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The orbital period variations of AH Virginis *

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Abstract We present a study of orbital period changes in AH Virginis. We perform a careful literature search for all available minima times, from which we derived a new linear ephemeris and constructed an $O-C$ curve. We found that the orbital period of AH Virginis shows a long-term increase, $dP/dt = (2.1869 \pm 0.0161) \times 10^{-7}$ d yr^{-1}, and a small periodic variation with a period of 37.19 yr. Since AH Virginis is an overcontact system and the primary component shows strong Hα and Mg II emission lines, we discuss the possible connection between mass transfer, magnetic activity and orbital period changes.

Key words: binaries: close — binaries: eclipsing — stars: individual (AH Virginis)

1 INTRODUCTION

AH Virginis (HD 106400, SAO 100003, ADS 8472A, BD $+12.2437°$; the companion ADS 8472B is at $1.3''$ separation), abbreviated AH Vir, was discovered to be a W UMa-type eclipsing variable by Guthnick & Prager (1929). It shows strong activity in Hα (Barden 1985) and in Mg II (Rucinski 1974, 1985), and the more massive component is much more active than the smaller secondary (Lu & Rucinski 1993). Since its discovery, photometric and spectroscopic studies have been carried out by many investigators (Prager 1929; Lause 1935a, 1935b, 1937; Zessewitsch 1944; Chang 1948; Huruhata & Nakamura 1951; Kitamura et al. 1957; Binnendijk 1960, 1984; Jabbar & Kopal 1983; Kaluzny 1984; Lu & Rucinski 1993). Prager (1929) published a photographic light curve from which he obtained the orbital period of AH Vir to be about 0.339 d. Lause (1935a, 1935b, 1937) made visual observations and improved the period to be 0.4075191 d. Chang (1948) carried out a spectroscopic study and determined the spectral type of both components to be K0. Binnendijk (1960, 1984) published photoelectric observations in the B and V bands and found that both the light curves and the orbital period show variability. He attributed such variations to the gaseous material that escaped from a larger star into circumstellar space, and stated that AH Vir is an overcontact system. Combining his observations with the data from Chang (1948), Binnendijk determined the parameters of both components to be $M_1 = 1.38\,M_\odot$, $R_1 = 1.47\,R_\odot$, $M_2 = 0.58\,M_\odot$ and $R_2 = 0.73\,R_\odot$. Bakos (1977) showed the light curves in the B and V bands observed in 1974 and 1975. He reported that only the larger star that is part of AH Vir is close to the inner Roche lobe (see fig. 6 of Bakos 1977). Kaluzny (1984) re-analyzed the light curves observed by Binnendijk (1960)

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and obtained $M_1 = 0.50\,M_\odot$, $R_1 = 0.98\,R_\odot$, $M_2 = 0.16\,M_\odot$ and $R_2 = 0.61\,R_\odot$. Lu & Rucinski (1993) acquired new spectroscopic observations. They refined the value of the geometric elements to be $M_1 = 1.36\,M_\odot$, $R_1 = 1.40\,R_\odot$, $M_2 = 0.41\,M_\odot$, $R_2 = 0.83\,R_\odot$, $T_1 = 5300$ K, $a = 2.80\,R_\odot$ and $i = 85.2°$.

Evidence of changes in orbital period was noted by Kwee (1958), Binnendijk (1960) and Wood & Forbes (1963). It was discussed by Bakos (1977), Demircan et al. (1991) and Hobart et al. (1998). With the minima in the photoelectric observations published from 1960 to 1977, Bakos (1977) revealed that the orbital period is increasing at $\Delta P/P \approx 1.28 \times 10^{-9}$. He attributed this variation to the mass thrown from the primary component forming a ring along the outer contact surface. Demircan et al. (1991) collected all available minima times published before that time. With the quadratic fits to the observed minus calculated ($O - C$) curve, they found that the orbital period of AH Vir shows both a periodic change and a long term increase. The long-term increase was found to be $\Delta P/\Delta E = 2.66 \times 10^{-10}$ d and the periodic change had a period of 11.2 yr. At the same time, Demircan et al. (1991) made linear fits to the $O - C$ curve and found that the orbital period showed there were abrupt changes of $\Delta P/P = 8.7 \times 10^{-6}$ and $\Delta P/P = 1.4 \times 10^{-5}$ around 1955 and 1971, respectively. They pointed out that the abrupt increases in period were due to the mass transfer from the less massive to the more massive component. Hobart et al.(1998) reported that the period increased at a rate of $dP/dt = 2.2687 \times 10^{-7}\ \mathrm{d\ yr^{-1}}$, but they did not give any explanation about why this occurs.

