LIGHT TIME EFFECT IN AR AUR

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ВЛИЯНИЕ ТРЕТЬЕГО ТЕЛА В СИСТЕМЕ AR Aur

Опубликованы новые моменты минимумов блеска затменной двойной AR Aur. Они соответствуют истолкованию их влиянием третьего тела, предложенным раньше (Зверко и др. 1981). Вычислены параметры орбиты третьего тела, и обсуждаются спектроскопические характеристики составляющих.

New times of minima of the eclipsing binary AR Aur are presented. They agree with the explanation by a light time effect as suggested earlier (Zverko et al. 1981). Parameters of the third body orbit are calculated and the spectroscopic characteristics of the components are discussed.

Key words: AR Aur — eclipsing binaries — multiple stars — HgMn stars

1. Introduction

The eclipsing system AR Aur (17 Aur; HR 1728; HD 34 364) was discovered by Pedersen and Steensgard (1931). Both eclipsing components are similar; Popper (1959) classified them as B 8 V and B 9·5 V. According to Wolff and Preston (1978), the primary component (B 8) is a HgMn star. A photoelectric light curve was obtained by Huffer and Stebbins in the years 1935–39 and analysed by Huffer and Eggen (1947). The components are detached, with radii less than 0·10. Six-colour photometry from the years 1965–68 was published by Johansen (1970). The orbital inclination is close to 90^0 – according to Johansen, $i = 88{\cdot}4°$. Spectroscopic elements were determined by Wyse (1936) from observations made in the years 1934–35 and by Harper (1937) from observations made in 1935–36. The masses of components according to Wyse are 2·48 and 2·29 $M_{\odot}$, according to Harper 2·68 and 2·36 $M_{\odot}$. Rachkovskaya (1985) observed the star in the years 1967–68 and 1981–82 and obtained the mass ratio $q = 1$.

O'Connel (1979) found that the period of AR Aur changed. To explain the changes, Zverko et al. (1981) suggested the presence of a third body in the system. In this paper new times of minima are given, and it is shown that they agree with the suggested interpretation. Parameters of the third-body orbit are presented, and some remarks concerning the characteristics of the components are added.

2. The Third-body Orbit

All photoelectric minima as compiled by O'Connell are given in Tab. 1. The new minima observed at the Skalnaté Pleso Observatory with the 60 cm telescope in the years 1979–86 are also included. The O–C diagram calculated according to the ephemeris

$$\text{Pri.Min.} = \text{JD hel. } 2\,427\,887{\cdot}7217 + 4{\cdot}1346662^{d}\,(E + 2543)$$

is plotted in Fig. 1. Since the secondary minima appear exactly in phase 0·5, they are also contained in Tab. 1 and Fig. 1. We have interpreted the period changes as a light-time effect. The formulae given by Irwin (1959) were used for the calculation. We have found that the O–C values known at present can be represented by a one-parametric family of solutions, for which the quality of the fit differs but slightly. In Tab. 2, two of these solutions are shown: No. 1, for which the scatter of the times of minima – characterized by $\sum(\text{O–C})^2$ – is at minimum, and No. 2, which agrees better with the recent minima. Both solutions are close to the extreme ones: with the lengthening (in case of No. 1) or shortening (No. 2) of the long period P', the corresponding values of $\sum(\text{O–C})^2$ rapidly increase. The residuals for both solutions are included in Tab. 1 as O–C_1, and O–C_2, respectively, and are presented in Fig. 2. After about 5 years, it will be possible to improve the accuracy of the elements of the orbit considerably.

