A&A 390, 555–559 (2002)
DOI: 10.1051/0004-6361:20020753

Astronomy & Astrophysics

Research Note

Period behavior of the W Ursae Majoris contact binary AH Tauri

Yulan Yang and Qingyao Liu

National Astronomical Observatories, Chinese Academy of Sciences, China
Yunnan Observatory, Chinese Academy of Sciences, Kunming, Yunnan Province, China
United Laboratory of Optical Astronomy, Chinese Academy of Sciences, China

Received 11 December 2001 / Accepted 29 April 2002

Abstract. New timing of minimum light determined from CCD observations of the W UMa type contact binary AH Tau is presented. From the present time of minimum light and those collected from the literature, the changes in the orbital period of the system are analyzed. The result reveals that the orbital period of AH Tau continuously decreased at a rate of $\frac{\Delta p}{p} = -1.4 \times 10^{-11}$ from 1944 to 1976 and suddenly and sharply decreased by about 0.33 s around 1976. After 1976 the orbital period of the system continually increased at a change rate of $\frac{\Delta p}{p} = 1.5 \times 10^{-10}$. A possible explanation of the changes in the orbital period of AH Tau is discussed. They may be the result of compound action of three mechanisms: the cyclical magnetic activity, the mass loss and the radius swelling of the two components of the system.

Key words. star: individual: AH Tau – stars: binary: eclipsing

1. Introduction

The variable AH Tau (HV 6187 = CSI+24-03442) was discovered by Shapley et al. (1934), who classified the star as a RRc type variable with a period of $0^{d}.1663334$. Binnendijk (1950) photographically observed AH Tau and classified the system as a β Lyr type eclipsing binary with a period of $0^{d}.33267447$, a spectral type of G1p and a $B-V$ color index of 0.50. Romano (1962) classified the system as a W UMa type binary and gave light elements on the basis of his photographical observations. Bookmyer (1971) published the first photoelectric observations in B and V bands with partial covering of phase and an improved ephemeris. She gave a $(B-V)$ color index of 0.66 and suggested a spectral type of about G5 for the system. The first complete photoelectric light curves in B and V bands were published by Magalashvili et al. (1980). They noticed that the light curves were asymmetrical and the secondary mid-eclipse occurred at a phase of 0.47. Then Liu et al. (1991) published new photoelectric observations in B and V bands and a photometric solution was obtained by using the Wilson and Devinney code. Their observations show some differences in the light curves from those obtained by Magalashvili et al. in 1973 and their photometric solution reveals that AH Tau is an A-subtype W UMa binary with a degree of overcontact of 9%.

The timings of light minimum for AH Tau were published by Binnendijk (1950), Romano (1962), Bookmyer (1971), Magalashvili et al. (1980), Liu et al. (1991), BBSAG 107, 108, 111, 113, 114, 115, 116, 117, 118, 119, 121 and 122, Nelson (2001) and Pribulla (2001), but the orbital period behavior of this system is still not known. Therefore, AH Tau was included in the program of short period variables running at the Yunnan Observatory using a 100-cm reflector telescope and a CCD photometric system.

2. Observations

The observations of AH Tau in the V band were carried out on December 7, 1999, with the PI1024 TKB CCD photometric system attached to the 100-cm reflecting telescope at the Yunnan Observatory in China. The effective field of view of the photometric system is 6.5 × 6.5 square arc minutes at the Cassegrain focus (the CCD chip of 1024 × 1024 pixels), and its BV color system approximates the standard Johnson BV photometric system (Yang & Li 1999). The coordinates of the comparison and check stars used are listed in Table 1, respectively. The comparison star and the check star are so close to the variable that they are in the same field of observation as the program star.