As far as we know, the orbital period of AH Vir has not been researched for more than 15 yr, since the work of Hobart et al. (1998). However, up to now, a large number of new minima times have been published by many authors (e.g., Paschke 2012; Hübscher et al. 2013; Parimucha et al. 2013; Samolyk 2013). This indicates that the orbital period of AH Vir needs to be further investigated. In this paper, we are making an attempt to collect all available minima times from the literature, construct the $O - C$ diagram, analyze orbital period variations and try to uncover the mechanism that may cause the orbital changes of AH Vir.

In Section 2, we present a detailed analysis of period changes in AH Vir. The mechanisms that may cause the period changes in AH Vir are discussed in Section 3. Section 4 gives the conclusion of the paper.

2 DATA COLLECTION AND PERIOD ANALYSIS

In order to construct the $O-C$ diagram and reveal the overall behavior of the orbital period variation of AH Vir, an extensive search for the light minima timings has been performed. We acquired 464 light minima timings from the $O - C$ gateway[1] and 36 data sets were collected from the literature (see Table 1).

We note that the linear elements of AH Vir published in the literature are very different (see Lause 1935a; Binnendijk 1960; Bakos 1977; Demircan et al. 1991; Hobart 1998; and Kreiner et al. 2001, 2004). In order to determine the linear element and to calculate the overall $O - C$ values, we apply linear fits to all available minima times and derive a new linear ephemeris as follows:

$$\begin{array}{rll} \mathrm{Min.I} = & \mathrm{HJD}2455673.6892 & +0.40752431^{\mathrm{d}} \times E. \\ & \pm 0.0010 & \pm 0.00000027 \end{array} \quad (1)$$

The $O - C$ values computed by the new ephemeris (Eq. (1)) are plotted in Figure 1, where open circles denote visual and photographic data, and solid dots are the photoelectric and CCD observations.

In Figure 1, one can see that the $O - C$ curve is smoothly and continuously variable. By setting weights of 1 to visual data, 3 to photographic observations, 8 to photoelectric and 10 to CCD data, a

[1] *http://var.astro.cz/ocgate/index.php?lang=en*

Table 1 Times of Minima of AH Vir

No.	JD. Hel. +2400000	Meth.	E	$(O-C)$ (d)	$(O-C)_1$ (d)	Residual (d)	Ref.
1	25002.4840	pg	−75262.5	0.0932	−0.002765	−0.002214	[1]
2	43176.8920	v	−30665.0	−0.0642	0.012782	0.008542	[2]
3	43243.7120	v	−30501.0	−0.0782	−0.001477	−0.006123	[2]
4	43948.7090	v	−28771.0	−0.0983	−0.024719	−0.033123	[2]
5	44324.6510	v	−27848.5	−0.0975	−0.025893	−0.035774	[2]
6	44635.8080	v	−27085.0	−0.0853	−0.015483	−0.026243	[2]
7	45797.6980	v	−24234.0	−0.0471	0.014773	0.003752	[2]
8	46875.6010	v	−21589.0	−0.0459	0.006829	−0.000685	[2]
9	46875.8000	v	−21588.5	−0.0506	0.002127	−0.005386	[2]
10	46924.6940	v	−21468.5	−0.0596	−0.007328	−0.014624	[2]
11	47161.8950	v	−20886.5	−0.0377	0.012313	0.006116	[2]
12	47658.6530	v	−19667.5	−0.0518	−0.006785	−0.010542	[2]
13	49821.8220	pe	−14359.5	−0.0219	−0.002876	0.001218	[3]
14	49830.7902	ccd	−14337.5	−0.0192	−0.000299	0.003807	[2]
15	50514.6350	v	−12659.5	−0.0002	0.009045	0.013548	[2]
16	50523.7930	v	−12637.0	−0.0115	−0.002389	0.002112	[2]
17	50545.6030	v	−12583.5	−0.0040	0.004792	0.009288	[2]
18	50547.6290	v	−12578.5	−0.0157	−0.006938	−0.002442	[2]
19	50572.6920	v	−12517.0	−0.0154	−0.007006	−0.002517	[2]
20	50580.6350	v	−12497.5	−0.0191	−0.010823	−0.006337	[4]
21	50921.7420	v	−11660.5	−0.0100	−0.006830	−0.002558	[4]
22	50926.6480	v	−11648.5	0.0057	0.008796	0.013063	[4]
23	50950.6870	v	−11589.5	0.0008	0.003529	0.007773	[4]
24	51257.7450	v	−10836.0	−0.0108	−0.012828	−0.008948	[4]
25	51260.6050	v	−10829.0	−0.0034	−0.005472	−0.001596	[4]
26	51262.6390	v	−10824.0	−0.0071	−0.009204	−0.005331	[4]
27	51271.6010	v	−10802.0	−0.0106	−0.012845	−0.008985	[4]
28	51315.6090	v	−10694.0	−0.0152	−0.018139	−0.014341	[4]
29	51629.6320	v	−9923.5	0.0103	0.002327	0.005627	[4]
30	51698.6940	v	−9754.0	−0.0031	−0.012200	−0.009019	[4]
31	51987.6390	v	−9045.0	0.0072	−0.006689	−0.004021	[4]
32	51996.6180	v	−9023.0	0.0206	0.006560	0.009211	[4]
33	52021.6790	v	−8961.5	0.0189	0.004438	0.007044	[4]
34	52028.7990	v	−8944.0	0.0072	−0.007382	−0.004788	[4]
35	55253.8132	ccd	−1030.5	0.0778	0.001240	0.004111	[5]
36	55698.6342	ccd	61.0	0.0860	−0.000308	0.003691	[6]

