Analyzing ι Ori Aa through high resolution spectroscopy: Orbital solution and apsidal motion

J. Eguren Brown,[1], G. Ferrero[1,2] & S. Simón Díaz[3,4]

[1] *Facultad de Ciencias Astronómicas y Geofísicas, UNLP, Argentina*
[2] *Instituto de Astrofísica de La Plata, CONICET–UNLP, Argentina*
[3] *Instituto de Astrofísica de Canarias, Tenerife, Spain.*
[4] *Departamento de Astrofísica, Universidad de La Laguna, Tenerife, Spain*

Contact / jordi@carina.fcaglp.unlp.edu.ar

Resumen / El sistema binario ι Ori Aa ha sido estudiado con diversas técnicas y desde diferentes puntos de vista. Las determinaciones de sus parámetros orbitales, realizadas por varios autores, son consistentes aunque difieren en la longitud del periastro. Aún así, la existencia de movimiento apsidal era dudosa. En este trabajo obtenemos un nuevo conjunto de velocidades radiales a partir de espectros de alta resolución, ajustamos una nueva solución orbital, separamos los espectros de sus componentes, mostramos que el movimiento apsidal claramente existe, y calculamos su velocidad.

Abstract / The binary system ι Ori Aa has been studied with different techniques and approaches. The orbital parameters determined by different authors are consistent, but differ in the value of the periastron longitude. However, the existence of apsidal motion in the system was quite controversial. In this work, we obtain a new set of radial velocities from high resolution spectra, fit a new orbital solution, separate the spectra of the two components, show that apsidal motion clearly exists, and calculate its rate.

Keywords / binaries: close — binaries: spectroscopic — stars: early-type — stars: individual: HD 37043

1. Introduction

ι Ori Aa (HD 37043, $\alpha = 05^h\ 35^m\ 25.98^s$, $\delta = -05^\circ\ 54'\ 35.64''$) is a massive, double line spectroscopic binary composed of an O9 III and a B1 IV-V star. Its first orbital solution was obtained by Plaskett & Harper (1909) and was later improved by Miczaika (1951) and Pearce (1953). It was noted by Gies & Bolton (1986) that the two components of the binary could not be coevals. This consideration, together with the high eccentricity of its orbit ($e \sim 0.7$), has led some authors (Bagnuolo et al., 2001) to propose that these components could have originally belonged to two different binary systems, and that the collision of said systems could have originated our object of study and the two close-by O9.5 V runaway stars AE Aur and μ Col. Later, Gualandris et al. (2004) postulated that both systems may have originated in the Trapezium cluster. Astroseismic activity of ι Ori Aa was studied using photometric data from the *BRITE Constellation* mission by Pablo et al. (2017) who discovered tidally excited oscillations in the primary star of the system, seen for the first time in an O-type star. Apsidal motion in the system was first proposed and measured by Stickland et al. (1987) and later rejected by Hilditch et al. (1991) due to unreliable measurements. It was reconsidered and measured by Marchenko et al. (2000) and finally by Ferrero (2016), who calculated the apsidal motion rate by fitting together all previous radial velocities (RVs) measurements in a single orbital solution. We intend to perform a thorough quantitative spectroscopic analysis of the two components of ι Ori Aa as well as of AE Aur and μ Col to shed light over this issue. As a first step, we present in this work the result of the orbital analysis of a new, high-quality spectroscopic dataset, including the results of the disentangling process and a new result for apsidal motion of the system.

2. Observations

This work is based on 63 high-resolution optical spectra obtained in the framework of the IACOB project (Simón-Díaz et al., 2015). In particular, the spectra were acquired with the HERMES instrument (Raskin et al., 2004) attached to the Mercator Telescope at the Roque de Los Muchachos Observatory on La Palma, Spain, during nights of the 2016 and 2017 season with a resolution of $R \sim$85 000, and typical signal to noise ratio $S/N \sim 300$.

3. Spectral disentangling

We measured the RVs and separated the spectra of the system components using the disentangling technique described by González & Levato (2006).

