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Research Note

The W Ursae Majoris system AK Herculis*

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Abstract. A detailed study of the period and the light-curve of the eclipsing binary AK Her is presented. Based on the study of the (O–C) curve, we find that the period variation of the system contains a component of a long-term decrease, and three other components of periodical variation. Our result is very different from that of other investigators. We compare light curves obtained by other groups and find that the light curve of the system has changed considerably. Based on the analysis, we investigate the physical mechanisms which may underlie the variations of the period and the light curve and obtain some new conclusions. According to the characteristics of rapid light variation of the system, we conclude that the rapid change is probably caused by pulsation of the common envelope, and that the physical mechanism causing the pulsation may be mass transfer between the two components. In addition, we find that the amplitude of the light curve variation is almost proportional to the rate of the period variation. Finally, the trends in the evolution of the system are discussed.

Key words. individual star: AK Her – binaries: eclipsing – stars: activity

1. Introduction

The W UMa-type eclipsing variable AK Her is the brighter component of the visual double star ADS 10408. The fainter component is at a distance of $4\farcs7$ in position angle 322°. The variable was discovered by Metcalf (cf. Pickering 1917), and has since been observed many times. The Photometric light curves were obtained by Stebbins (see Woodward 1942), Seyfert & Mason (1951), Labs & Stock (1953), Schmidt & Herczeg (1959), Hindeger (1960), Binnendijk (1961), Bookmyer (1972), Woodward & Wilson (1977), Bookmyer & Kaitchuck (1979), Barker & Herczeg (1979), Glownia (1985), and Tunca et al. (1987). The system shows a variable light curve and an obvious O'Connell effect. Spectroscopic observations were made by Sanford (1934). The period studies of AK Her were performed by Schmidt & Herczeg (1959), Binnendijk (1961), Herczeg (1962), Purgathofer & Prochazka (1966), Woodward & Wilson (1977), Barker & Herczeg (1979), Bookmyer & Kaitchuck (1979), Rafert (1982), Glownia (1985), Tunca et al. (1987), and Rovithis-Livaniou et al. (1999). So far most of the studies investigated variations in the period, and the detected periodicities range from 58 to 78 years.

Although many authors have investigated the system, no physical explanations for some observed appearances have been given, such as the rapid light variation, the trend of the O'Connell effect variation, etc. When investigating the period variation of the system, the periods of the period change obtained were often longer than the intervals of the minimum times adopted. Thus, the results have little physical meaning. We have collected all available minimum times which span an interval of 76.36 years, and correct five minimum times which Rovithis-Livaniou et al. (1999) have adopted. Based on these minima, we again investigated the period variation, obtaining a result different from previous studying. In this paper, we present these studies of the period variation and the light curve change of the system AK Her, and discuss the evolution of the system.

2. O–C curve analysis

For the present study, we collected as many minima times found in the literature and calculated the (O–C) values according to the old ephemeris formula by Bookmyer et al. (1979),

$$\mathrm{Min.I} = \mathrm{HJD}\ 2438176.5092 + 0.42152368 \times E\ . \qquad (1)$$

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* Table 3 is only available in electronic form at http://www.edpsciences.org

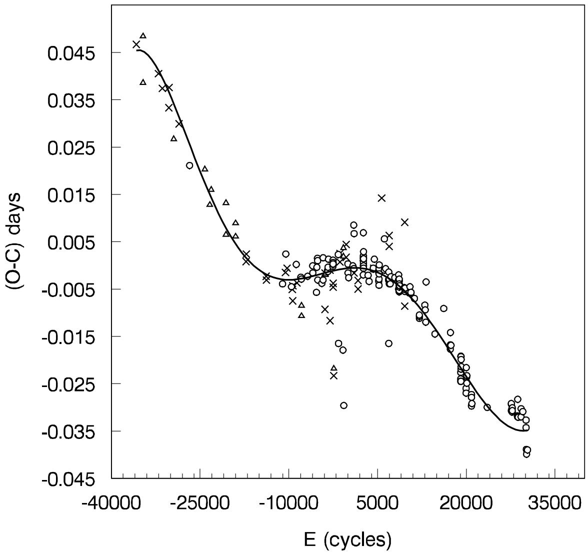

Fig. 1. The O–C diagram of AK Her and its description by a least-square polynomial. Circles, crosses, and triangles represent the photoelectric observations, visual observations and photographical observations respectively. The solid line represents the fitted curve

