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TIMES OF MINIMUM FOR AR Aur AND β Aur AND A NEW PERIOD DETERMINATION FOR β AURIGAE

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AR Aurigae: A photometrically determined time of primary minimum has been observed for the eclipsing binary AR Aur, which is a triple system showing light time effect. Nordström and Johansen (1993) pointed out that new times of minimum were needed to constrain the properties of the third component, which might be a pre-main-sequence star (Johansen and Nordström 1994). The new time of minimum occurred on

$$\text{HJD } 2449280.4987 \pm 0.0004$$

This value has been published in Danish by Johansen et al. (1994).

β *Aurigae*: For this bright eclipsing binary there has been some doubt whether the period is constant, and a changing period could indicate the existence of a third star. Also, the latest published ephemeris does not fit the later observations. Therefore new photoelectric observations were obtained, and two moments of primary minimum determined:

$$\text{HJD } 2449748.3530 \pm 0.0023$$
$$\text{HJD } 2450441.3552 \pm 0.0035$$

The new times of minimum, together with the previously published observations (see references in Table 1), have allowed us to determine a new ephemeris for β Aur:

$$MinI \ \ \text{HJD} = 2431076.7269 \pm 0.0010 + (3.96004732 \pm 0.00000032) \times E \qquad (1)$$

The period in Eq. 1 is at least to be considered a mean period, and it is concluded, that it has been impossible to verify any variation of the period of β Aur.

The new observations were carried out by H.S., using a 20 cm Schmidt-Cassegrain telescope equipped with an SSP-3 photodiode photometer and a Johnson V filter. Complete light curves are not necessary to discuss period variability. For AR Aur the phase interval covered is $\Delta\phi = 0.029$. For β Aur observations during 3 primary minima plus a few observations between the minima were obtained. Two primary minima with an epoch difference equal to 2 were combined using the period P_1, see below. The combined minimum, Sørn1, covers the phase interval $\Delta\phi = 0.041$ and the last minimum, Sørn2, covers 0.026. Finally the times of minimum were determined by means of the method given by Kwee and van Woerden (1956).

Table 1: Times of minimum for β Aur.

Series	Time of MinI	ΔT	$(O-C)_1$	E	com.	Reference
Tikhf	2415996.8650 ± .0047	15795-16201	−.0017	−3808	spH	Baker (1910)
Vogel	16499.7991 ± .0047	16471-16520	.0064	−3681	spH	Vogel (1904)
Belo1	16602.7683 ± .0080	16573-16610	.0144	−3655	spH	Belopolsky (1909)
Belo2	16602.7556 ± .0054	16573-16610	.0017	−3655	spH	ibid.
Belo3	17913.5293 ± .0020	17215-18638	−.0003	−3324	sp	ibid.
Baker	18269.9281 ± .0044	18181-18345	−.0058	−3234	spH	Baker (1910)
Stebb	19018.3848 ± .0046	18935-19119	.0020	−3045	pe	Stebbins (1911)
Berg1	20325.1972 ± .0029	19846-20961	−.0012	−2715	sp	Berg (1927-1929)
Berg2	22055.7475 ± .0060	21987-22772	.0084	−2278	sp	ibid.
Berg3	24202.0861 ± .0348	24171-24227	.0013	−1736	sp	ibid.
Smith	31076.7305 ± .0024	31047-31075	.0036	0	spH	Smith (1948)
Johs1	36842.5537 ± .0013	36836-36950	−.0021	1456	pe	Johansen (1971)
Johs2	37650.4025 ± .0022	37648-37694	−.0030	1660	pe	ibid.
Johs3	39099.7850 ± .0011	39068-39930	.0022	2026	pe	ibid.
GaGue	39234.4678 ± .0135	39130-39544	.0434	2060	spH	Galeotti, Guerrero (1968)
Humml	47439.64 ± .01	47439-48945	−.0024	4132	int	Hummel et al. (1995)
Hippc	48334.6119 ± .0012	47835-49043	−.0012	4358	pe	ESA (1997)
Sørn1	49748.3530 ± .0023	49748-49756	.0030	4715	pe	This paper
Sørn2	50441.3552 ± .0035	50441	−.0031	4890	pe	ibid.

Comments:

Col. 6: sp: spectroscopic, pe: photoelectric, int: interferometric observations. H: It is not mentioned whether the times have been corrected to the Sun or not. If *not*, the following corrections should be added to the values of Col. 2 : Tikhf: +.0028, Vogel: +.0045, Belo1: −.0029, Belo2: −.0030, Baker: +.0035, Smith: +.0052, GaGue: +.0024. This would change the period to 3.96004709 ± 0.00000043, where the increased scatter indicates that in most cases the times have already been reduced to the Sun.

Tikhf: Concerning HJD correction see Belo1,2,3 and Baker.

Belo1,2,3: Belo1 (ultraviolet) and Belo2 (blue) are observed on the same nights. We consider Belo2 to be most reliable since systematic errors could exist in the ultraviolet. Belopolsky gives heliocentric PMT (Pulkovo Mean Time) for the times of Belo3. In his discussion he does not use Belo1 and Belo2 and he mentions their times only as PMT. He uses the Tikhf series (observed by Belopolsky himself); however he mentions its times as PMT, the same values of times are referred to and used by Vogel and Baker.