Table 1

Photoelectric minima of AR Aur

JD hel. 2 400 000+	*E*	Date	O-C	O-C_1	O-C_2	Source
27 887·7217	−2543	1935·23	·0000	·0000	−0·003	1
27 889·7892	−2542·5	1935·24	+·0002	+·0002	−·0001	1
38 404·2504	0·5	1964·03	+·0052	−·0001	−·0001	2
38 435·2603	8	1964·11	+·0051	−·0004	−·0004	2
39 098·8783	168·5	1965·93	+·0092	−·0001	·0000	3
39 154·6964	182	1966·08	+·0093	−·0003	−·0002	3
39 940·2880	372	1968·23	+·0143	+·0007	+·0010	2
40 246·2538	446	1969·07	+·0148	+·0001	+·0004	2
40 248·3215	446·5	1969·08	+·0152	+·0005	+·0008	2
40 498·4683	507	1969·76	+·0147	−·0005	−·0003	4
40 930·5414	611·5	1970·94	+·0151	−·0003	−·0003	5
41 941·464	856	1973·71	+·0119	−·0002	−·0013	6
44 153·5008	1391	1979·77	+·0022	+·0010	+·0008	7
44 612·4465	1502	1981·02	·0000	·0000	+·0003	7
44 614·5139	1502·5	1981·03	+·0001	+·0002	+·0004	8
44 860·5260	1562	1981·70	−·0005	·0000	+·0004	9
44 980·4305	1591	1982·03	−·0013	−·0006	−·0002	9
45 290·5298	1666	1982·88	−·0019	−·0009	−·0004	9
46 082·3196	1857·5	1985·04	−·0007	·0000	+·0001	9
46 365·5448	1926	1985·82	−·0001	+·0001	·0000	9
46 367·6122	1926·5	1985·83	−·0001	+·0001	·0000	9
46 423·4304	1940	1985·98	+·0001	+·0002	·0000	9
46 702·5216	2007·5	1986·74	+·0009	+·0003	−·0002	9

Sources: 1 — Huffer and Eggen (1947); 2 — O'Connell (1979); 3 — Johansen (1970); 4 — Gülmen (1970); 5 — Battistini et al. (1973); 6 — Kizilirmak and Pohl (1974); 7 — Zverko et al. (1981); 8 — Zverko et al. (1981, revised;) 9 — this paper.

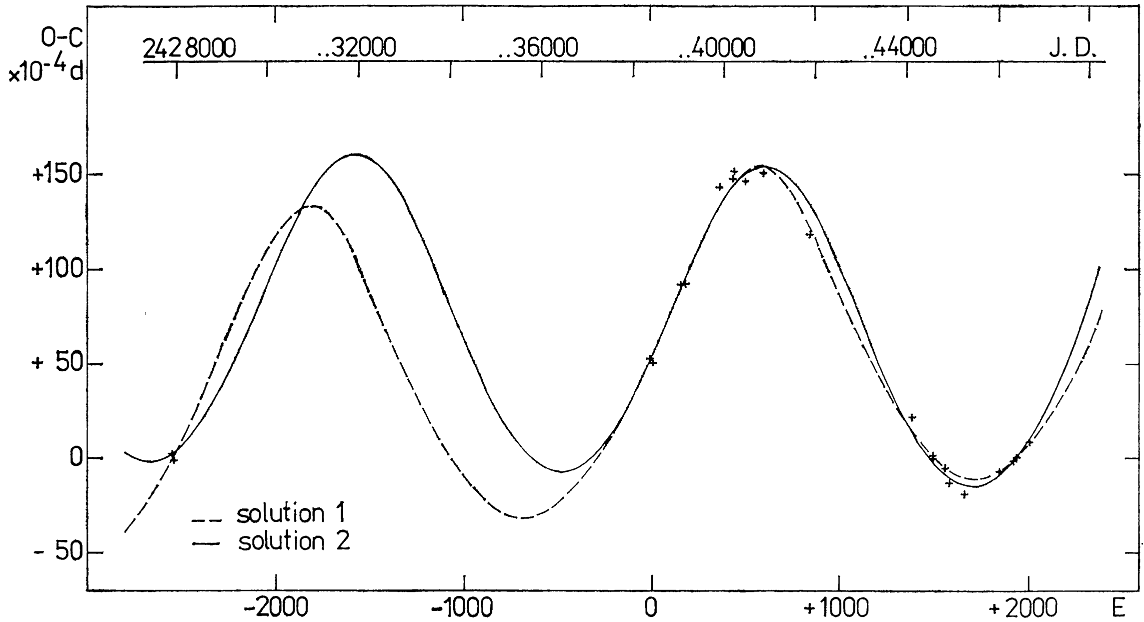

Fig. 1. O-C graph according to the linear ephemeris. Only photoelectric minima are plotted. The parameters of solutions Nos 1 and 2 are listed in Tab. 2.