The minima times and the (O–C) values are listed in Table 3. The corresponding (O–C) diagram for AK Her is presented in Fig. 1. We analyzed the (O–C) diagram using the method proposed by Kalimeris et al. (1994a,b). According to the method, the differences $\Delta T(E)$ between the observed and the calculated times of minima are given for any cycle E by a polynomial form

$$\Delta T(E) = \sum_{j=0}^{n} c_j E_N^j, \tag{2}$$

where $E_N = E/c$, and c is a scale constant such that, if $E_{\min}$ and $E_{\max}$ are the minimum and maximum cycles of the approximated segment of an O–C curve, then:

$$|\max(E_{N,\min}, E_{N,\max})| < 1.$$

The real period of a system at any cycle E is given by the following equation

$$P(E) = P_{\rm e} + \Delta T(E) - \Delta T(E-1), \tag{3}$$

where $P_{\rm e}$ is the ephemeris period. The rate of the period change at any cycle E is given by

$$\dot{P}(E) = \frac{\mathrm{d}P}{\mathrm{d}E} = \frac{1}{c}\left(\sum_{j=0}^{n-1}(j+1)c_{j+1}E_N^j - \sum_{j=0}^{n-1}(j+1)c_{j+1}\left(\frac{E-1}{c}\right)^j\right). \tag{4}$$

In the case of AK Her, a weighted least-squares polynomial of 6th order fitted very well the observed times of minima (see Fig. 1). The values of the polynomial coefficients $c_j, j = 0(1)6$ and the value of the scale constant are listed in Table 1.

Table 1. Polynomic coefficients and scale constant

c_0	$-6.0670\ 10^{-4}$
c_1	$4.6114\ 10^{-3}$
c_2	-7.443910^{-2}
c_3	-0.1716
c_4	0.2010
c_5	0.1494
c_6	-0.1162
scale constant	40 000

3. The period variation of AK Her

So far, the orbital period studies of the system have been performed by many groups. Most of studies investigate the period variations and the detected periodicities range from 58 to 78 years. Due to the different observational material at the time of analysis, and to the fact that the search for periodicities was based on different O–C diagrams, which depend on the ephemeris used, all periods of period change obtained are different from each other. Schmidt & Herczeg (1959) found a periodicity of 64 yr, Woodward & Wilson (1977) of 58 yr, Barker & Herczeg (1979) of 78.03 yr, Glowia (1985) of 65.95 yr, and Tunca et al. (1987) of 75.72 yr. Rovithis-Livaniou et al. (1999) used a method described by Kaliameris et al. (1994a, 1995), they computed the period variation $P(E)$ and its rate of change. From the Fourier spectrum of the $P(E)$ function, they obtained two periodicities of 76.16 yr and 38.1 yr, with amplitudes 0.071 s and 0.002 s, respectively.

From the present analysis, which includes the minima times available. These minima times span an interval of 76.36 yr. It is shown (Fig. 1) that the orbital period of AK Her does not follow a sinusoidal variation. The photoelectric, photographic and visual residuals display a wave-like regularity in their distribution, which might be thought of as a light-time effect.

Using Eqs. (3) and (4) we calculated the period $P(E)$ and the period change rate $\Delta P(E)$ of the system. In Fig. 2 we plotted the difference between the real period P and the ephemeris period $P_{\rm e}$, and the relative change rate $\mathrm{d}P/P$. AK Her presents a smooth period variation with a relatively small amplitude. The variation is not in a single sinusoidal form, implying that the variation of the system is not caused by any single physical mechanism. Through a spectral analysis of the period function $P(E)$, we obtained three different spectral frequencies (see Fig. 3) of $P(E)$ function of the system. They correspond to periods of 42.39 yr, 7.64 yr and 5.10 yr with amplitudes of 0.042 s, 0.0074 s, and 0.0066 s respectively. We suggest that the periodical variation of the period of the system is caused by three periodical physical mechanisms. Our result is different from that of the investigators mentioned above, and the interval of the minima times which we adopt is longer. The period of the period change of the system which they obtained, is longer than the spans of their available

