The third body in the eclipsing binary AV CMi: Hot Jupiter or brown dwarf?

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Abstract

New transit light curves of the third body in the system AV CMi have been obtained. The eclipsing pair's light curves were re-analysed with the W-D code and new absolute elements were derived for the two components who are found to be Main Sequence stars moving in eccentric orbits. Moreover the new light curves (together with those given by Liakos & Niarchos 2010) of the third body transiting one of the components were analysed with the Photometric Software for Transits (PhoS-T). The results from both analyses are combined with the aim to study the nature of the third component.

1. Introduction

The eclipsing binary AV CMi (P=2.277751 days, B=11.8 mag) was discovered by Hoffmeister (1968). The system was generally neglected, and the only complete light curves were obtained by Liakos & Niarchos (2010) who also presented the first photometric solution. However, the spectral type of AV CMi is still uncertain since various catalogues give very different values. Liakos & Niarchos (2010) discovered a tertiary component in the system transiting one of the components, and after two years of systematic observations they concluded that the third body has an orbital period of ~0.5192 days. The curent work presents: **a)** New modelling of AV CMi, **b)** absolute parameters and evolutionary status of the eclipsing components, **c)** new observations of the transit of the third body and **d)** analysis of the transits in order to conclude about the nature of the tertiary companion.

2. Observations

The complete light curves of the system were obtained in 2007-2008 (for details see Liakos & Niarchos 2010). The new transit observations were obtained with a 40-cm Cassegrain telescope equipped with the CCD camera ST-10XME and by using only the I-filter, in order to achieve a better time resolution and higher signal-to-noise ratio. 11 new transit light curves were obtained in the years 2009-2011 increasing the total number to 18.

3. Photometric analysis of the eclipsing binary and absolute parameters

The light curves of AV CMi were analysed with the *PHOEBE v.0.29d* software (Prša & Zwitter 2005). The same method of analysis as in the paper of Liakos & Niarchos (2010) was followed. The only difference between the present and the previous analysis, which leaded into different solutions, is the spectral type of the system. A primary's temperature of 7900 K was adopted according to the B-V index of the system (0.14-0.2) as given in many catalogues (e.g. NOMAD, NPM2, ASCC-2.5 V3). Due to the presence of the tertiary component the third light option was trialled. Moreover, the absolute parameters of the eclipsing components were derived in order to check their evolutionary status and they were used for the calculation of some of the tertiary component's characteristics (see next session). The light curve fitting and the location of the eclipsing components in the Mass-Radius diagram are shown in Figs 1 and 2, respectively, while the derived parameters are given Table 1.

Table 1. Light curve solution of AV CMi and absolute parameters of the eclipsing components

Par.	Value	Par.	Value			Par.	Value	
q	0.843 (3)	Filter	V	R	I	Component	P	S
i [deg]	83.6 (1)	x_1	0.527	0.443	0.353	M [$M_\odot$]	1.90*	1.60 (1)
e	0.11 (1)	x_2	0.522	0.444	0.357	R [$R_\odot$]	2.38 (5)	1.72 (4)
ω [deg]	17.2 (6)	L_1/L_T	0.654 (2)	0.646 (2)	0.634 (2)	T [K]	7900*	7897 (8)
Ω_1	5.73 (1)	L_2/L_T	0.341 (1)	0.337 (1)	0.331 (1)	L [$L_\odot$]	19.8 (8)	10.3 (4)
Ω_2	6.76 (1)	L_3/L_T	0.004 (2)	0.016 (2)	0.036 (3)	M_{bol} [mag]	1.5 (5)	2.2 (4)
A_1=A_2	1*					a [$R_\odot$]	5.2 (2)	6.2 (1)
g_1=g_2	1*					log g [cm/s²]	3.96 (2)	4.17 (2)