Table 2

Triple system orbital parameters

Solution No.	1	2
P' (long period)	$9\,894^d$ (27·09 years)	$9\,040^d$ (24·75 years)
P (eclipsing pair)	$4{\cdot}1346671^d$	$4{\cdot}1346659^d$
JD_0 (time of minimum)	2 438 402·1841	2 438 402·1852
T' (time of periastron)	2 440 908	2 441 177
A' (semi-amplitude)	$0{\cdot}0088^d$	$0{\cdot}0083^d$
$a' \sin i'$	228×10^6 km	215×10^6 km
e' (eccentricity)	0·208	0·060
ω'	97·5°	99·7°
$\Sigma(O-C)^2$	388×10^{-8} (day)^2	515×10^{-8} (day)^2
σ (r.m.s.)	$0{\cdot}00041^d$	$0{\cdot}00047^d$

Note: the primed values hold for the orbit of the eclipsing pair around the centre of gravity of the triple system.

The small amplitude of the light-time effect indicates that other than photoelectric minima times are useless for studying the period changes, and also that the third-body mass function

$$f(m_3) = \frac{(m_3 \sin i')^3}{(m_1 + m_2 + m_3)^2} = 5{\cdot}22 \times 10^6 \frac{A'^3}{P'^2}$$

(where m_i are masses of the components, i' the inclination of the third-body orbit, A' the light-time effect

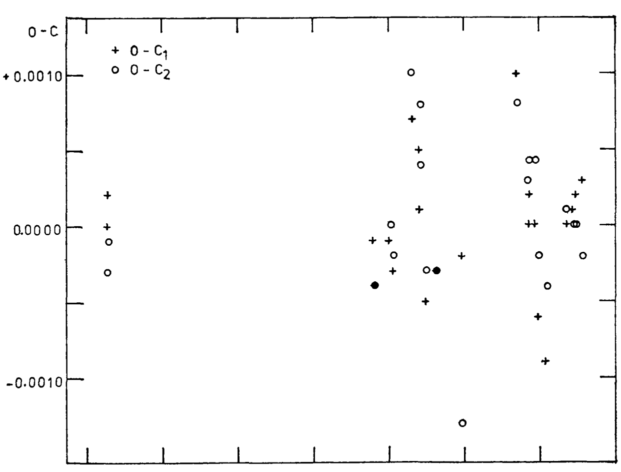

Fig. 2. Deviations of the observed minima times from the light-time effect curves calculated according to solutions Nos 1 ($O-C_1$) and ($O-C_2$).

amplitude in days and P' the long period in years) is rather small. For both solutions, as given in Tab. 2, it is only 0·0049 $M_\odot$. If we take $m_1 + m_2 = 4{\cdot}77\ M_\odot$ according to Wyse (1936), the minimum mass of the third body is then 0·51 $M_\odot$.

3. Other Observational Effects

It may be of interest to calculate the amplitude of the gamma velocity of the eclipsing pair corresponding to the observed light-time effect. The formula for the semi-amplitude

$$K' = 29{\cdot}785(1 - e'^2)^{-1/2}\, P'^{-1} a' \sin i'$$

(where the semi-major axis of the third-body orbit a' is in AU) yields $K' = 1{\cdot}7\ \mathrm{km\,s^{-1}}$ for both solutions. Wyse's (1936) result was $\gamma = 25 \pm 1\ \mathrm{km\,s^{-1}}$, Harper's (1937) 25·6 ± 0·8 and Rachkovskaya's (1985) 27 ± ± 2 km s^{-1}. Unfortunately, the unsuitable distribution of data in time and rather large errors make the comparison of observations with the prediction impossible.