The integration time for each image was 100 s. A total of 99 images during the secondary eclipse was obtained for one night in December, 1999. The aperture photometry package of

Send offprint requests to: Yulan Yang,
e-mail: bily@public.km.yn.cn

Table 1. The coordinates of the variable, comparison star and check star.

star	RA (2000.0)	Dec (2000.0)
variable	$03^{\mathrm{h}}47^{\mathrm{m}}12^{\mathrm{s}}$	$25°07'02''$
comparison star	$03^{\mathrm{h}}47^{\mathrm{m}}20^{\mathrm{s}}$	$25°08'36''$
check star	$03^{\mathrm{h}}47^{\mathrm{m}}00^{\mathrm{s}}$	$25°05'29''$

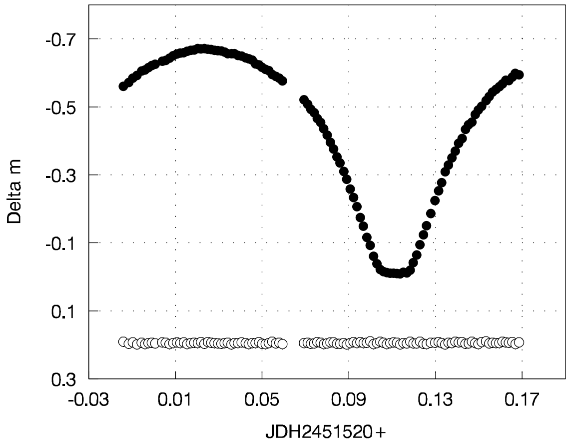

Fig. 1. The V observations for AH Tau. Full circles: the variable star minus the comparison star; Open circles: the check star minus the comparison star.

IRAF was used to reduce the images. The reduced results show that the difference between the magnitude of the check star and that of the comparison star is constant within a probable error of ±0.006 mag. Extinction corrections were not made since the comparison star is very close to the variable. The observations are shown in Fig. 1.

From the observations, one time of minimum light was derived by using a parabolic fitting. The new time of minimum light and the times published by other authors are listed in Table 2, where symbol pe indicates photoelectric times of light minimum, pg^* refers to mean values of photographic times of light minimum with the almost same epoch numbers and symbol s shows visual times of light minimum.

3. Change in the orbital period

The $(O–C)_1$ residuals listed in Table 2 are calculated by means of the light elements (Magalashvili et al. 1980):

$$\text{Min. } I = \text{HJD } 2443462.3183 + 0\overset{\mathrm{d}}{.}33267538E. \quad (1)$$

The $(O–C)_1$ values of the minima computed with the above ephemeris are plotted in Fig. 2, where open circles indicate the mean points obtained from the photographic observations, full circles show the photoelectric observations, and the crosses indicate the visual observations. This diagram shows that the orbital period of AH Tau is unstable.

The epochs of minimum light listed in Table 2 were introduced into a least squares solution for a redetermination of the ephemeris. The improved light elements for a period from 1944 to 1976 are:

$$\text{Min. } I = \text{HJD } 2443462.3186(6) + 0\overset{\mathrm{d}}{.}33267538(8)E, \quad (2)$$

Table 2. The times of minimum light of AH Tau.