To obtain a first estimation of the RVs, we measured the position of the baricenter of the spectral lines He I $\lambda\lambda$5015 and 5875. The fact that these lines are not contaminated by other lines and are located in a spectral region free from telluric absorption made them ideal

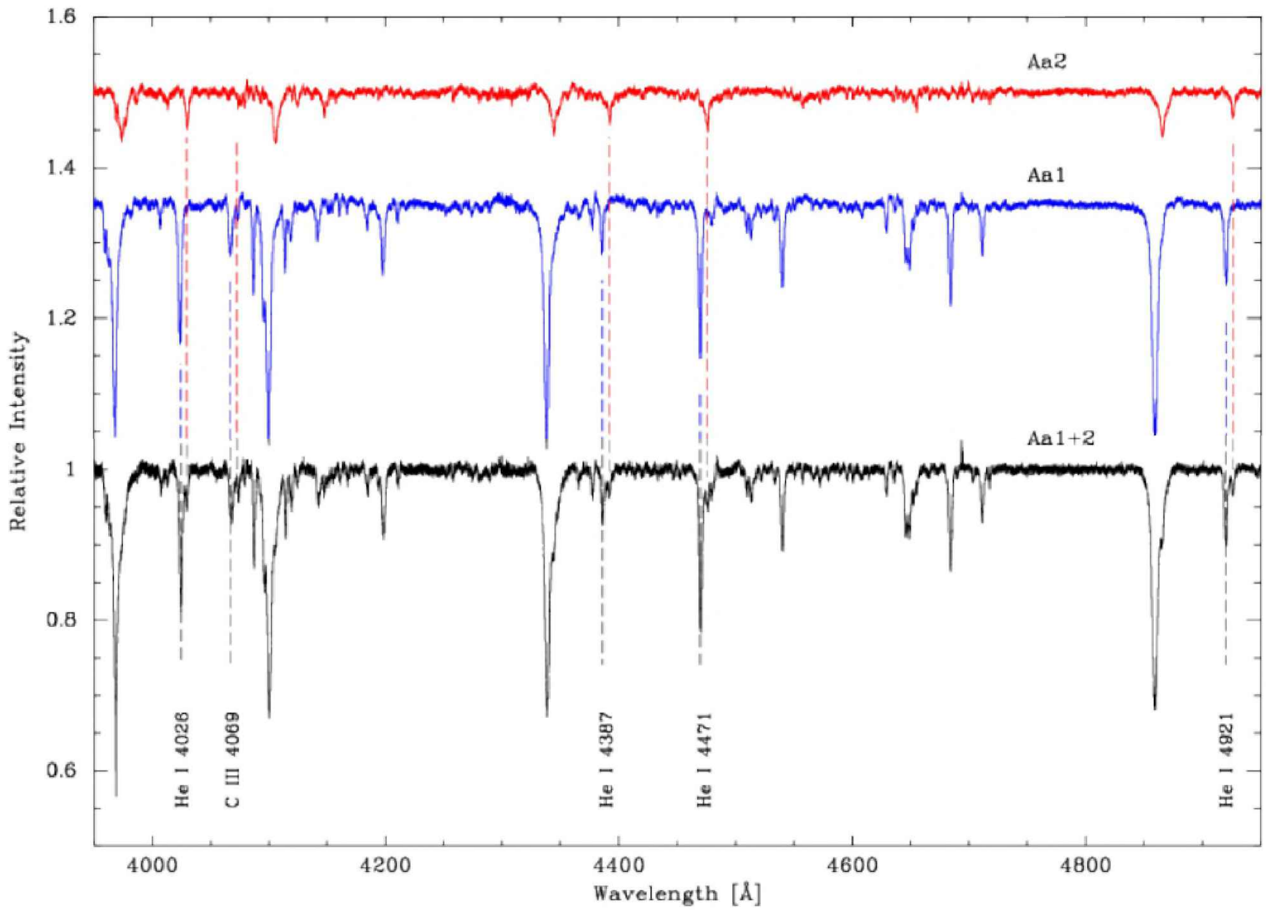

Figure 1: Disentangled spectra of both components in ι Ori Aa, and one of the composite ones.

candidates for these measurements. As a first step, we fitted Gaussian functions to the line profiles by mean of the NGAUSS task within IRAF. RV measurements of the secondary component were only possible for phases close to the quadratures due to line blending. Because of the high eccentricity of the system there were just ten spectra that fulfill this condition. Even so, the resulting separated spectra have a satisfactory S/N of ~ 700 (see Fig. 1).

