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Period change investigation of the low mass ratio contact binary BO Ari

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HIGHLIGHTS

- The low mass ratio contact binary BO Ari with a fillout of 27.72% is presented.
- The long-term orbital period decreases at a rate of $dP/dt = -3.49 \times 10^{-7}$ d yr^{-1}.
- BO Ari may evolve into a deeper contact system.

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ABSTRACT

A photometric study and period change analysis for the A-type low mass ratio contact binary BO Ari is presented. The *BVR* light curves were fitted by using the Wilson–Devinney method. The photometric solution yields a low mass ratio of $q = 0.1754(\pm 0.0016)$ with a contact degree of $f = 27.72\%(\pm 2.37\%)$. We found a long-term orbital period decrease at a rate of $dP/dt = -3.49 \times 10^{-7}$ d yr^{-1}. This result indicates that the system is undergoing mass transfer from the primary component to the secondary with a mass transfer rate of $\dot{m}_1/m_1 = -7.77 \times 10^{-8}$ yr^{-1}. With the period decrease, the inner and outer critical Roche surfaces will tighten and cause the degree of contact to increase. Therefore, BO Ari may evolve into a deeper contact system.

1. Introduction

A system consisting of two stars close enough to embedded in a common envelope, is called contact binary. These systems are classified as A-type for a system in which the more massive component is eclipsed by the other one at primary minimum, or W-type for the opposite case (Binnendijk, 1970). Typically, the A-type systems tend to be hotter (Yakut and Eggleton, 2005) and have longer orbital periods (e.g. Rucinski and Duerbeck, 1997; Gazeas and Niarchos, 2006; Terrell et al., 2012) than the W-type systems. The more massive component of the contact system is generally a main sequence star, while the less massive one is oversized due to its advanced evolutionary stage (Stępień, 2006).

Many researches found orbital period variations, explained by mass exchange between the components (Singh and Chaubey, 1986; Pribulla, 1998). A long-term period decrease is usually interpreted as the system is undergoing a process of mass transfer from more massive component to the less massive one and/or angular momentum loss (AML) by magnetic breaking (e.g. Vilhu, 1981; Rucinski, 1982). The result of an orbital period decrease is a deeper contact degree (e.g. Christopoulou et al., 2011; Yang, 2011). On the other hand, systems with a period increase, are predicted by the thermal relaxation oscillation (TRO) theory (e.g. Lucy, 1976; Robertson and Eggleton, 1977), to evolve into TRO cycle (e.g. Li and Qian, 2013; Liu et al., 2014). The shorter-term cyclic period change can be explained by the light time effect (LTE) due to a third body orbit around the eclipsing pair in the triple system (Irwin, 1952; Pribulla and Rucinski, 2006).

BO Ari (RA(2000) = $02^h12^m08^s.78$, Dec.(2000) = $27°08'18''.2$), was identified as EW type binary by Nicholson and Varley (2006) with the first measured light minimum of HJD = 2451479.6566 and the orbital period of 0.3182 d. The revised period was obtained to be 0.3181963 d by Acerbi et al. (2011). BO Ari was classified as an A-type system. Acerbi et al. (2011) reported a mass ratio of $q = 0.1889$ and fillout of $f = 58.7\%$. Furthermore, $B_{\rm Tycho} = 10.664$ and $V_{\rm Tycho} = 10.083$ for BO Ari were reported in the Tycho 2 catalogue (Høg et al., 2000).

This study presents *BVR* observations for BO Ari and investigation on the orbital period change, cyclic vairation and an analysis of the photometric light curve. Section 2 presents the photometric observations. An analysis for long-term orbital period changes and cyclic vairations is described in Section 3. Section 4 presents a model fit to the light curve and derivation of the system parameters. Finally, Section 5 contains discussion and conclusions.

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2. Observations

BO Ari was observed at Sirindhorn Observatory, Chiang Mai University on November 21, 24 and 26, 2011. The 0.5-m telescope, equipped with a SBIG ST10-XME CCD, was used for *BVR* filter bands with an exposure time of 30 seconds. A total of 1446 individual observations were obtained for all three filter bands (482 observations per filter band). Data reduction and *BVR* differential magnitude measurements were made with the IRAF package.

GSC 1761–1578 (RA(2000) = $02^h12^m11^s.18$, Dec.(2000) = $27°10'19''.8$) and TYC 1761-2130-1 (RA(2000) = $02^h11^m53^s.48$, Dec.(2000) = $27°15'34''.5$) were used as comparison and check stars, respectively. The observed *BVR* light curves for the three nights covered five times of minimum light, as shown in Fig. 1. All minimum light times were found by phase shifting by about half an orbital period with respect to previous minimum light times. The amplitudes were about 0.47, 0.45 and 0.44 mag, for the *B*-, *V*- and *R*-bands, respectively.

3. Orbital period analysis

This study obtained three primary and two secondary minima. In order to analyze the orbital period change of BO Ari, orbital phases of all available minimum light times were shifted with 0.5 periods from the original sources to correspond with the data in this study as listed in column 4 of Table 1. Early minimum light times were found with nearly equal depths of primary and secondary eclipses such the primary minima could not always be distinguished from secondary minima. This is why we applied a 0.5 phase shift on previous data. This study found that the primary minima had become clearly deeper than the secondary ones but this did not always agree with the previous series of minimum light. After phase shifting, all minimum light times at present were fitted with a linear least-squares as shown in Eq. (1). The result gave a revised orbital period of 0.3181945(±0.0000002) d.

$$\text{Min.I} = \text{HJD}2455887.1405(\pm 0.0006) + 0.3181945(\pm 0.0000002) \times E \quad (1)$$