HJD2400000+	method	E	$(O–C)_1$	$(O–C)_2$	ref.
31062.5081	pg^*	−37273	−0.0008	−0.0011	[1]
32880.5809(6)	pg^*	−318.8	0.0011	0.0008	[2]
39824.8471	pe	−10934	0.0014	0.0011	[3]
42748.3969(6)	pe	−2146	−0.0000	−0.0003	[4]
42750.3929(6)	pe	−2140	−0.0001	−0.0004	[4]
43462.3183(5)	pe	0	0	−0.0003	[4]
46771.0541(4)	pe	9946	−0.0535	−0.0043	[5]
46771.2209(5)	pe	9946.5	−0.0531	−0.0039	[5]
46772.0526(3)	pe	9949	−0.0531	−0.0039	[5]
46772.2182(4)	pe	9949.5	−0.0539	−0.0046	[5]
49615.567(3)	s	18496.5	−0.081	0.001	[6]
49631.372(5)	s	18544	−0.079	0.004	[7]
49694.237(5)	s	18733	−0.089	−0.006	[7]
49781.406(5)	s	18995	−0.081	0.003	[7]
50042.392(4)	s	19779.5	−0.079	0.008	[8]
50079.309(3)	s	19890.5	−0.089	−0.001	[8]
50279.570(2)	s	20492.5	−0.099	−0.008	[9]
50370.390(6)	s	20765.5	−0.099	−0.007	[9]
50421.463(5)	s	20919	−0.092	0	[10]
50422.300(5)	s	20921.5	−0.086	0.006	[10]
50486.339(5)	s	21114	−0.087	0.005	[10]
50691.579(3)	s	21731	−0.090	0.005	[11]
50754.466(7)	s	21920	−0.097	−0.001	[12]
50761.284(5)	s	21940.5	−0.098	−0.003	[13]
50855.275(8)	s	22223	−0.088	0.009	[14]
51033.581(5)	s	22759	−0.096	0.003	[12]
51138.539(4)	s	23074.5	−0.097	0.003	[15]
51411.495(3)	s	23895	−0.102	0.002	[16]
51520.1111(3)	pe	24221.5	−0.1039	0.0009	[17]
51549.227(7)	s	24309	−0.097	0.008	[18]
51823.8420(1)	pe	25134.5	−0.1056	0.0028	[19]
51956.2457(2)	pe	25532.5	−0.1067	0.0032	[20]

[1] = Binnendijk (1950); [2] = Romano (1962); [3] = Bookmyer (1971); [4] = Magalashvili et al. (1980); [5] = Liu et al. (1991); [6] = BBSAG 107 (1994); [7] = BBSAG 108 (1995); [8] = BBSAG 111 (1996); [9] = BBSAG 113 (1996); [10] = BBSAG 114 (1997); [11] = BBSAG 115 (1997); [12] = BBSAG 118 (1998); [13] = BBSAG 116 (1998); [14] = BBSAG 117 (1998); [15] = BBSAG 119 (1999); [16] = BBSAG 121 (2000); [17] = this paper; [18] = BBSAG 122 (2000); [19] = Nelson (2001); [20] = Pribulla et al. (2001).

which is used to compute the $(O–C)_2$ values from JD 2431062 to JD 2443462 in Table 2. The $(O–C)_2$ values from JD 2431062 to JD 2443462 vs. epochs E computed by Eq. (2) are shown in Fig. 3, which reveals that the orbital period of AH Tau continuously decreased from 1944 to 1976. A quadratic ephemeris determined by a least squares fit is as follows,

$$\text{Min. } I = \text{HJD } 2443462.3179(4) + 0\overset{\mathrm{d}}{.}33267513(8)E$$
$$-6\overset{\mathrm{d}}{.}9(7) \times 10^{-12}E^2. \quad (3)$$

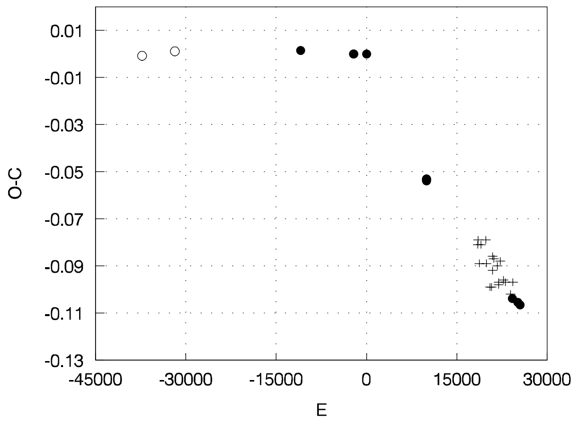

Fig. 2. The (O–C) diagram of the period change for AH Tau. The open circles indicate the mean points determined by Binnendijk (1950) and Romano (1962) from the photographic observations, the full circles show the photoelectric ones and the crosses indicate the visual ones.

