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The Triple Star AR Aurigae

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Abstract. New period of the third body in the system of the eclipsing HgMn binary star AR Aur was derived based on new photoelectric and CCD observations.

1 Introduction

AR Aur (HD 34364, HR 1728) is a double–lined spectroscopic well–detached eclipsing binary with orbital period of $4\overset{d}{.}13$. The system is very young with a primary located on the ZAMS, while its secondary component is evolving towards it. The primary and secondary eclipses are very similar and nearly total since the orbit inclination is $i = 88.5°$ and radii of components are roughly equal; the orbits are nearly circular (see Nordström & Johansen, 1994). The spectral type of the primary is B9.5 V with apparent HgMn–type peculiarity. Recently, Hubrig et al. (2006) found strong variations in spectral line profiles of several overabundant chemical elements (Pt, Hg, Sr, Y, Zr, He and Nd) and interpreted it as the consequence of their uneven distribution on the surface of the primary.

To investigate the system comprehensively we need a precise knowledge of the photometric phasing of the eclipsing binary. This is complicated by a third body in the system (see Chochol et al., 1988; Albayrak et al., 2003) inducing a well pronounced light–time effect (hereinafter LiTE). The aim of this study is to describe the LiTE ephemeris of AR Aur in a simple form, and to test our method of determination of times of eclipses. The method will be described in detail in a forthcoming paper.

2 Observations

First photoelectrically detected minima of AR Aur were published by Huffer & Eggen (1947). Eight new photoelectric minima (including two based on the observations by Johansen (1970) were published by O'Connel (1979), who found that the period of AR Aur has undoubtedly changed. To explain these changes Zverko et al. (1981) and Chochol et al. (1988) acquired 11 new epochs of minima and explained the observed changes by a light time effect due to a third body in the system. Nordström & Johansen (1994) and Albayrak et al. (2003) on the basis of their new photoelectric