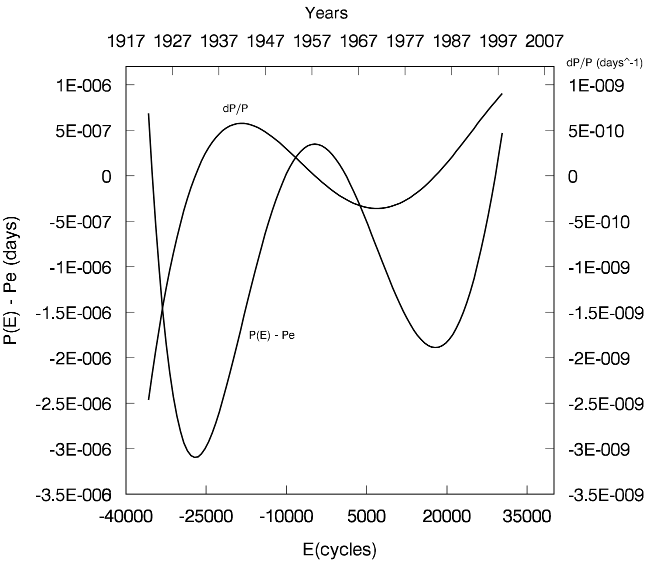

Fig. 2. The period of AK Her as a function of time and its relative rate of change. The difference $P - P_{\rm e}$ refers to the ephemeris period $P_{\rm e} = 0.42152368$ d

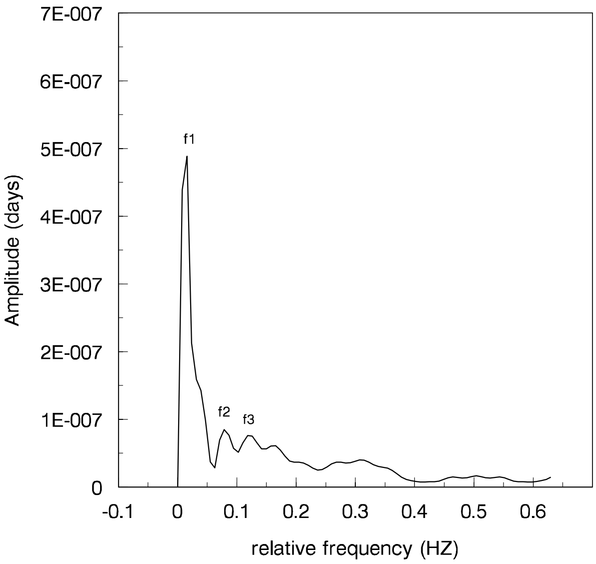

Fig. 3. The spectrum of the function $P(E)$ of AK Her

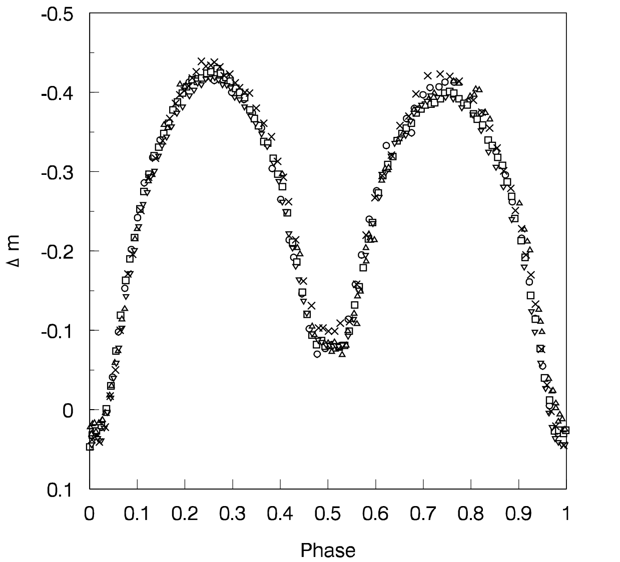

Fig. 4. The variation of the light curve of AK Her. Open circles represent observations in 1960, squares represent observations in 1966, triangles represent observations in 1971, inverted triangles represent observations in 1973, crosses represent observations in 1986