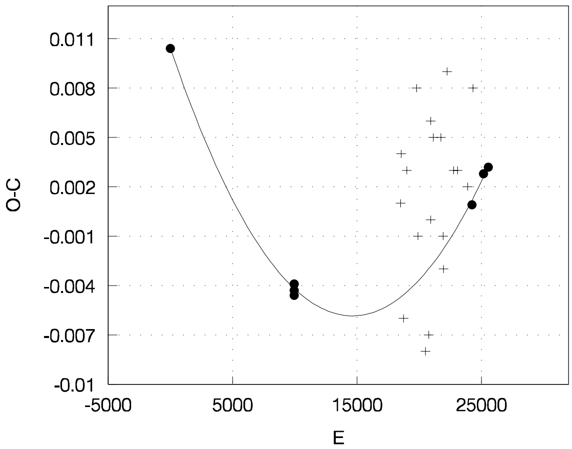

Fig. 4. The period change of AH Tau from 1976 to 2001. The full circles: the photoelectric observations; the crosses: the visual ones; the curve: the fit to the photoelectric observations.

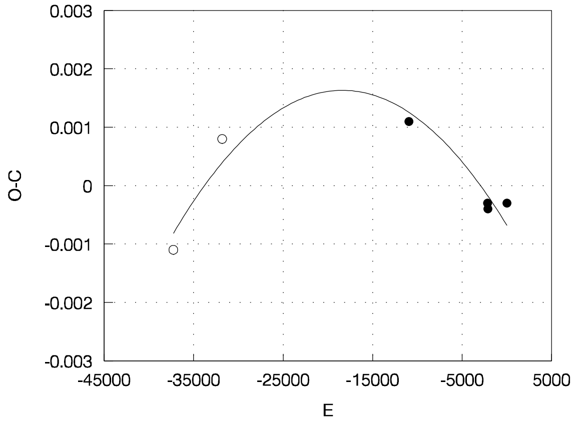

Fig. 3. The period change of AH Tau from 1944 to 1976. Open circles: the mean points of the photographic observations; full circles: the photoelectric ones; the curve: the fit to the observations.

The period change rate is $\frac{\Delta p}{p} = -1.4 \times 10^{-11}$.

A sudden and sharp decrease in the orbital period of the system occurred around 1976 and after that the orbital period of AH Tau increased continuously. With fitting to the photoelectric minima after JD2443462, a linear ephemeris suitable for the period from 1976 to 2001 was obtained as follows:

$$\text{Min. } I = \text{HJD } 2443462.3079(12) + 0\overset{\text{d}}{.}33267148(4)E, \quad (4)$$

which is used to compute the $(\text{O–C})_2$ values after JD 2443462 in Table 2. The $(\text{O–C})_2$ values after JD 2443462 vs. epochs E computed by Eq. (4) are shown in Fig. 4, which reveals that the orbital period of AH Tau continuously increased after 1976. A quadratic ephemeris determined by a least squares fitting to the photoelectric minima is as follows,

$$\text{Min. } I = \text{HJD } 2443462.3183(4) + 0\overset{\text{d}}{.}33266926(8)E + 7\overset{\text{d}}{.}6(6) \times 10^{-11} E^2. \quad (5)$$

Around 1976, the orbital period of the system suddenly decreased by about 0.33 s. After 1976, the orbital period of the system continuously increased at a rate of $\frac{\Delta p}{p} = 1.5 \times 10^{-10}$.

From Figs. 2, 3 and 4 one can see that the period changes for AH Tau from 1944 to 2001 show three kinds of the behavior. Figure 2 clearly shows that a sudden decrease in the orbital period of the system occurred around 1976. Figure 3, revealing a continuous decrease in the orbital period from 1944 to 1976, consists of fewer points, but these points are all of high precision, because the two open circles are both average values of many photographic observations and the full circles are formed from photoelectric observations. Figure 4 indicates that the orbital period of the system increases continuously after 1976. This result has been obtained from the photoelectric observations of high precision, while the visual times of light minimum (the cross points in Fig. 4) are also in agreement with the above conclusion, despite the fact that they show large scatter. Although the observational data do not adequately cover the whole period, their good time-distribution makes it clear that the general trend of the O–C curve suggests a continuous increase in the orbital period after 1976. Therefore the three kinds of the behavior of the period changes occur from 1944 to 2001.