4. Spectral classification

Following the criteria from Sota et al. (2011), since in the primary He II $\lambda4542$ > He I $\lambda4388$, He II $\lambda4200$ > He I $\lambda4144$ and He II $\lambda4686$ is in strong absorption, we propose to classify it as O8 III. For the secondary, according to Walborn & Fitzpatrick (1990), since the He II $\lambda4686$ line is present and considering the ratio Si III $\lambda4552$/He I $\lambda4388$, we propose a B0.5 V type. Both classifications agree with previous determinations (e.g. Bagnuolo et al. 2001).

5. Orbital solution

We fitted an orbital solution to our RV measurements using the FOTEL code (Hadrava, 2004), with the initial values taken from Ferrero (2016). During the fitting process, lower weight was assigned to individual data that accumulate in a short phase range (e.g., $\phi \sim 0.25$). Most of the parameters in our solution are in accordance with calculations by previous authors. The results are shown in Table 1 and Fig. 2.

Table 1: Orbital parameters obtained by fitting our RVs, measured in He I $\lambda\lambda5015$ and 5875.

Parameter	Value	+/−
P [days]	29.1350	0.0002
T_0 [HJD]	2455608.11	0.01
e	0.713	0.003
ω [°]	126.3	1.4
γ_1 [km s^{-1}]	33	1
γ_2 [km s^{-1}]	21	1
K_1 [km s^{-1}]	105.3	0.1
K_2 [km s^{-1}]	195.7	0.2
$a_1 \sin i$ [$R_\odot$]	42.2	0.2
$a_2 \sin i$ [$R_\odot$]	78.6	0.3
$M_1 \sin^3 i$ [$M_\odot$]	18.2	0.2
$M_2 \sin^3 i$ [$M_\odot$]	9.8	0.2
q	0.538	0.007
RMS [km s^{-1}]	2.0	

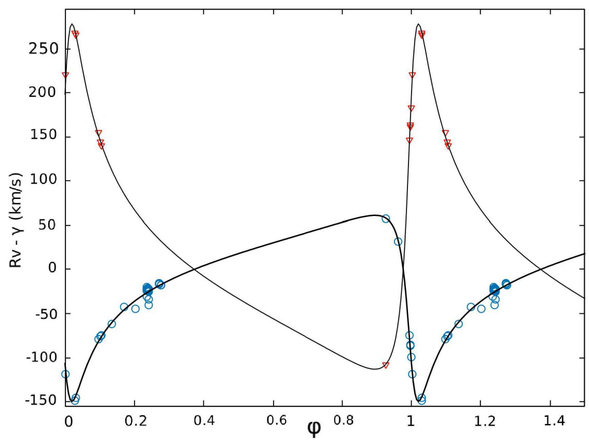

Figure 2: Radial velocity curves of both components in ι Ori Aa (blue points: primary; red: secondary).

Table 2: Apsidal motion rate measurements by other authors.

Author	$\dot{\omega}$ [° day^{-1}]	±
Stickland et al, (1987)	0.00041	0.00003
Marchenko et al, (2000)	0.00049	0.00003
Ferrero (2016)	0.00037	0.00012

6. Analysis of apsidal motion

We compared our new orbital solution with the already published ones. The major disagreement among orbital parameters is in the longitude of the periastron. When present and previous studies are plotted together, it is clear that there is a linear trend in the longitude of the periastron against time. By computing a linear regression to these data, we obtained a value for the apsidal motion rate $\dot{\omega} = 0.00029 \pm 0.00003$ ° day^{-1} (see Fig. 3). Our result alongside previous calculated values (see Table 2) leaves little room for doubt regarding the existence of the apsidal motion.