Ref.: [1] Prager (1929); [2] Baldwin & Samolyk (1997); [3] Hobart et al. (1998); [4] Baldwin & Samolyk (2002); [5] Samolyk (2010); [6] Samolyk (2012).

weighted least-squares fit yields the following equation:

$$\begin{aligned}(O-C) \;=\; & -0.0858^{\rm d}(\pm 0.0007) \\ & +0.9049^{\rm d}(\pm 0.0053)\times 10^{-5}\times E \\ & +0.1220^{\rm d}(\pm 0.0009)\times 10^{-9}\times E^{2}. \end{aligned} \tag{2}$$

From Equation (2), the long-term increase rate of orbital period for AH Vir can be calculated to be $dP/dt = (2.1869 \pm 0.0161) \times 10^{-7}$ d yr^{-1}. The corresponding residuals of $(O-C)_1$ from Equation (2), plotted in the middle panel of Figure 1, show a small wave-like variation.

Using a least-squares method to fit $(O-C)_1$, we obtain the following solution:

$$\begin{aligned}(O-C)_1 \;=\; & +0.1268^{\rm d}(\pm 0.0303)\times 10^{-2} \\ & +0.0074^{\rm d}(\pm 0.0005)\sin\Big[0.0108^{\circ}(\pm 0.0001)\times E - 4.4885^{\circ}(\pm 3.0862)\Big]. \end{aligned} \tag{3}$$

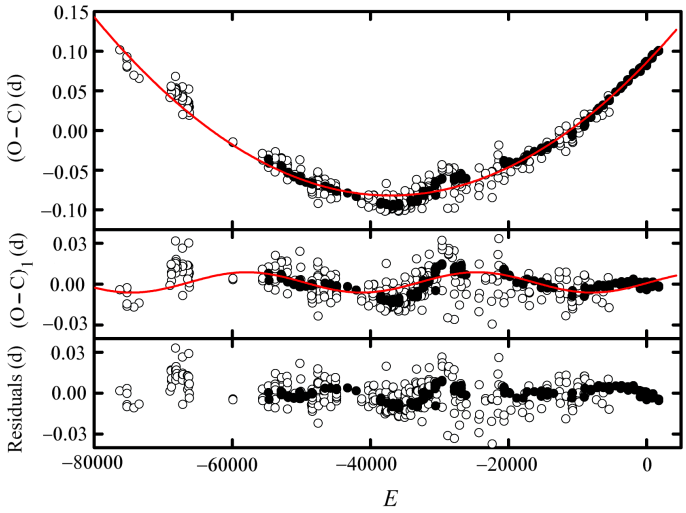

Fig. 1 $(O-C)$ curve of AH Vir based on Eq. (1) and its representation by Eq. (2) (*solid line* in the upper panel). The $(O-C)_1$ residuals and their descriptions in Eq. (3) are plotted in the middle panel, showing a small wave-like variation. The final residuals are plotted in the bottom panel.