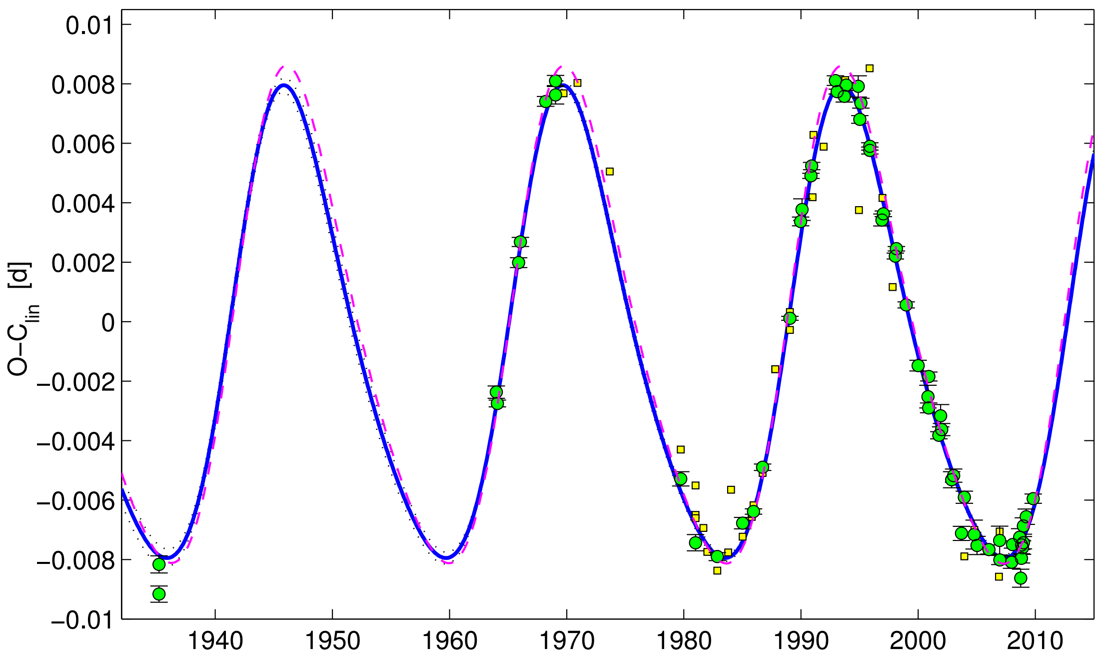

Figure 1: O–C diagram of AR Aur. Full line: our solution (Table 1), dashed line: Albayrak et al. (2003), dotted line — uncertainty of the solution. Circles — minima times computed by our method, squares — minima times adopted from literature.

minima determinations published new periods of the third body and new physical characteristics of the system.

Up to now almost all studies dealing with changes of periods in eclipsing binaries have been based on the analysis of times of minima determined by different methods. Thus, the results of such analyses were influenced by uneven treatment of individual photometric measurements and, namely, by the unreliability of the indicated accuracies of the minima times determined. To avoid this inconvenience, we use preferentially original observational data in our method, and only in the case that some are definitely lost, we utilize the published times of minima.

We collected altogether 18 009 individual measurements of the AR Aur system starting with the first photoelectrically observed minima acquired by Huffer & Stebbins in the year 1935 (Huffer & Eggen, 1947).

The present analysis is based on 17 482 mostly our own individual photometric measurements comprising 55 minima and 39 times of minima (both primary and secondary ones) adopted from Kreiner et al. (2001) and Paschke & Brát (2009). All these data were processed simultaneously assuming that both the shapes and amplitudes of the light curves are constant. This assumption considerably cuts the number of free parameters and enables to derive reliable values of minima times as well as their uncertainties.

The efficiency of this approach (Mikulášek et al., 2006) is substantiated by the fact that the scatter of the published times of minima is more than 2.5 times larger than the scatter of the values obtained by our method.