Table 3

Third-body mass and luminosity

i'	$m_3/M_\odot$	L_3 [1])
90°	0·51	0·001
60°	0·6	0·002
30°	1·1	0·02
20°	1·7	0·11

[1]) $L_1 + L_2 + L_3 = 1$

In Tab. 3 we give mass of the third body for different inclinations of the orbit. The corresponding luminosity shown in the third column has been calculated according to the empirical formula $L \sim M^4$ (Harris III et al., 1963). Cester et al. (1978) do not mention any third light in their solution of the AR Aur light curves, so we can suppose that the third-light contribution cannot be higher than a few per cent. Therefore, the upper limit of the third-body mass seems to be about $1{\cdot}1\ M_\odot$. However, even this rather small value would be admissible only if both orbits were strongly non-coplanar.

The small mass of the third body can mean that the present third-body evolutionary phase is the contraction towards the main sequence, since the eclipsing components – both in the main sequence – should be younger than 3×10^8 years, and a star with mass close to $0{\cdot}5\ M_\odot$ may need as many as $1{\cdot}5 \times 10^8$ years to attain the main sequence. In such a case, perhaps, some matter may leave the third star and produce observable effects. Rachkovskaya (1985) mentioned an asymmetry in the Mg II and Ca II lines of both components on a plate, showing a shift towards the red. Such an asymmetry can be explained by matter falling simultaneously to both eclipsing components.

4. Spectral Characteristics of Eclipsing Components

As mentioned in the Introduction, Wolff and Preston (1978) classified AR Aur as a HgMn star. Rachkovskaya (1985) also noted the spectral peculiarity, manifested by weak (not detectable) He lines and strong lines of metals. Based on published *uvby* colour indices of both components (Johansen 1970) it is possible to show that the MgMn classification agrees with the photometry. In Figs 3, 4 and 5, the positions of the AR Aur components are marked in graphs compiled by Cameron (1966). We see that, in Fig. 3, the primary

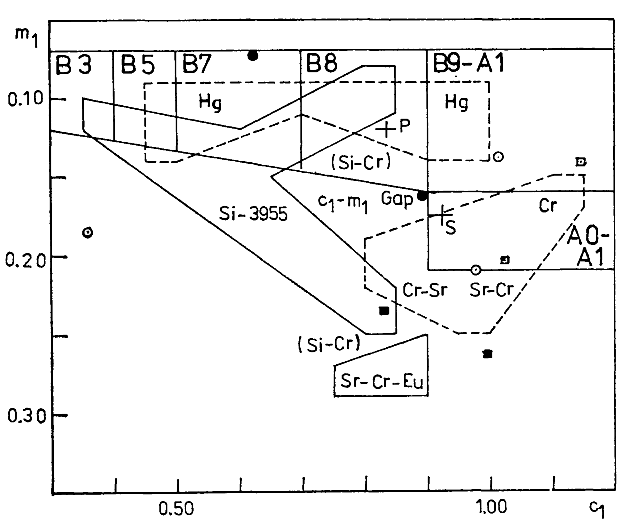

Fig. 3. Positions of the primary (P) and secondary (S) components of AR Aur in Cameron's graph for early-type peculiar stars.

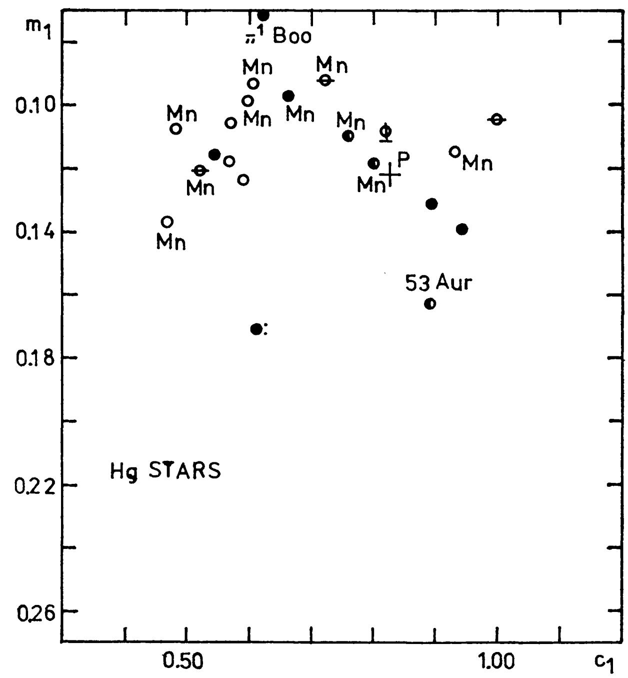

Fig. 4. The position of the primary component of AR Aur (P) has been added to Cameron's graph for Hg Mn stars.

