CHAPTER 8

Physical Properties of Algol-type Eclipsing Binary AO Ser

8.1 Introduction

The Algol-type binary is a semi-detached system of stars whose less massive component transfers mass to the other one due to filling its Roche lobe, causing mass and angular momentum loss. A study of Algol-type binaries is very interesting because one of the crucial properties for understanding the stellar structure, dynamics of binaries and their evolution is the period variations in their systems. AO Ser (RA_{2000} = $15^{h}58^{m}18^{s}$, Dec_{2000} = $+17^\circ16'09''$ (Hog et al., 1998)) is an eclipsing binary with a pulsating component. It is a faint star with magnitudes $B = 11.26$ mag, $V = 11.04$ mag, $J = 10.287$ mag, $H = 10.093$ mag, and $K = 10.031$ mag (Cutri et al., 2003). The first light curve of AO Ser was published by Hoffmeister (1935) 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. Koch, 1961; Wood and Forbes, 1963). The orbital period was derived by Koch (1961). AO Ser was discovered to be an oEA binary by Kim et al. (2004). This class of star is an Algol type eclipsing binary with a pulsating component which is defined by Mkrtichian et al. (2004). The oscillation period of AO Ser is lower than 0.05 d and the amplitude of 0.02 mag in B band. The first multiband photometry of AO Ser was presented by Yang et al. (2010) 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. Hambálek (2015) 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. Currently, no radial velocity curves have been studied. Thus, the study of AO Ser both photometrically and spectroscopically to obtain a more accurate set of physical parameters are presented in this chapter.

8.2 Observations and data reduction

8.2.1 Photometric data

Paul Van Cauteren (Beersel Hills Observatory, now observing at the Humain station of radio-astronomy of the Royal Observatory of Belgium) 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 40cm f4.9 Newton telescope equipped with a ST10XME (SBIG) camera, field of view 17.2×25.5 arcmin^2. A total of 546 images was obtained in the V band and 577 images were obtained in the B band. The differential photometry technique using Mira-AP was applied to the data. The journal of B and V photometric observations is presented in Table 8.2.

Table 8.1: Coordinates from the catalogue of reference and check stars for AO Ser

Stars	GSC Catalogue	RA(J2000)	Dec.(J2000)
AO Ser	GSC 1496-00003	15:58:18.000	+17:16:09
Reference star	GSC 1496-01169	15:57:59.517	+17:19:26.34
Check star 1	GSC 1496-00227	15:58:02.440	+17:21:13.60
Check star 2	GSC 1496-01071	15:58:19.905	+17:19:45.38

8.2.2 Spectroscopic data

Dr. P. Lampens (Royal Observatory of Belgium) 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) (Raskin et al., 2011) 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 additional radial velocity measurements for AO Ser components determined by Hoffmann (2009), 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. The journal of the spectroscopic observations is presented in Tables 8.3 and 8.4.