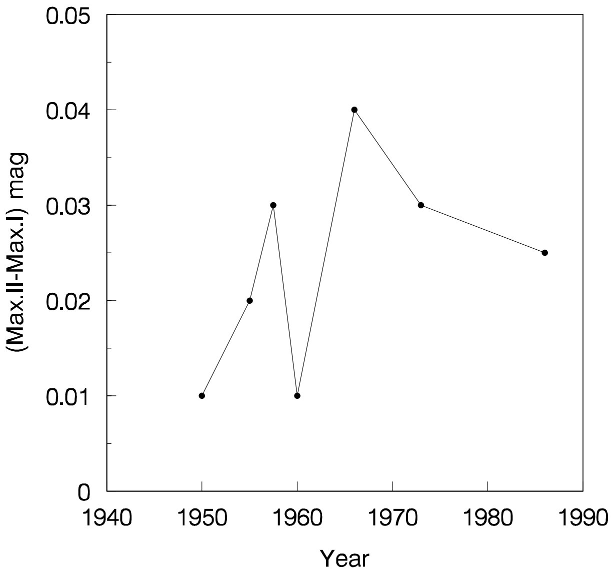

Fig. 5. Maximum after secondary minimum compared with maximum after primary minimum (B-band in magnitude scale)

observations, so their results have little physical meaning. In addition, Rovithis-Livaniou et al. (1999) used five minima which had been pointed out to be wrong by Borkovits et al. in 1998. We used the five corrected minima (Borkovits et al. 1998) to study the period variation of the system, and therefore feel that our results are more reliable.

4. The variation of the light curve

For the present study, we have collected as many light curves as we could find in the literature. We present five light curves in yellow obtained by Binnendijk (1961) in 1960, Bookmyer (1972) in 1966, Barker et al. (1979) in 1971, Woodward & Wilson (1977) in 1973, and Tunca et al. (1987) in 1986. All of the data are plotted in Fig. 4.

We list the values (in magnitude) of the (Max.II-Max.I) in different years in Table 2, which contains the information about the variation of the O'Connell effect. We find that none of the values is negative in Table 2. Figures 5 and 6 show the variation in the (Max.II-Max.I) with observed time. As seen in Fig. 4, the system exhibits a long-term light variation, and achieved brighter magnitudes in 1986. Thus, the brightness of the system has been increasing recently. As seen in Figs. 5 and 6, the system exhibited an O'Connell effect from 1952 to 1986, and the O'Connell effect showed a periodical variation. The variation trend of the O'Connell effect seems to be strengthened in the

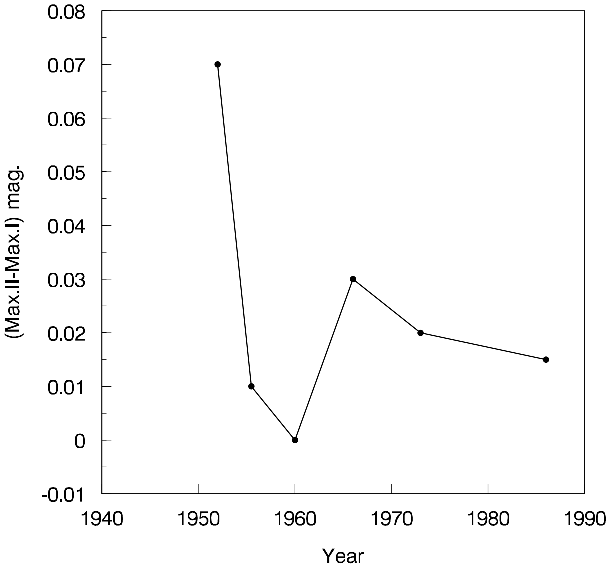

Fig. 6. Maximum after secondary minimum compared with maximum after primary minimum (V-band in magnitude scale)

Table 2. The secondary Maximum compared with the primary Maximum

Years	color	(Max.II-Max.I)	ref.
1950	B (4124)	+0.01	Bookmyer (1972)
1952	V (4700)	+0.07	Bookmyer (1972)
1955–56	B (3875)	+0.02	Bookmyer (1972)
1955–56	V (5050)	+0.01	Bookmyer (1972)
1957–58	B (4500)	+0.03	Bookmyer (1972)
1960	B (4420)	+0.01	Bookmyer (1972)
1960	V (5300)	+0.00	Bookmyer (1972)
1966	B (4400)	+0.04	Bookmyer (1972)
1966	V (5500)	+0.03	Bookmyer (1972)
1973	B (4400)	+0.03	Woodward (1977)
1973	V (5500)	+0.02	Woodward (1977)
1986	B (4320)	+0.05	Tunca et al. (1987)
1986	V (5500)	+0.015	Tunca et al. (1987)

system. The first point is much higher than other points in Fig. 6. This may be caused by the large difference of the wavelength from the others, or observational error.