The orbital period of BO Ari in this study was shorter than the value obtained by Acerbi et al. (2011). The $(O-C)$ residuals were calculated by using Eq. (1), and listed in the Table 1. Quadratic least-squares fitting was applied to the $(O-C)$ as shown in Eq. (2) with the *rms* of the $(O-C)$ curve residuals of about 0.00134 d. The $(O-C)$ curve and corresponding residuals are plotted in Fig. 2. The fitting solution indicated that a long-term orbital period decrease of BO Ari at a rate of $dP/dt = -3.49 \times 10^{-7}$ d yr^{-1}.

$$(O-C) = 0.0000(\pm 0.0003) - 1.17(\pm 0.12) \times 10^{-6}E - 1.52(\pm 0.12) \times 10^{-10}E^2 \quad (2)$$

As shown by the residuals in Fig. 2, it seems that there may be a cyclic variation, which can be produced by a LTE due to the presence of a third body in the system (Irwin, 1952; Pribulla and Rucinski, 2006). This cyclic period change can be analyzed with the following formula:

$$\text{Min.I} = T_0 + PE + AE^2 + \tau_3 \quad (3)$$

where $T_0 + PE + AE^2$ includes the quadratic long-term period change. T_0 and P are revised initial epoch and period, and A is a half of the period change per cycle. τ_3 is added for the LTE due to the third companion (e.g. Lee et al., 2011; Zhu et al., 2011), as follows:

$$\tau_3 = K\left[\frac{1-e^2}{1+e\cos\nu}\sin(\nu+\omega) + e\sin\omega\right] = K[\sqrt{1-e^2}\sin E^*\cos\omega + \cos E^*\sin\omega] \quad (4)$$

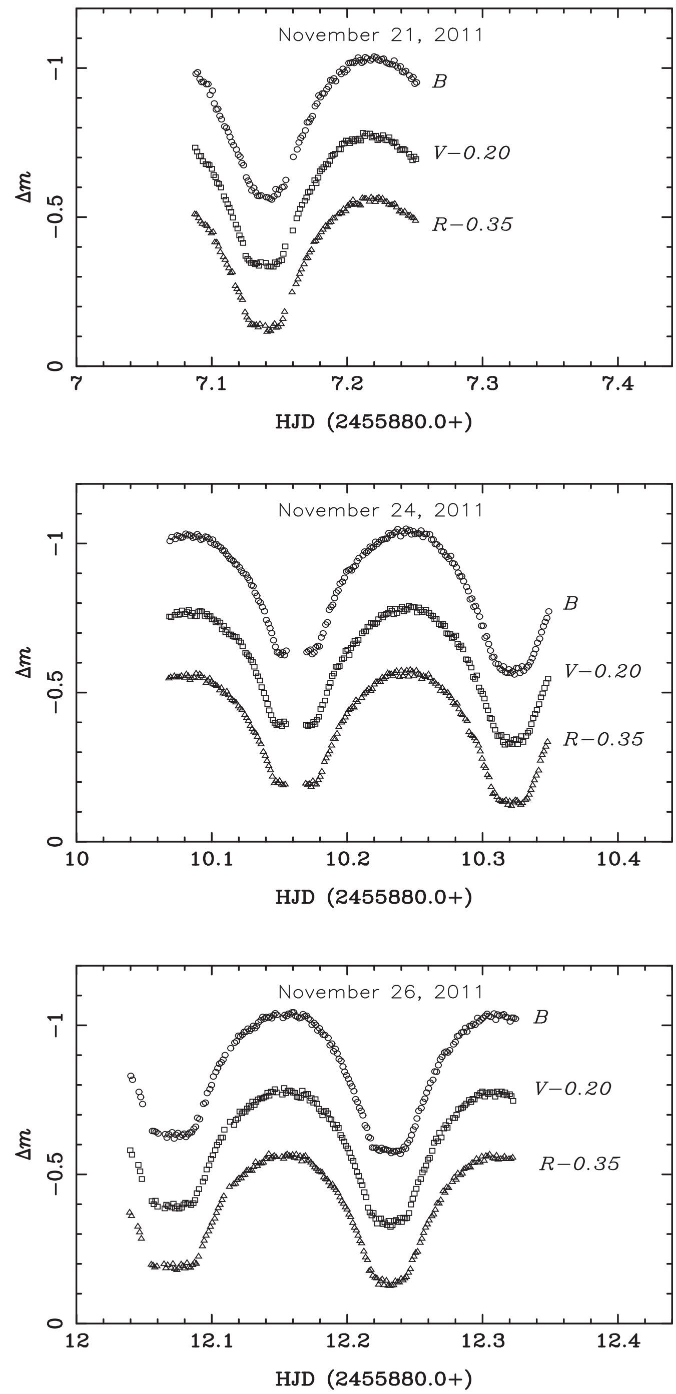

Fig. 1. The observed light curves in *B* (open dots), *V* (squares) and *R* (triangles) filter bands for BO Ari on November 21 (top), 24 (middle) and 26 (bottom), 2011.

where $K = a_{12}\sin i_3/c$ is the amplitude of the cyclic variation. The parameters a_{12}, i_3, e and ω are the semi-major axis, inclination, eccentricity and longitude of the periastron of the binary's orbit around the mass center of the triple system, respectively, and ν is the true anomaly of the position of the binary's mass center in the orbit. E^* is the eccentric anomaly, computed together with Eq. (5) (e.g. Irwin, 1952; Zhu et al., 2011; Kriwattanawong and Poojon, 2015):

$$2\pi\frac{t-T}{P_3} = M = E^* - e\sin E^* \quad (5)$$

where M is the mean anomaly, t is the time of minimum light, T is the time of periastron passage for the third body and P_3 is the