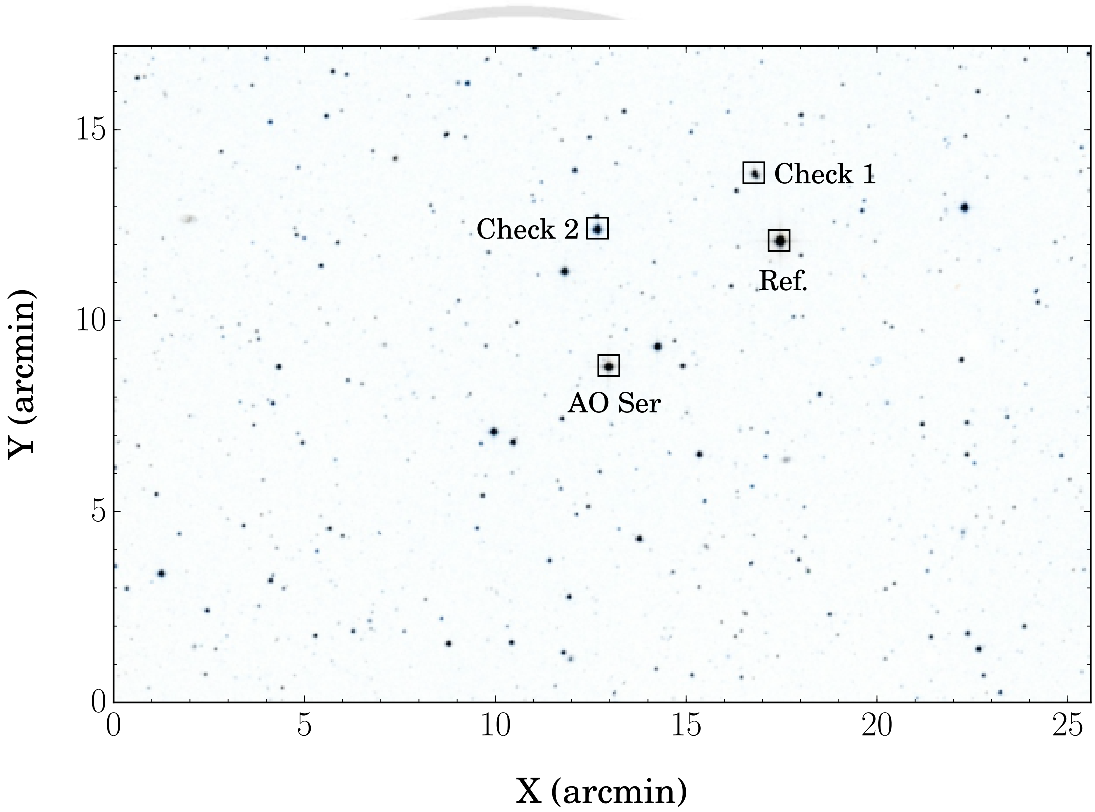

Figure 8.1: Finding chart of AO Ser (25.5′×17.2′, north is up and east is to the left). Eclipsing binary AO Ser is indicated with the black square. The size of image shows the field covered by our observations.

Table 8.2: Journal of photometric observations of AO Ser in B and V bands (Courtesy of P. Van Cauteren (Beersel Hills Observatory, Belgium))

Date	Start time (HJD)	Length (days)	Frames (filter V)
15/3/2007	2454175.493	0.169	84
26/3/2007	2454186.487	0.162	80
10/4/2007	2454201.438	0.164	85
11/4/2007	2454202.445	0.203	70
26/4/2007	2454217.385	0.033	17
05/5/2007	2454226.355	0.082	40
23/5/2007	2454244.369	0.222	100
29/5/2007	2454250.403	0.120	60
Total			536
Date	Start time (HJD)	Length (days)	Frames (filter B)
10/4/2007	2454201.439	0.162	56
11/4/2007	2454202.446	0.203	70
19/4/2007	2454210.431	0.108	52
20/4/2007	2454211.379	0.275	135
22/4/2007	2454213.338	0.112	56
30/4/2007	2454221.355	0.142	71
01/5/2007	2454222.357	0.278	137
Total			577

Table 8.3: Journal of spectroscopic observations of AO Ser using the HERMES spectrograph. Table presents both radial velocities of primary and secondary components.

Date	BJD	Phase (km/s)	RV_1 (km/s)	σRV_1 (km/s)	RV_2 (km/s)	σRV_2
23/05/2011	2455705.44113	0.81676	62.696	3.985	-206.535	30.001
23/05/2011	2455705.45213	0.82927	62.513	2.763	-192.663	13.368
19/04/2013	2456401.54875	0.43619	-0.811	7.026	-	-
27/04/2014	2456774.53049	0.59416	48.572	4.491	-	-
27/04/2014	2456775.46899	0.66143	60.027	2.414	-	-
30/04/2014	2456778.48260	0.08853	-14.191	5.930	-	-
05/05/2014	2456780.46680	0.34498	-24.371	4.349	-	-
05/05/2014	2456783.46380	0.75319	68.007	1.889	-209.293	20.260
05/05/2014	2456783.47479	0.76569	66.737	2.566	-211.987	18.818
19/01/2016	2457406.77932	0.59284	43.259	7.430	-	-
25/01/2016	2457412.78618	0.42389	-6.236	5.346	-	-
29/04/2016	2457508.49470	0.26443	-33.957	1.941	278.27	34.928
05/05/2016	2457513.56263	0.02772	-11.019	7.693	-	-

Table 8.4: Journal of spectroscopic observations of AO Ser using the Dual Imaging Spectrograph (DIS) instrument and one spectrum from the Echelle instrument at the Apache Point Observatory (Courtesy of Hoffmann (2009)). Table presents both radial velocity of primary and secondary components. [a]ARCES (Echelle) data