The system exhibited rapid light variation night by night (Tunca et al 1987; Bookmyer 1972), especially at the regions near the two maxima and the two minima. This appearance has been observed in many contact binaries, such as V719 Her (Goderya et al. 1996), AQ Tuc (Hilditch & King 1986), DN Aur (Goderya et al. 1997a), V508 Cyg (Goderya et al. 1995), CN And (Keskin 1989), KN Per (Goderya et al. 1997b). In these binaries, this is especially apparent in the regions near the two maxima and two minima of the light curve. The light variation generally has an amplitude of about 0.01–0.03 mag with a period between a few hours and a few days. Therefore, this phenomenon may be caused by the pulsation of a common envelope caused by some physical mechanism(s). According to the distribution of the intensity of the oscillation, we suggest that the location of the source of oscillation should be in the neck of the contact binary. The mechanism causing the pulsation of the common envelope may be mass transfer between the two components. It is apparent that the rapid light variation is observed near the two maxima. The light variation near the two minima may be caused by diffraction of the wave, because the regions near the two minima are indeed the two diffractive spots. In some deep-contact binaries, such as AW UMa (Hrivnak 1982), TZ Boo (Hoffmann 1978, 1980), etc., this appearances can be observed in almost any phase with the larger amplitude of variation, and this may be caused by the wave diffraction. The period of the light variation of AK Her is between a few hours and a few days. If the period is too long or too short, this kind of light variation is not easily detected. The period and amplitude of light variation are very similar to those of the pulsating variable. Thus we propose that this kind of light variation may be caused by the pulsation of the common envelope.

5. Discussion

The periodical variations in the period of the system is likely influenced by three different mechanisms with different periods. AK Her is the brighter component of visual binary ADS 10408, while the fainter component can lead to a light-time effect and give rise to the period change of AK Her with a period of about 42.39 yr. It is well known that the period of magnetic activity of the Sun is about 11 yr. AK Her is a solar-like star with a spectral type of F7-8 (Woodward & Wilson 1977). The magnetic activity of the system may lead to the period variation of the system with a period of about 7.64 yr. The rotation of the system is much faster than the Sun, therefore it is not surprising that the magnetic activity of the system is more frequent than that of the Sun. The variation with a period of about 5.10 yr may be caused by the periodical mass transfer between two components of the system.

In addition, the fit coefficient c_2 of $\Delta T(E)$ is negative. This suggests that the period of the system still contains a component of long-term decrease. This may be caused by the loss of angular momentum of the system due to magnetic braking or gravitational wave radiation. We use the formulae adopted by de Kool (1992) for angular momentum loss timescales for magnetic braking and gravitational wave radiation, and combined with the formula adopted by Han (1998), obtain the following formulae

$$\tau_{\rm GR} = \frac{J_{\rm orb}}{\dot{J}_{\rm orb}} = 1.24\ 10^9$$
$$\times \left(\frac{M_1}{M_\odot}\right)^{-1} \left(\frac{M_2}{M_\odot}\right)^{-1} \left(\frac{M_1+M_2}{M_\odot}\right)^{-1} \left(\frac{a}{R_\odot}\right)^4 \ {\rm yr}, \quad (5)$$

$$\tau_{\rm MB} = \frac{J_{\rm orb}}{\dot{J}_{\rm orb}} = 4.5\ 10^6$$
$$\times \left(\frac{M_1}{M_\odot}\right)\left(\frac{M_1+M_2}{M_\odot}\right)^{-2}\left(\frac{R_2}{R_\odot}\right)^{-\gamma}\left(\frac{a}{R_\odot}\right)^5 \text{ yr}, \qquad (6)$$

where $\tau_{\rm GR}$, $\tau_{\rm MB}$ are timescales of angular momentum loss due to magnetic braking and gravitational wave radiation. $M_{1,2}$ are masses of two components of the system. R_2 is the radius of the more massive component. a is the orbital separation. $M_\odot$ and $R_\odot$ are the mass and the radius of the Sun. We take $\gamma = 2$ as adopted by most of investigators.