4. Discussion

An investigation of changes in the orbital period is important to understand the activity, structure and evolution of W UMa type contact binaries. Theoretical study of these systems has shown that the evolution of the contact binaries is guided by their stability properties and the presence of dynamic phenomena. Orbital period changes originating from dynamic instability of contact binary systems are observable. From observations, it is known that orbital period changes are common for many W UMa type contact binaries. In general, types of changes in the orbital period of W UMa contact binaries can be classified as continuous increase, continuous decrease, cyclical change, sudden jump and multi-period. For AH Tau, the strange behavior of changes in the orbital period is interesting. The period of the system slowly and continuously decreased from 1944 to 1976. Around 1976, a sharp and sudden decrease in the orbital period of AH Tau occurred. Since 1976 the period has continuously increased. This phenomenon of changes in the orbital period of W UMa type contact binaries is very rare, but AM Leo (Demircan & Derman 1992) and Y Sex (Wolf et al. 2000) seem to show similar period behavior.

AH Tau is a solar type contact binary (Binnendijk 1950; Romano 1971) with a mass ratio of 0.502. Since there are deep convection currents and rapid rotation of the components, intense magnetic activity for the components could be expected. When the magnetic activity was at a lower level, the orbital period of the system slowly and continuously decreased since magnetic braking in the orbital motion of the components increases with enhancement of the magnetic activity. When the surface activity reaches a sufficiently high level, some matter could be thrown out of the system, and then the period of the system suddenly and sharply decreases. The asymmetrical light curves obtained by Magalashvili et al. (1980) from 1975 to 1977 (the secondary mid-eclipse occurred at a phase of 0.47) indicated that the surface activity of AH Tau during this period reached a very high level. Assuming that some matter could be lost from the system during the intense activity, a sudden decrease in the orbital period of the system must occur.

Kepler's Third Law can be written as

$$M = \frac{A^3}{74.5p^2} \tag{6}$$

where A is the separation between the two components in solar radii, p represents the orbital period in days and M indicates the total mass of the two components in solar mass. From the Eq. (6), one can obtain a relation between the mass loss ΔM and the period change Δp:

$$\Delta M = -2M\frac{\Delta p}{p}\cdot \tag{7}$$

The total mass of the two components of AH Tau is 1.61 $M_\odot$ (Liu et al. 1991), the period of the system is 0.33267 days and the period sudden decrease in 1976 is $\Delta p = -3.9 \times 10^{-6}$ days. Therefore, the mass loss of the system around 1976 can be estimated as $\Delta M = 3.8 \times 10^{-5}\ M_\odot$.

After 1976, the magnetic activity of the system fell to such a low level that the mass loss stopped, and then the decrease in the orbital period also stopped. Although higher activity levels causing the mass loss may last several years, the resultant change in the orbital period appears to occur suddenly since the lower time resolution in the O–C diagram.

The continuous increase of the period since 1976 may have been caused by two physical mechanisms: decrease of the magnetic braking and/or swelling of the components. With reduction of the magnetic activity level, the magnetic braking of the orbital motion of the components must decrease and then the orbital period of the system increases. However, the reduction of the magnetic braking seems unable to cause so great a period change rate as $\frac{\Delta p}{p} = 1.5 \times 10^{-10}$ because the period decrease rate caused by enhancement of the magnetic braking is very small, just $\frac{\Delta p}{p} = 1.4 \times 10^{-11}$. Therefore, the continuous increase of the period after 1976 may be caused by a change in the dynamic structure of the system. Since the system suffered significant mass loss around 1976, the original dynamic stability of the system was broken so that the period suddenly decreased by about 0.33 s. Since 1976, although the mass loss and then the period decrease had stopped, the orbital period of the system has not returned to stability but has continuously increased. This suggests that after the stability of the dynamic structure of the system was disturbed suddenly in 1976, the system has adjusted its dynamic structure to reach a new stability. The continuous increase in the orbital period of the system possibly is an observed effect of some adjustment in the dynamic structure of the system. The system lost matter through the second Lagrangian point, so the mass loss must have caused a great amount of orbital angular momentum loss. After the mass loss of AH Tau around 1976, the system may have undergone an adjustment course of angular momentum distribution. A part of the rotation angular momentum of the two components may have been transformed into the orbital angular momentum, therefore, swelling of the radii of the two components of the system would be expected.