Date	BJD	Phase	RV_1 (km/s)	RV_2 (km/s)
24/05/2008	2454610.86132	0.0500	-28.020	101.232
25/05/2008	2454611.91582	0.2491	-44.318	232.901
26/05/2008	2454612.80633	0.2619	-43.820	268.044
26/05/2008	2454612.90843	0.3780	-25.109	188.789
21/06/2008	2454638.80556	0.8288	46.063	-220.507
22/06/2008	2454639.83978	0.0048	-12.927	0.608
24/07/2008	2454671.64052	0.1692	-33.838	235.409
24/07/2008	2454671.75811	0.3028	-49.039	247.278
06/06/2009	2454988.81891	0.8696	28.595	-151.515
06/06/2009	2454988.93090	0.9971	11.572	...
07/02/2009	2454869.92907[a]	0.6663	42.585	-251.300

8.3 Data analysis and results

Epochs from data collected in 2007 of primary light minima along with others compiled from the literature (Yang et al., 2010) were used to find the new ephemeris. By using the least squares fitting method, the new linear ephemeris is

$$\text{Min I (HJD)} = 2454175.5429 + 0.879349(\pm 0.000002)E. \qquad (8.1)$$

We obtained the phase diagrams in B and V bands as shown in Figure 8.2. In the search of binary model, the system's parameters were calculated using the Wilson-Devinney code with Kurucz models of atmosphere (Wilson and Devinney, 1971). We applied the fixed parameters: the temperature for Star 1 of T_1, the bolometric and monochromatic limb-darkening cofficients of x_1 and x_2 were taken from (van Hamme, 1993), the bolometric albedo coefficients of A_1 = 1 and A_2 = 0.5 (Ruciński, 1973). the gravity darkening exponents of g_1 = 1.0 and g_2 = 0.32 (Lucy, 1967). 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 (Kurucz, 1993). Our new CCD B and V-band light curves and radial velocity curves of two components were applied in the same time to calculate 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 Figure 8.3. 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 8.5.

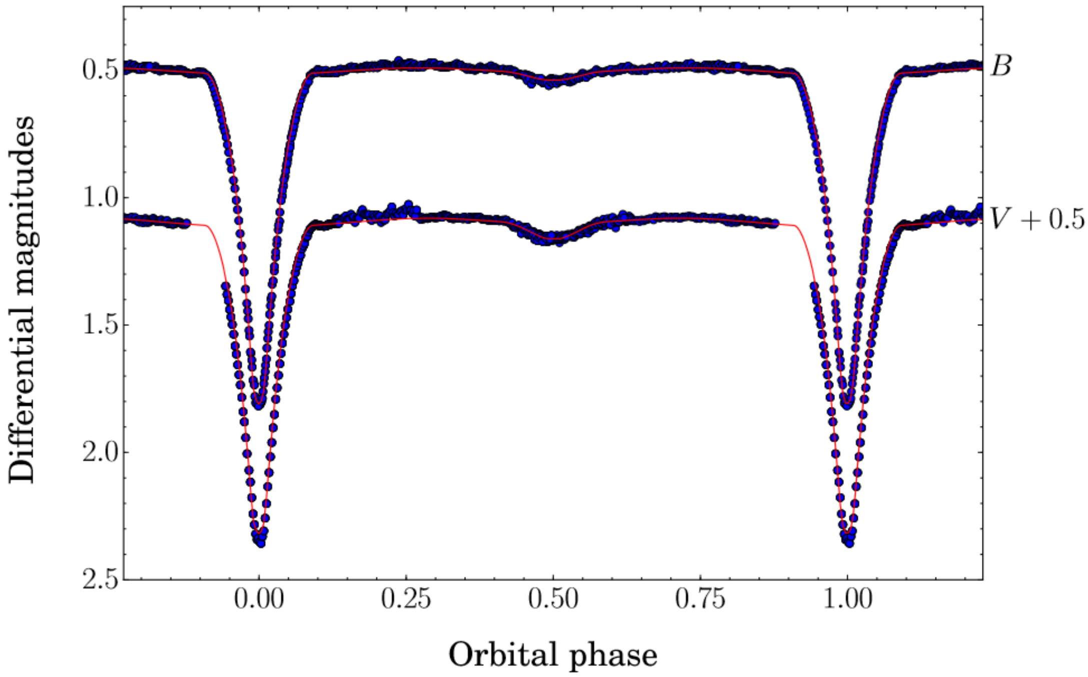

Figure 8.2: B and V light curves for the eclipsing binary AO Ser observed from March to May in 2007 at the Beersel Hills Observatory (BHO), Belgium. Blue dots show the observational data and red lines present the synthetic light curves from program PHOEBE.