Maceroni van't Veer (1996) have obtained the absolute parameters of AK Her. For AK Her, $\tau_{\rm GR}$ and $\tau_{\rm MB}$ are $1.158\ 10^{11}$ yr and $0.41\ 10^8$ yr respectively. The timescale of variation of the angular momentum is similar to the timescale of period variation caused by the change in the variation of the angular momentum. A quadratic fit to the (O–C) indicates that the period of the system decreases continuously, and the period decrease rate is the order of $-1.9624\ 10^{-12}$ days/cycles. The decrease of the period thus operates on a timescale

$$\tau_{\rm PD} = \frac{P}{\dot{P}} = 2.480\ 10^8 \text{ yr}, \qquad (7)$$

$\tau_{\rm MB}$ is not much different from $\tau_{\rm PD}$. Since the theory of magnetic braking is not yet well developed, the Eqs. (5), (6) cannot be taken as accurate. The long-term decrease in the period of the system is likely caused mainly by magnetic braking. Kolb (1993) pointed out that if the mass of a star is lower than about 0.366 $M_\odot$, the star becomes fully convective. According to the known theory of magnetic braking, the star does not give rise to a magnetic braking effect. For AK Her, the masses of the two components are 1.30 $M_\odot$ and 0.30 $M_\odot$ respectively. So the magnetic braking effect is more likely caused by magnetic activity of the primary.

The light curve of the system varies rapidly. These changes may be caused by magnetic activity, the mass transfer between the two components, or mass loss. The O'Connell effect and its variation may be caused by magnetic activity and the periodic variation of the magnetic activity. The light curves of the system exhibited an O'Connell effect from 1952 to 1986, suggesting that magnetic activity existed in the system during this time. The periodic variation of the (Max.II-Max.I) indicates that the location and the region of the magnetic activity probably also vary periodically with time. Although the O'Connell effect of the system exhibited a periodic variation from 1952 to 1986, the trend of the effect variation strengthened. This lead us to propose that the variation trend of magnetic activity is strengthened during this period. The strengthening may be caused by period decrease of the system. The decrease in the period speeds up the rotation of the system, and fast-rotation can increase the level of the magnetic activity. The variations of the period and the light curve make AK Her an interesting binary which should be studied further, and these variations indicate that the system is very unstable. From Figs. 2 and 4, we find that the variation of the light curve is related to the rate of the period variation. The amplitude of the light curve variation is almost proportional to the rate of the period variation. This indicates that the same physical mechanism(s) may be playing an important role in variations of the period and light curve change.

According to the observed properties of the system mentioned above, we can infer the possible evolutionary progress of the system. Because of the magnetic activity and the mass loss due to stellar wind, the orbital angular momentum may decrease rapidly. The decrease of the orbital angular momentum will give rise to the decrease in the period and the orbital separation of the system. The decrease of the period could increase the rotation, and rapid rotation can increase the level of the magnetic activity. Therefore the variation of the period of the system would become faster and faster. Once the variation of the period is fast enough, the rotation of the common envelope of the system cannot catch up with the rotation of the internal binary, and can give rise to asynchronous rotation between the common envelope and the internal binary. According to the theory of Meyer & Meyer-Hofmeister (1979), the asynchronous rotation can produce "frictional luminosity" in the differentially rotating region, and lead to the transfer of the angular momentum from the internal binary to the common envelope. The frictional luminosity adds to the luminosity of the system to increase the total luminosity. Because of the transfer of the angular momentum, the period of the system will decrease. If the total luminosity increases the common envelope can expand, the internal binary may collapse, and the luminosity of the nuclear reaction will increase. The total luminosity of the system will then increase rapidly. The rapid increase of the total luminosity probably would produce an expansion wave or even an explosive wave. These waves may lead to the loss of the common envelope. These conclusions are consistent with a scenario in which AK Her evolves into a cataclysmic binary in the future.

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