Baker: Baker computed new spectroscopic elements for all data between 1900 and 1910. For the Tikhf and Vogel series he introduces a systematic error in the fourth decimal in the transformation of times from PMT and CET to GMT, and his own observations are reduced to normal points in phases published only with 3 decimals of a day. He does not mention heliocentric correction. Thus maybe some astronomers of that time using the long exposure times with the nonlinear photographic technique did not care to apply the

HJD correction or maybe the time designation made by Belopolsky is incomplete.

Berg1,2,3: The observations are carried out by Belopolsky. The large σ of Berg3 is due to the fact that 5 out of the 6 observations are at phases near maximum velocity.

Johs1,2,3: Systematic differences exist between the series (Johs1,2) and Johs3, since the photometric elements determined from the light curves differ systematically. Thus the errors of Col. 2, which are internal errors, are too small.

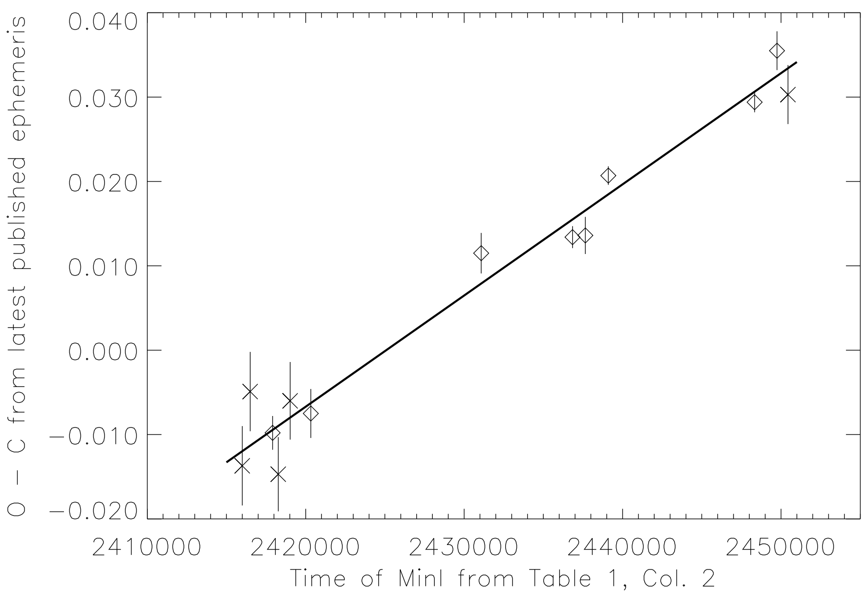

Figure 1. β Aur: O−C from the latest published ephemeris (Smith 1948) in days. The line represents the ephemeris of Eq. 1. Diamonds: $\sigma < 0.0030$, crosses: $0.0030 < \sigma < 0.0050$.

β Aur has been observed several times since 1900. The published values of the period, P, based on observations from the beginning of this century are close to 3.960000 days. The earliest works were reviewed by Baker (1910), who found $P = 3.960027 + 0.000010 \times (t - 1906)$ with an error of 0.000004 days. Later Berg (1936), as referred by Smith (1948), published the value $P = 3.960027 + 0.0000035 \times (t - 1906)$. The most recent period determination was carried out by Smith (1948) and yielded the ephemeris $MinI = 2431076.719 + 3.9600421 \times E$, with the error of P equal to 0.0000013. Smith concluded, that although the data indicated a slight increase in the period from 1900 to 1943 it would not be safe to infer that the period had changed. However Smith's ephemeris does not fit the later more accurate photoelectric observations.

Eq. 1 was obtained as follows: A preliminary mean period P_1 equal to 3.96004758 days was determined from all observational series. For spectroscopic observations the final times of MinI are determined using the SBOP code (Etzel 1985) assuming a period equal to P_1. Complete photoelectric light curves are published by Stebbins (1911), Johansen (1971) and ESA (1997). For these light curves phases have been calculated using P_1, and the final times of MinI were determined using the EBOP code (Etzel 1981) and the photometric elements found by Nordström and Johansen (1994). The orbit was assumed circular. For spectroscopic observations we chose an epoch close to the mean of the Julian dates where observations occurred, and for photoelectric observations we chose an epoch close to the mean of the Julian dates on which minimum observations have been obtained. Thus a wrong value of the period only introduces a scatter, not a systematic error in the times of MinI.

The 13 most accurate series were used to determine Eq. 1. Since the errors σ determined by SBOP and EBOP are internal and systematic errors probably exist, series with $\sigma <$ 0.0030 have been given equal weight 1, and series with $0.0030 < \sigma < 0.0050$ weight 0.5. The period, P, of Eq. 1 deviates so little from P_1 that a reduction with P would change the phase, ϕ, of any observation by ≤ 0.000014. The iteration has converged.

Table 1 and Fig. 1 give the results. The columns of Table 1 are: 1) Name of series. 2) Observed times of primary minimum found by means of the above-mentioned iterative procedure and found from the published data directly. We have also given the uncertainties σ determined by means of the SBOP, EBOP codes or the Kwee and van Woerden computations where these methods were applied. 3) Time interval, ΔT, of observation in JD$-$2400000. 4) $(O-C)_1$ from Eq. 1. 5) Epoch. 6) Comments. 7) References.

As a check we used SBOP to determine the actual period P_a and the radial velocity V_o of the center of mass for each spectroscopic series. If a third star exists, P_a and V_o are related. Several values of P_a deviate more than 2 σ from the period of Eq. 1. However, the values of V_o allow a maximum variation in P_a equal to 0.000087 ± 0.000022, showing that only for the Belo3 series P_a equal to 3.959973 ± 0.000021 could eventually be real.

We conclude that the period of β Aur is probably constant.

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