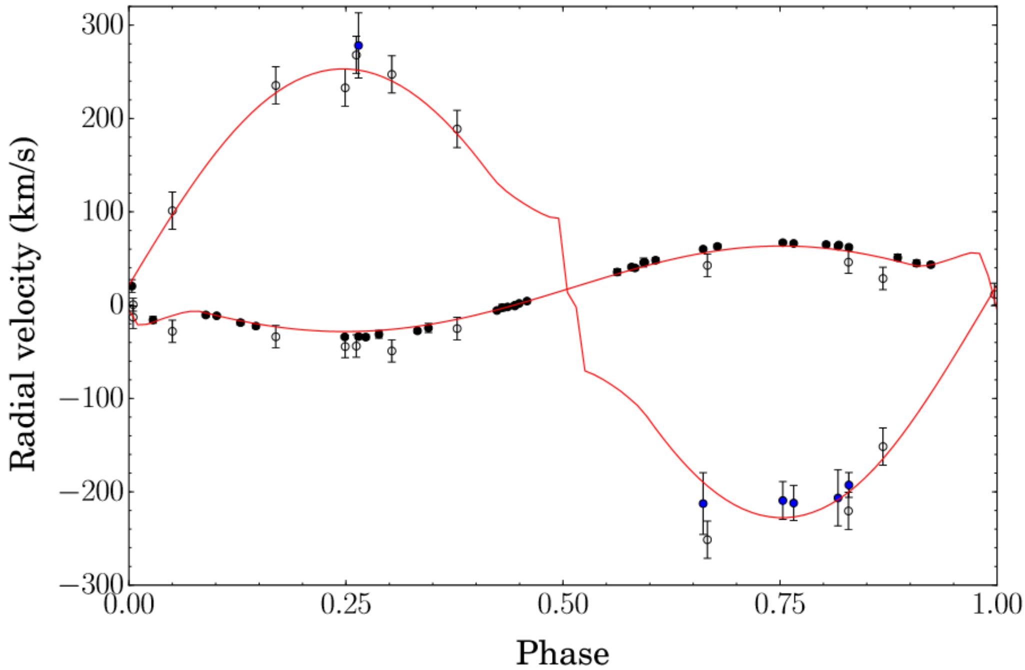

Figure 8.3: Radial velocity measurements of AO Ser. Black and blue filled circles are primary and secondary components, respectively. Open circles show additional radial velocity measurements determined by Hoffmann (2009). Red lines present the synthetic light curves from a modeling with program PHOEBE. The velocities are relative to the barycentric velocity of the system.

Table 8.5: The physical parameters of AO Ser

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

8.4 Summary and Conclusions

CCD times of the light minimum in *B* and *V* bands of AO Ser were obtained during 13 nights using the telescope at Beersel Hills Observatory and spectroscopic data using HERMES high-resolution spectrograph. These 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.

8.5 Acknowledgment

This research is part of a stay at the ROB in the context of the PhD research of N.Chehlaeh at Royal Observatory of Belgium under the supervision of P. Lampens, D. Mkrtichian and S. Komonjinda. This study is supported by the Development and Promotion of Science and Technology Talents Project (DPST), Department of Physics and Materials Science, faculty of Science and Graduate school, Chiang Mai University. The authors would like to thank Royal Observatory of Belgium (ROB) and the National Astronomical Research Institute of Thailand (NARIT) for their support in this work. Based on observations made with the Mercator Telescope, operated on the island of La Palma by the Flemish Community, at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofsica de Canarias. Based on observations obtained with the HERMES spectrograph, which is supported by the Research Foundation - Flanders (FWO), Belgium, the Research Council of KU Leuven, Belgium, the Fonds National de la Recherche Scientifique (F.R.S.-FNRS), Belgium, the Royal Observatory of Belgium, the Observatoire de Genéve, Switzerland and the Thüringer Landessternwarte Tautenburg, Germany.