COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS

Number 5696

Konkoly Observatory
Budapest
3 May 2006

HU ISSN 0374 – 0676

BVRI CCD OBSERVATIONS AND ANALYSIS OF THE WUMa CONTACT BINARY, AR BOOTIS

SAMEC, RONALD G.[1,3]; LOFLIN, TREVOR S.[1,3]; VAN HAMME, WALTER[2]

[1] Astronomy program, Department of Physics, Bob Jones University, Greenville, SC 29614

[2] Physics Department, Florida International University, Miami, Fl and SARA Observatory

[3] Visiting Astronomer, SARA Observatory

AR Bootis (GSC 1999 11, $\alpha(2000) = 07^{\rm h}03^{\rm m}2^{\rm s}\!.89$, $\delta(2000){=}0^\circ 13' 49''\!.1$) was observed as a part of our study of solar type near contact binary candidates. It was discovered by Kurochkin (1960) in the remote neighbourhood of M3. The initial period was calculated as 0.416718 d. Houck and Polluck (1986) reported a photographic B light curve, and corrected the period, $P = 0.34470\,\mathrm{d} \pm 0.00001$. Their curve shows unequal eclipse depths and an asymmetry in maxima of 0.1 mag. The solution by Milano et al. (1989) indicated that both stars were very slightly under-filling their respective Roche lobes. However, they showed no light curves nor gave any observations. Wolf et al. (1998) observed B, V curves and conducting a period study with 44 eclipse times. This gave an ephemeris with a positive quadratic term. Additional timings have been reported by Zejda (2002, 2004), Diethelm (1996, 1997, 1998, 2001), Bakis et al. (2005a, b), Hübscher et al. (2005), Krajci (2005), Wolf et al. (1998), Blättler (2002, 2005), Milano et al. (1989) and Safár & Zejda (2000, 2002).

The present observations were taken in Kitt Peak, AZ, at the Southeastern Association for Research in Astronomy Observatory (SARA) using a remote link. The 0.9-m reflector was used with the AP7 camera with $UBVR_cI_c$ filters on 5, 9 May and 8 June 2004, by RGS and TSL. We took 130, 132, 127, 128 observations $BVRI$, respectively. The observations are given in electronic Table 1, available on the IBVS website as `5696-t1.txt`. The comparison and check stars were GSC 162 1551 ($\alpha(2000) = 07^{\rm h}02^{\rm m}59^{\rm s}\!.60$, $\delta(2000){=}$ $0^\circ 14' 32''\!.8$) and GSC 162 1709 ($\alpha(2000) = 07^{\rm h}03^{\rm m}12^{\rm s}\!.16$, $\delta(2000){=}\ 0^\circ 14' 31''\!.1$), respectively. A finding chart of AR Boo (V), the comparison star (C), and check star (K) is given as Figure 1. The light curves are given in Figures 2 and 3, as normalized flux versus phase.

Three mean epochs of minimum light were determined from eclipse timings in all four pass bands, using parabola fits: HJD Tmin I = 2453131.8527(±0.0003), and
HJD Tmin II = 2453165.8238(±0.0003) and 2453135.81834(±0.0013).

From all 66 available timings of minimum light, we calculated the following linear and quadratic ephemerides:

$$\mathrm{HJD\ TMin\ I} = 2450182.49268(\pm 0.00181) + 0.3448710186(\pm 0.0000001947)\mathrm{d} \times \mathrm{E} \qquad (1)$$

$$\mathrm{HJD\ TMin\ I} = 2450182.47781(\pm 0.00036) + 0.344874262(\pm 0.000000056)\mathrm{d} \times \mathrm{E} + 0.000000000128(0.000000000002) \times \mathrm{E}^2 \qquad (2)$$

Electronic Table 2 (available on the IBVS website as `5696-t2.txt`) gives the $O-C$ residuals of Equation 1 and 2. We note that the quadratic term is highly significant. The recent precision timings show this effect also. The period is increasing. A sine curve was also fit to the curve. Both of the curves have a 'goodness of fit' R value of 0.96 and look very similar. It is impossible to determine from the fit alone which characterizes the system. However, the amplitude of the sine curve is 0.11 ± 0.03d or about 19 AU and the period is 342 ± 60 years. A three star system producing such an orbital motion would have a minimum mass of only 0.06 solar masses, so it is unlikely that a third body is present.

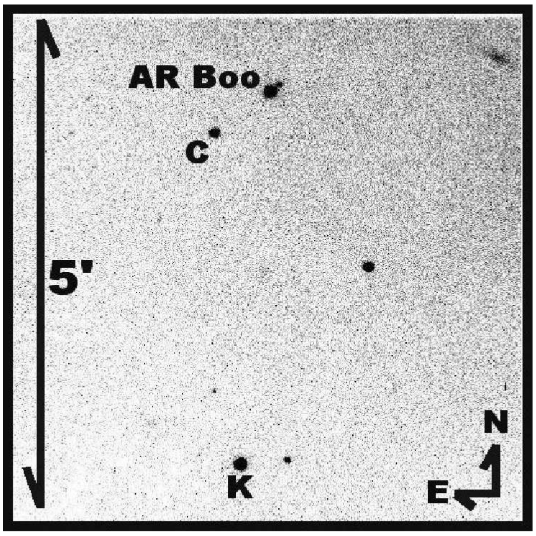

Figure 1.