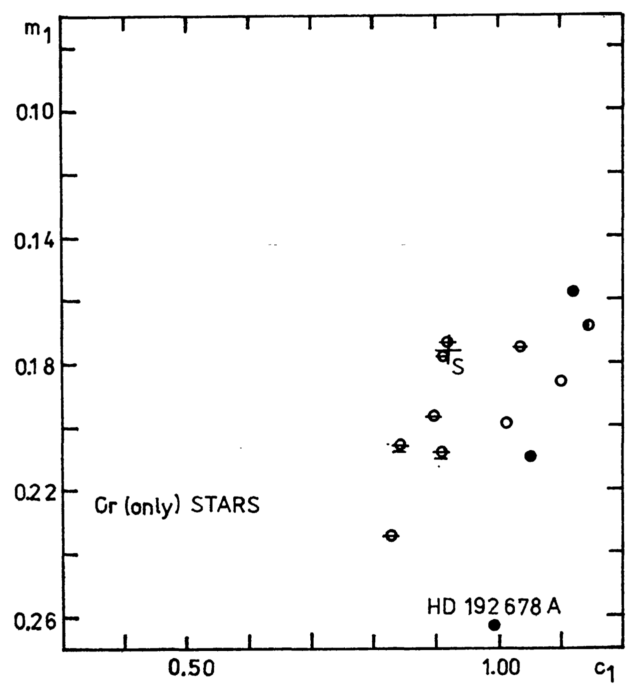

Fig. 5. The position of the secondary component of AR Aur (S) has been added to Cameron's graph for Cr stars.

component lies among B 8·5 Hg stars, the secondary among A0 Cr stars. This is in agreement with Fig. 4 (primary component among Hg stars) and Fig. 5 (secondary component among Cr stars).

Precise photometric classification is, of course, difficult since the intrinsic colours and, therefore, also the interstellar reddening are uncertain in case of a peculiar star. Nevertheless, a temperature difference about 800 K between both components follows from the *UBV* (O'Connell, 1979) as well as *uvby* indices. This difference corresponds to an 0·5 – 1·0 spectral subtype. However, the definite classification of the secondary component will have to be found by spectroscopy.

There are several unexplained effects in this system. If both eclipsing components are in the main sequence (this also follows from the colour indices), the primary minimum should be a transit, however, this has not yet been demonstrated by light-curve solutions. Also the appearance of the Hg II line 398·4 nm, as reported by Takeda et al. (1979) and Takada (1980), has not yet been explained. If this line originates in a photospheric spot, a magnetic field of the primary component should be observable. Therefore, further photometry and spectroscopy of the star are necessary.

It is of interest to note that AR Aur has a visual component, HR 1732, which was classified as A0p–Si, or Si 4200, by Bertaud and Floquet (1974), and suspected to be a physical binary with AR Aur according to Hoffleit (1964). This component is 8′ distant and, as noted by Sargent and Eggen (1965), its proper motion and radial velocity agree well with those of AR Aur. If the stars are connected gravitationally, their orbital period should be of the order of 10^7 years.

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INVESTIGATION OF THE CLOSE BINARY SYSTEM XY Cep

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ИССЛЕДОВАНИЕ ТЕСНОЙ ДВОЙНОЙ СИСТЕМЫ ХУ ЦЕФЕЯ

Приводится фотоэлектрические наблюдения и анализ тесной двойной системы ХУ Цефея. Из наблюдений были получены эпохи минимумов. Было доказано сокращение орбитального периода и представляются причины, которые могли бы этот эффект объяснить.

Photoelectric observations of the close binary system XY Cep are presented and analysed. The epochs of minimum are derived from observations. A decrease of the period has been proved and causes explaining this phenomena have been given.

Key words: stars: binaries: close

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