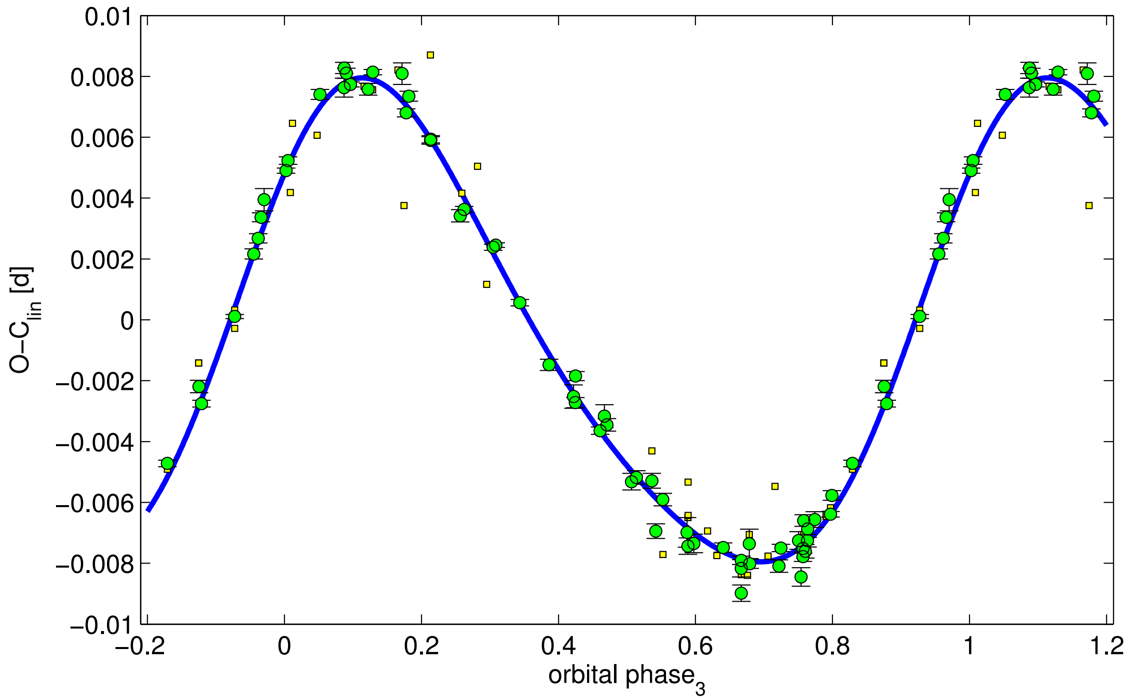

Figure 2: Phase diagram of the third body effect in AR Aur, $P = 23.79$ yr. Same symbols are used as in Fig. 1.

3 Light–Time Effect in AR Aur

The LiTE ephemeris is described:

$$\tau = M_0 + P \times K + \Delta(t,\, A,\, \omega,\, \varepsilon,\, T,\, P_3), \tag{1}$$

where τ is HJD of primary (K is an integer)/secondary (K is an integer + 0.5) light minimum of the eclipsing binary, P is its orbital period in days and Δ is the time shift, caused by orbital motion of the eclipsing binary with respect to the gravity center of the triple system. This problem has been solved by Irwin (1959) and Mayer (1990):

$$\Delta = \mathrm{O} - \mathrm{C} = A\left(\frac{(1-\varepsilon^2)\sin(\nu+\omega)}{1+\varepsilon\cos\nu} + \varepsilon\sin\omega\right), \tag{2}$$

where $A = 0.005776 \times a_{12}\sin i$ [d/AU], $a_{12}\sin i$ is the projection of the semimajor–major axis of the orbit of the eclipsing binary around the centre of gravity of the system, ε its eccentricity, ω is the argument of perihelion, and ν is the true anomaly. According to the second Kepler's law and the implicit Kepler's equation:

$$\tan\frac{\nu}{2} = \sqrt{\frac{1+\varepsilon}{1-\varepsilon}}\,\tan\frac{E}{2}, \tag{3}$$

$$E = M + \varepsilon\sin E, \quad \text{where} \quad M = \frac{2\pi\,(t-T)}{P_3}. \tag{4}$$

Table 1: Comparison of parameters of the triple system

Parameter	Albayrak et al.	this paper
M_0	2 452 596.4927(21)	2 448 858.75467(8)
P	$4\overset{\rm d}{.}1346657(10)$	$4\overset{\rm d}{.}13466570(5)$
ε	0.20 ± 0.04	0.320 ± 0.016
ω	$33.0^\circ \pm 2.0^\circ$	$35.6^\circ \pm 2.7^\circ$
T	2448090 ± 45	2448193 ± 60
P_3	23.68 ± 0.17 yr	23.79 ± 0.09 yr
A	$0.0084(2)\mathrm{d_l}$	$0.00824(7)\mathrm{d_l}$
$a_{12}\sin i$	1.47(4) AU	1.427(12) AU
$f(m_3)$	$0.0057(4)\,\mathrm{M_\odot}$	$0.00505(14)\,\mathrm{M_\odot}$

E and M are eccentric and mean anomalies, t is the instant HJD time, T is the perihelion passage date, and P_3 is the orbital period of the third body in days. The implicit Kepler equation (4) can be well solved by a simple iterative procedure. Hence, for the complete expression of τ we need seven parameters defining the column vector $\overrightarrow{\beta} = (\beta_1; \beta_2; \ldots; \beta_7)$, especially the orbital period of the eclipsing binary P, the basic minimum M_0, the orbital period of the third body P_3, T the perihelion passage date, eccentricity ε, the argument of perihelion ω, and the projected semi–major axis A in light days ($\mathrm{d_l}$). Applying a non–linear weighted LSM procedure we arrived at the system parameters, which are compared to those by Albayrak et al. (2003) in Table 1.

4 Acknowledgements

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