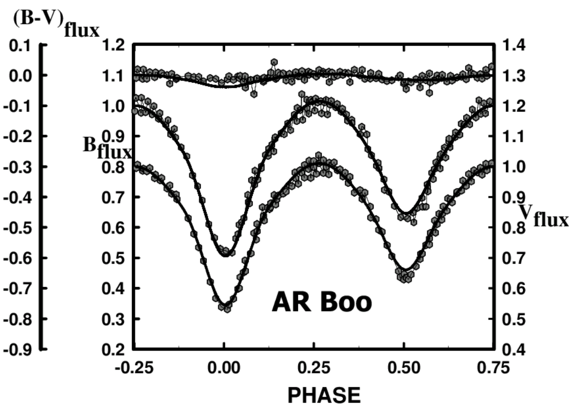

Figure 2.

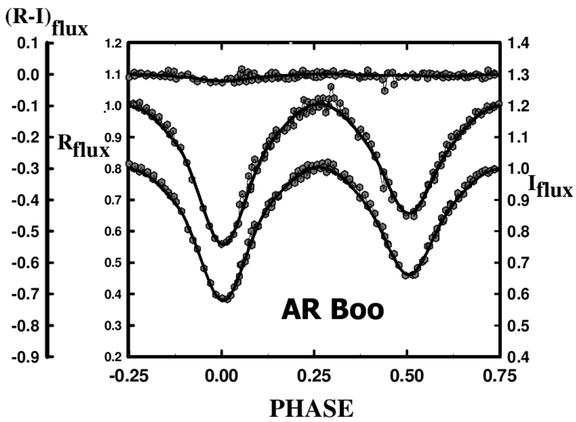

Figure 3.

Standard magnitudes of AR Boo, comparison and check were determined from our observations from measurements of Landolt standard stars G44 27, PG1034+001, SA103 302, SA104 306, SA104 444 and SA104 335. Electronic Table 3 (available on the IBVS website as `5696-t3.tex`) gives our results. The comparison and check magnitudes were determined from the averages of 38-40 individual measurements while the phase averages for the variable were determined from 3-5 measurements determined about the phase in question. From these measurements, we estimated the temperature of the the primary, more massive component to be 4750 ± 150 K.

Our B and V curves were individually fit with Binary Maker 2.0 (Bradstreet 1992). We attempted both A and W-type and contact configurations. The best Binary Maker fits were of W-Type (the primary, more massive component was cooler.) with a single spot region. Using the results as starting parameters, we calculated a Wilson code (Wilson and Devinney 1971, Wilson 1990, Wilson 1994) $BVRI$ simultaneous synthetic light curve solution. It gave similar results. The solution is given as Electronic Table 4 (available on the IBVS website as `5696-t4.tex`), and the synthetic light curves overlying the observations are given in Figure 2 and 3. The Roche-lobe surface is shown in Figure 5. The binary is a W-Type W UMa shallow contact system. The W-type designation indicates heavy, saturated magnetic activity on the primary star. The shallow contact and the sizable difference in temperatures of the components may indicate that AR Boo just recently reached contact as two quite different mass stars. Alternatively, the period increase and mass ratio would suggest that it is coming out of the contact phase of thermal relaxation oscillations and that the binary is somewhat evolved. Further study, including spectroscopy may determine which is the best scenario. We note here that errors given in the table are formal errors. Also, the mode that we used in conjunction with the mass ratio (>1.0) forced us to adjust the cooler star's temperature, T2. So we set the initial T1 so that T2 would be near the 4750 K value set by the photometry.

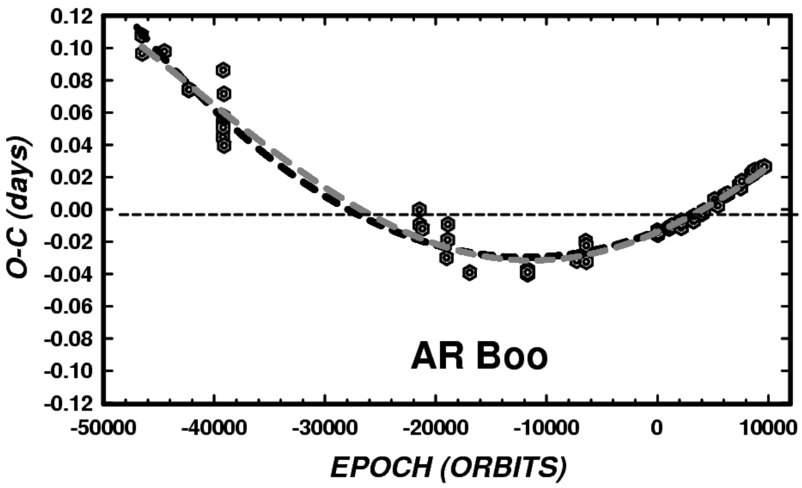

Figure 4.

We wish to thank the SARA TAC for their allocation of observing time and Bob Jones University for their support with computational and observational facilities for remote observing.

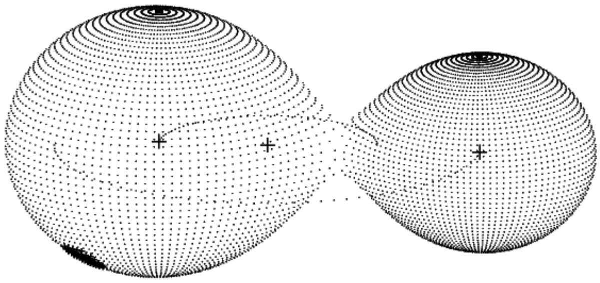

Figure 5.

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