7. Summary and future work

We measured RVsfor the binary system ι Ori Aa, obtained a new orbital solution and were able to disentangle the spectra of its components, which allowed us to spectrally classify it. We confirmed the existence of apsidal motion and calculated its rate.

The next stage of this work consists in the determination of the fundamental parameters and photospheric abundances of the two components of the binary system ι Ori Aa, as well as of AE Aur and μ Col. This will be done using IACOB–GBAT tool developed by Simón-Díaz et al. (2011) and will require to refine the separated spectra using more available data.

Acknowledgements: JEB thanks the Facultad de Ciencias Astronómicas y Geofísicas, UNLP, for their financial support. Special thanks to P. Hadrava for providing the FOTEL code. S. S.-D. acknowledges financial support from the Spanish MINECO and the Gobierno de Canarias.

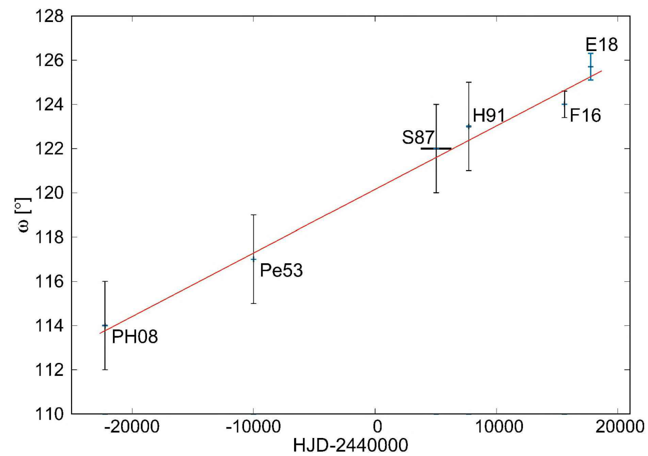

Figure 3: Secular variation of the periastron longitude in ι Ori Aa. PH09: data adjusted by Plaskett & Harper (1909); Pe53: Pearce (1953); S87: Stickland et al. (1987); H91: Hilditch et al. (1991); F16: Ferrero (2016), E18: determined in this work. Horizontal bars: time span of RVs data. Red line: linear regression.

References

Bagnuolo Jr. W.G., et al., 2001, ApJ, 554, 362

Ferrero G., 2016, *Estudio de la variación de la línea de las ápsides en sistemas binarios masivos*, Ph.D. thesis, Univ. Nac. de La Plata

Gies D.R., Bolton C.T., 1986, ApJS, 61, 419

González J.F., Levato H., 2006, A&A, 448, 283

Gualandris A., Portegies Zwart S., Eggleton P.P., 2004, MNRAS, 350, 615

Hadrava P., 2004, Publications of the Astronomical Institute of the Czechoslovak Academy of Sciences, 92, 1

Hilditch R.W., et al., 1991, The Observatory, 111, 14

Marchenko S.V., et al., 2000, MNRAS, 317, 333

Miczaika G.R., 1951, ZA, 29, 305

Pablo H., et al., 2017, MNRAS, 467, 2494

Pearce J.A., 1953, AJ, 58, 223

Plaskett J.S., Harper W.E., 1909, ApJ, 30, 373

Raskin G., Van Winckel H., Davignon G., 2004, A.F.M. Moorwood, M. Iye (Eds.), *Ground-based Instrumentation for Astronomy, Proc. SPIE* , vol. 5492, 322–330

Simón-Díaz S., et al., 2011, *Journal of Physics Conference Series, Journal of Physics Conference Series*, vol. 328, 012021

Simón-Díaz S., et al., 2015, A.J. Cenarro, F. Figueras, C. Hernández-Monteagudo, J. Trujillo Bueno, L. Valdivielso (Eds.), *Highlights of Spanish Astrophysics VIII*, 576–581

Sota A., et al., 2011, ApJS, 193, 24

Stickland D.J., et al., 1987, A&A, 184, 185

Walborn N.R., Fitzpatrick E.L., 1990, PASP, 102, 379