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THE THIRD BODY IN THE ECLIPSING BINARY AS CAMELOPARDALIS

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The eclipsing binary AS Cam (HD 35111 = BD+69°325 = SAO 1357 = BV 268, $V_{\rm max} = 8^{\rm m}_{.}6$; Sp.: B8 + B9.5 V) is a well-known system having an eccentric orbit (e = 0.17) and an orbital period of $P_{\rm orb}$ = 3.43 days. The AS Cam system was discovered photographically by Strohmeier (1963). Hilditch (1969) obtained spectra and reanalyzed the photographic data, supplemented by photoelectrically determined times of minima, to show that AS Cam consists of a pair of B9 V stars. Hilditch (1972a) estimated the masses of the components to be $M_1 = 3.3\,M_\odot$ and $M_2 = 2.5\,M_\odot$. He obtained a two-year long photometric dataset extending from 1968 to 1970.

In 1981 we began the photoelectric observations of the star with a 50-cm Cassegrain reflector of the Tien-Shan observatory of the Sternberg Astronomical Institute. Observations of the primary and secondary minima were carried out on November 28 and 30, 1981, respectively, and the corresponding light curves can be found in the paper by Khaliullin and Kozyreva (1983). Our observations provide complete and accurate coverage of all parts of the light curve minima except for a small interval at the beginning of the descending branch of the primary minimum. On the average, the standard error of individual observation is $\sim 0^{\rm m}_{.}004$ in V. We also determined the orbital elements and physical parameters of the components (Khaliullin and Kozyreva, 1983).

On the base of comparison with the observations of Hilditch we discovered AS Cam to be the system with a large disagreement between the observed apsidal motion rate (Khaliullin and Kozyreva, 1983) ($\dot\omega_{\rm obs}$ = 16°/100 years) and its theoretical value ($\dot\omega_{\rm obs}$ = 44°/100 years) This discrepancy was confirmed by others (Maloney *et al.*, 1989). A similar surprising result concerning another close binary with relativistic apsidal motion was obtained by Martynov and Khaliullin (1980): for DI Her, the theoretically expected apsidal motion caused by relativistic contribution is larger than the classical component by a factor of two. The observed apsidal motion in this system is smaller than that theoretically expected by a factor of three and, moreover, $\dot\omega_{\rm obs}$ is even smaller than $\dot\omega_{\rm cl}$. Both these results require adequate theoretical explanation.

Such disagreements were investigated by Maloney *et al.* (1989) but they did not find acceptable explanations for the conflict between theory and observations in the framework of the classical theory of gravitation.

A successful explanation has been suggested for the discrepancy between theory and observations for DI Her by Khaliullin, Khodykin and Zakharov (1991). They developed a model of a hierarchical triple system with non-coplanar orbits and found no conflict between theoretically calculated and observed apsidal motion parameters for the given longitude of periastron. The above authors give a detailed description of the domain of acceptable positions of the third body and its mass. The computations are based on observational data. This model assumes that the orbital plane of the third body is almost perpendicular to the line of sight.

Khodykin and Vedeneev (1996) showed that a third body in AS Cam can resolve the discrepancy between the theoretical and observed apsidal motion rates provided that its mass is at least 1.1–1.45 $M_{\odot}$. To reveal the effects due to the third body required accumulation of extensive and homogeneous observational datasets.

We performed our photoelectric observations in 1991–1996 at the Tien-Shan observatory. Most of the observations were obtained with the same telescope as the one used for 1981 photometry. As a light receiver we used a four-channel *WBVR* photometer with dichroic filters (Kornilov and Krylov, 1993). We have obtained light curves of 7 primary and 12 secondary minima. The most accurate light curves are those in the V-band because atmospheric extinction in this filter is the lowest. The standard error of photometry for the minima of 1991–1996 was equal to $0^{\rm m}_{.}01$ and the error was as small as $\sim 0^{\rm m}_{.}006$ on the best nights. We performed the observations using differential method with HD 34463 as a comparison star and HD 34886, as a check star. We found the rms scatter in the V-magnitude difference between AS Cam and HD 34463 outside the minima to be $0^{\rm m}_{.}025$, whereas the corresponding scatter for the magnitude difference between the comparison and check stars did not exceed $0^{\rm m}_{.}005$. Gülmen *et al.* (1976), who earlier observed this star, also pointed out a possible $\sim 0^{\rm m}_{.}03$ variability in the V-band outside of the eclipses. Physical variability of AS Cam really exists and contributes to the errors in the elements inferred from light curve analysis. It is therefore very desirable to understand the nature of this variability. To do this we have to secure and analyze sufficiently long datasets obtained outside eclipse.

Various methods are used to determine the times of minima for eclipsing variables. They usually involve finding the symmetry axis of the light curve. One of the most widely used method consists in fitting a parabola to a light curve minimum. However, the shape of the light curve differs from a parabola and therefore the times of minima thus obtained depend on the configuration of the binary and on the time interval during which the light curve is observed, resulting in a systematic error of the method.