From Equation (3), we can derive the period of oscillation to be $P = 37.19$ yr, and the corresponding amplitude is $A = 0.0074^{\rm d}(\pm 0.0005^{\rm d})$. With the following equation

$$\Delta P = 2\pi A P_e / P\,, \tag{4}$$

we can obtain the amplitude of the oscillation in orbital period to be $\Delta P = 1.3942 \times 10^{-6}$ d.

3 DISCUSSION

Our results suggest that the orbital period of AH Vir exhibits a secular increase, $dP/dt = (2.1869 \pm 0.0161) \times 10^{-7}$ d yr^{-1}, and a small periodic variation with period of 37.19 yr. If AH Vir is an overcontact system (Binnendijk 1960, 1984), the secular increase in period may be due to mass transfer from the less massive to the more massive component (but this is not quite the case for an overcontact binary). However, Bakos (1977) showed the configuration of AH Vir is a semi-contact case (see fig. 6 of Bakos 1977). He stated that the larger star of AH Vir is close to the inner Roche lobe and attributed the increase in orbital period to the mass transfer from the larger to the smaller component in the form of gas streams. The question of whether AH Vir is an overcontact or semi-contact system leads us to consider the configuration of this system. From the Lu & Rucinski (1993) results, the absolute parameters of AH Vir are $M_1 = 1.36\,M_\odot$, $M_2 = 0.41\,M_\odot$, $R_1 = 1.40\,R_\odot$, $R_2 = 0.83\,R_\odot$ and $a = 2.80\,R_\odot$. Using the equation (Eggleton 1983)

$$\frac{r_L}{a} = \frac{0.49q^{\frac{2}{3}}}{0.6q^{\frac{2}{3}} + ln(1+q^{\frac{1}{3}})}\,, \tag{5}$$

and with $q_1 = M_1/M_2$ and $q_2 = M_2/M_1$, we can compute the radii of Roche lobes of AH Vir to be

$$r_{L_1} = 1.35\,R_\odot < R_1 = 1.40\,R_\odot$$

and

$$r_{L_2} = 0.79\,R_\odot < R_2 = 0.83\,R_\odot\,.$$

This indicates that AH Vir is a true overcontact system. In this case, the secular increase in the orbital period of AH Vir can be explained by other mechanisms besides the mass transfer from the larger to the smaller component in the form of gas streams, as Bakos (1977) pointed out. It may result from the mass transfer from the smaller to the larger component. With equation (5) of Kwee (1958), and taking $M_1 = 1.36\,M_\odot$ and $M_2 = 0.41\,M_\odot$, we can calculate the mass exchange rate to be $dM_1/dt = -dM_2/dt = 1.05 \times 10^{-7}\,M_\odot\,\mathrm{yr}^{-1}$.

Since AH Vir shows strong activity in Mg II (Rucinski 1985) and Hα (Barden 1985) and the more massive component is much more active than the smaller secondary (Lu & Rucinski 1993), we assume that the oscillation in period is caused by the magnetic activity cycle of the primary component. The theory that the magnetic activity causes the change in orbital period in the binary was first proposed by Applegate (1992). It was later developed by Lanza et al. (1998, 2002). By using the formula from Applegate (1992)

$$B^2 \sim 10\frac{GM^2}{R^4}\left(\frac{a}{R}\right)^2\frac{\Delta P}{P}, \tag{6}$$

and adopting the parameters $M = M_1 = 1.36\,M_\odot$, $R = R_1 = 1.40\,R_\odot$, $a = 2.80\,R_\odot$, $P = 37.19$ yr and $\Delta P = 1.3942 \times 10^{-6}$ d, the mean surface magnetic field of the component due to activity can be calculated to be $B = 1.487$ kG.

4 CONCLUSIONS

We have made a satisfactory fit to the $O - C$ diagram by using a weighted least-squares method. We conclude that the orbital period of AH Vir is undergoing both a secular increase in period and cyclic variations. The cyclic variations may originate in the cycle of magnetic activity of the primary component. The long-term increase in period can be interpreted as mass transfer from the smaller to the larger component.

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