From the definition of the relative radius of one of the two components, one may have

$$A = \frac{R_1 + R_2}{r_1 + r_2}\cdot \tag{8}$$

According to Binnendijk (1970), one may have

$$r_1 + r_2 = 0.76. \tag{9}$$

Inserting the Eqs. (8) and (9) into the Eq. (6), one may acquire

$$R_1 + R_2 = 3.2p^{2/3}M^{1/3}. \tag{10}$$

Assuming conservation of the total mass of the system after 1976, from the Eq. (10), one may obtain

$$\delta(R_1 + R_2) = 2.1p^{2/3}M^{1/3}\frac{\delta p}{p}\cdot \tag{11}$$

Adopting $\frac{\delta p}{p} = 1.5\times 10^{-10}$, from the Eq. (11) one may estimate that the swelling rate of the radius sum of the two components is about 135 m/year.

The change in the orbital period of AH Tau may be caused by the three mechanisms: the cyclic magnetic activity, the mass loss and the radius swelling of the two components. The continuous decrease in the orbital period before 1976 may have been caused by slow enhancement of the magnetic braking effect for the magnetic activity of the system. The sudden decrease in the orbital period around 1976 may have been due to the mass loss from the system. The continuous increase in the orbital period after 1976 could result from compound action of the slow decrease of the magnetic braking and the radius swelling of the two components of the system, but contribution of the radius swelling was dominant over the continuous increase in the orbital period of the system.

Acknowledgements. The authors would like to thank Dr. Qian for his assistance in the observation, Mr. A. Steil for improving the authors' English prose, and Dr. P. G. Niarchos for his comments and suggestions. The authors would also like to express their gratitude for the support from the Chinese National Science Foundation Committee and the Yunnan Provincial Science & Technology Department.

References

Binnendijk, L. 1950, Bull. Astron. Inst. Netherlands, 11, 209
Binnendijk, L. 1970, Vistas Astron., 12, 217
Bookmyer, & Beverly, B. 1971, Pub. Astron. Soc. Pacific, 83, 211
Demircan, O., & Derman, E. 1992, AJ, 103, 593
Liu, Q., Yang, Y., Zhang, Y., & Wang, B. 1991, AcApS, 11, 44
Locher, K. 1994, Bull. BBSAG, 107, 12
Locher, K., & Peter, H. 1996, Bull. BBSAG, 113, 11
Locher, K. 1997, Bull. BBSAG, 115, 11
Locher, K. 1998, Bull. BBSAG, 116, 12
Locher, K. 1999, Bull. BBSAG, 119, 6
Locher, K. 2000a, Bull. BBSAG, 121, 6
Locher, K. 2000b, Bull. BBSAG, 122, 7
Magalashvili, H. L., & Kytcishvili, Y. E. 1980, Pub. Apact. Astrophys. Obs., 53, 23
Nelson, R. H. 2001, IBVS, No. 5040
Paschke, A., & Locher, K. 1998, Bull. BBSAG, 118, 7
Peter, H., & Locher, K. 1995, Bull. BBSAG, 108, 10
Peter, H., & Locher, K. 1996, Bull. BBSAG, 111, 7
Peter, H., & Locher, K. 1997, Bull. BBSAG, 114, 10
Peter, H. 1998, Bull. BBSAG, 117, 8
Pribulla, T., Vanko, M., Parimucha, S., & Chochol, D. 2001, IBVS, No. 5056
Romano, G. 1962, Mem. Soc. Astron. Ital., 33, 17
Shapley, H., & Hughes, E. 1934, Harv. Ann., 90, 168
Wolf, M., Molik, P., Hornoch, K., & Sarounova, L. 2000, A&AS, 147, 243
Yang, Y., & Li, L. 1999, Publication of Yunnan Observatory, 1, 32