We determined the times corresponding to the minimum projected distances between stars. To this end, we used a model consisting of two spherical stars with a linear limb darkening, moving in an elliptical orbit. Adopting a particular model allows homogeneous determination of the times of minima during eclipses. The timings of minima were calculated simultaneously with the photometric elements. Note that some of the latter could be fixed corresponding to the solution of a best light curve (Khaliullin and Kozyreva, 1983).

Table 1 gives the times of minima for AS Cam derived using the adopted model. Besides our minima, the timings of minima were used that we inferred from the published light curves of Hilditch (1972b) (JD 2440132, 2440147, 2440185, 2440204, 2440545, 2440590) and Lines *et al.* (1989) (JD 2447443 and 2447465) and from those kindly provided by E.F. Guinan and M. Wolf, in the framework of our model. Besides, we used some timings of minima taken from the original papers.

Table 1: Photoelectric timings of minima of AS Cam obtained at Tien-Shan observatory.

$JD_{\odot}$ 2400000+	O−C	Min	$JD_{\odot}$ 2400000+	O−C	Min
44939.2457	$0^{d}.0005$	I	48869.2220	$0^{d}.0032$	II
48538.3247	−0.0016	I	48982.4411	0.0003	II
48881.4241	0.0014	I	49003.0268	0.0001	II
48998.0740	−0.0014	I	49236.3317	−0.0010	II
49238.2405	−0.0024	I	49332.3975	−0.0024	II
49341.1695	−0.0023	I	49339.2600	−0.0018	II
49557.3235	0.0010	I	49610.3109	0.0023	II
49622.5124	0.0016	I	49634.3272	0.0018	II
49773.4737	0.0005	I	49778.4265	0.0003	II
50418.4975	0.0031	I	50056.3322	−0.0027	II
50425.3566	0.0002	I	50063.1937	−0.0031	II
44937.3262	0.0005	II	50423.4506	0.0018	II
48536.4094	−0.0052	II			

The period of the apsidal motion is much larger than the whole interval covered with observations, therefore the O−C for Min I as well as for Min II could be reproduced with linear function of time.

$$C_{I} = JD_{\odot}\ 2444939.24524 + 3^{d}.4309638 \times E,$$
$$\pm 54 \qquad\qquad \pm 4$$

$$C_{II} = JD_{\odot}\ 2444937.32567 + 3^{d}.4309713 \times E.$$
$$\pm 63 \qquad\qquad \pm 5$$

The O−C residuals for Min I and Min II, after subtraction of linear trend due to apsidal motion, are shown in Fig. 1. Zero point corresponds to year 1981.

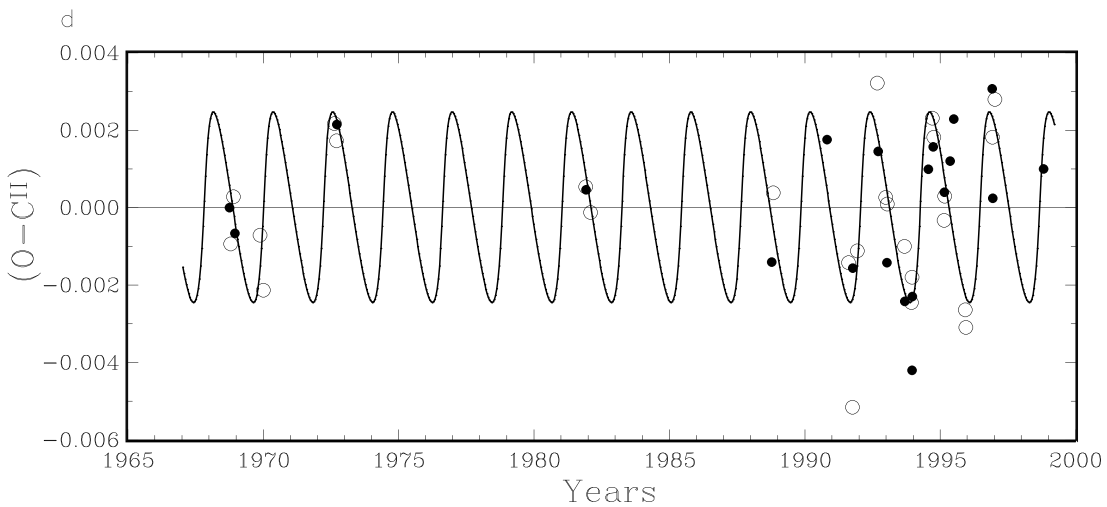

Figure 1. O−C diagram for photoelectric minima with linear trend subtracted. Individual primary (•) and secondary (∘) minima are shown. Zero O−C corresponds to JD 2444939 (year of 1981). The O−C residuals can be fitted by a theoretical calculated curve (solid line).

We see that the O−C residuals are subject to variations with a period of ≈ 2.2 years for both eclipses. This can be considered as evidence for a third body in the system. The amplitude of variations, period and eccentricity are calculated by the least square method. They are equal to

$$\frac{a' \sin i'}{c} = 4.18 \text{ min}, \qquad e' = 0.5, \qquad P' = 805^{\rm d}.$$

Our investigations concerning the mass of the third body will be described elsewhere. Here we only publish that the mass of the third component is approximately 1.1–1.7 $M_\odot$.

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