2 were taken from van Hamme [13], the bolometric albedo coefficients of $A_1 = 1$ and $A_2 = 0.5$ [14]. the gravity darkening exponents of $g_1 = 1.0$ and $g_2 = 0.32$ [15]. The adjustable parameters are the orbital inclination, i, the temperature of Star 2, T_2, the potential of Star 1, Ω_1, and the monochromatic luminosity of Star 1, L_1. The relative brightness of Star 2 was calculated by the stellar atmosphere model [16]. Our new CCD B and V-band light curves and radial velocity curves of two components were simultaneously applied to deduce the system's parameters. The temperature for Star 1 was fixed as $T_1 = 9000$ K following the spectral type A2 of the system and we calculated the best value of mass ratio, q, from radial velocity curves which shown in Fig 2. The best fit model for the binary system presents a semi-detached configuration, secondary star fills Roche lobe. The best value of system's parameters are shown in Table 1.

4. Summary and Conclusions

Our new light and radial velocity curves of AO Ser were simultaneously analyzed using the Wilson-Devinney technique. We confirmed a semi-detached configuration of the system, determined an accurate mass ratio from the binary radial velocity orbit and absolute physical parameters, effective temperatures, radii and a surface gravity of components. We can interpret the stellar type of secondary component as K2 III. The new accurate parameters will be used for spectroscopic modelling and analyses of pulsation line-profile variations in the primary component caused by non-radial pulsations.

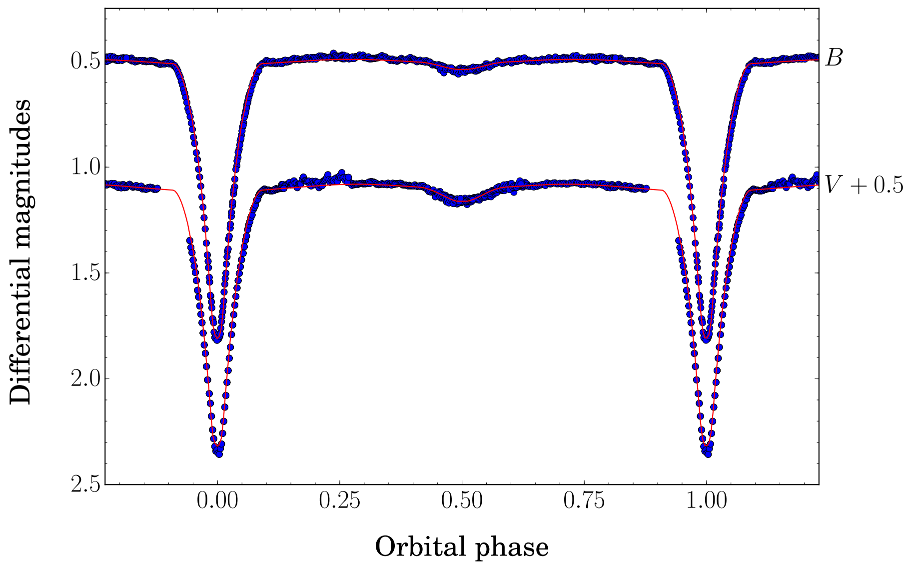

Figure 1. *B* and *V* light curves for the eclipsing binary AO Ser observed from March to May in 2007 at the Beersel Hills Observatory (BHO), Belgium. Blue dots show the observational data and red lines present the synthetic light curves from program PHOEBE.

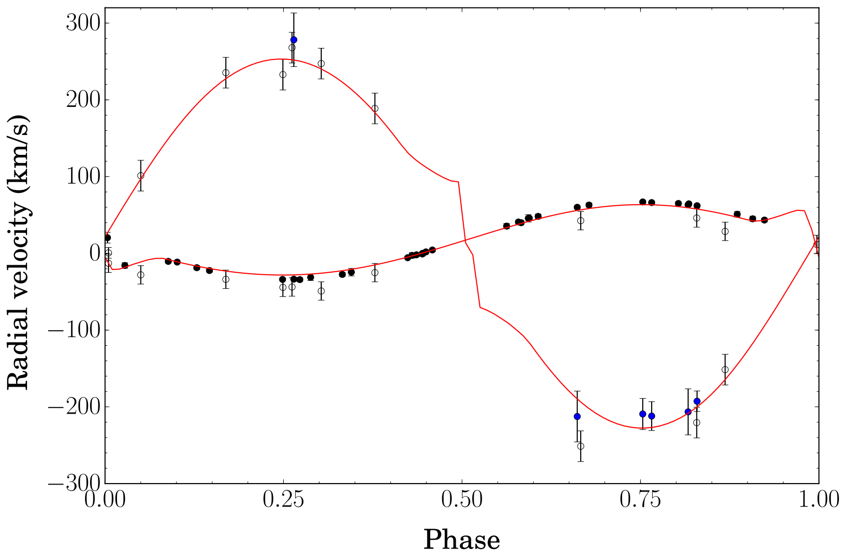

Figure 2. Radial velocity measurements of AO Ser. Black and blue filled circles are primary and secondary components, respectively. Open circles show additional radial velocity measurements determined by Hoffmann [11]. Red lines present the synthetic light curves from a modeling with program PHOEBE. The velocities are relative to the barycentric velocity of the system.

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Table 1. The physical parameters of AO Ser

Parameters	Best-fit value	Parameters	Best-fit value	Parameters	Best-fit value
P (d)	0.879349±0.000002	e	0.005±0.094	$a(R_\odot)$	5.15±0.07
$i(^\circ)$	89.42± 0.04	$\omega(^\circ)$	4.91±0.09	$R_1(R_\odot)$	1.49±0.02
$q = m_2/m_1$	0.183± 0.003	γ(km/s)	16.7±0.4	$R_2(R_\odot)$	1.26±0.03
T_1 (K)	9000 (fixed)	$x_{B,1}$	0.759	$M_1(M_\odot)$	2.01±0.09
T_2 (K)	4922±24	$x_{V,1}$	0.659	$M_2(M_\odot)$	0.37±0.02
Ω_1	3.669± 0.004	$x_{B,2}$	0.845	$\log(g)_1$	4.39±0.05
Ω_2	2.20 (fixed)	$x_{V,2}$	0.804	$\log(g)_2$	3.80±0.05

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