*assumed, $L_T = L_1+L_2+L_3$

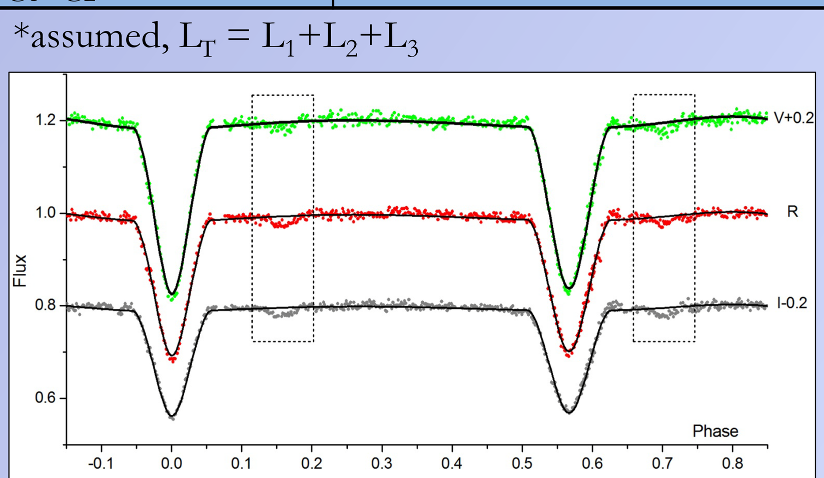


Fig. 1. Observed (symbols) and synthetic (lines) light curves of AV CMi. The dashed boxes indicate transits of the tertiary component in front of one of the components of the eclipsing pair.

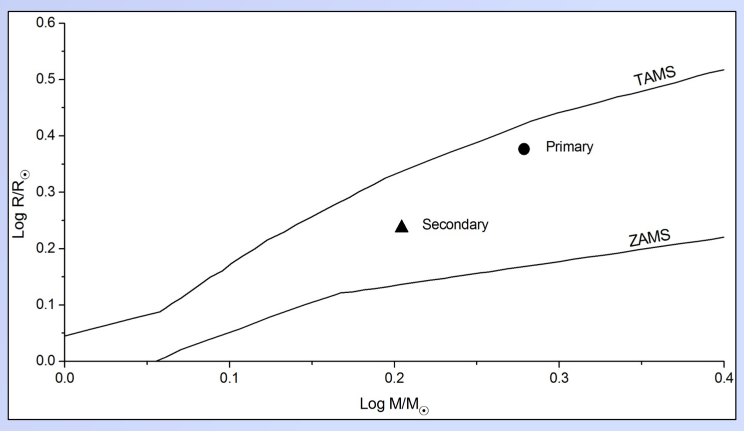


Fig. 2. The position of the components of AV CMi in the M-R diagram.

4. Analysis of transits

Five complete transit light curves were analysed with the Photometric Software for Transits (*PhoS-T*) (Mislis et al. 2011). For a first approach of the third body's parameters, the following hypotheses were considered: **Case A:** The third body orbits the primary and **Case B:** it orbits the secondary component. For each case the light contribution of the binary component around which the third body is not orbiting (secondary in case A and primary in case B) was subtracted from the total light (of the triple system) by taking into account its fractional luminosity (see Table 1) and the residual light curves were re-normalized. This caused the difference in the depths of transits as seen in Figs 4-8 for each case. The masses of the components and the period of the third body were used to find the semi-major axis of the tertiary component's orbit (assumed a circular one) for each hypothesis (a_3=0.016 AU for case A and a_3 =0.015 AU for case B). The period and the semi-major axis of the third body, the radius and the limb darkening coefficients (Claret 2004) of the "host" component were kept fixed in the programme, while the radius and the inclination of the orbit of the third body were adjusted. In Fig. 3 all the observed transits are plotted against the binary's phase, in Figs 4-8 the fitting on complete transit light curves and the corresponding 3D plot for each case are illustrated, and in Table 2 the analyses results are listed.

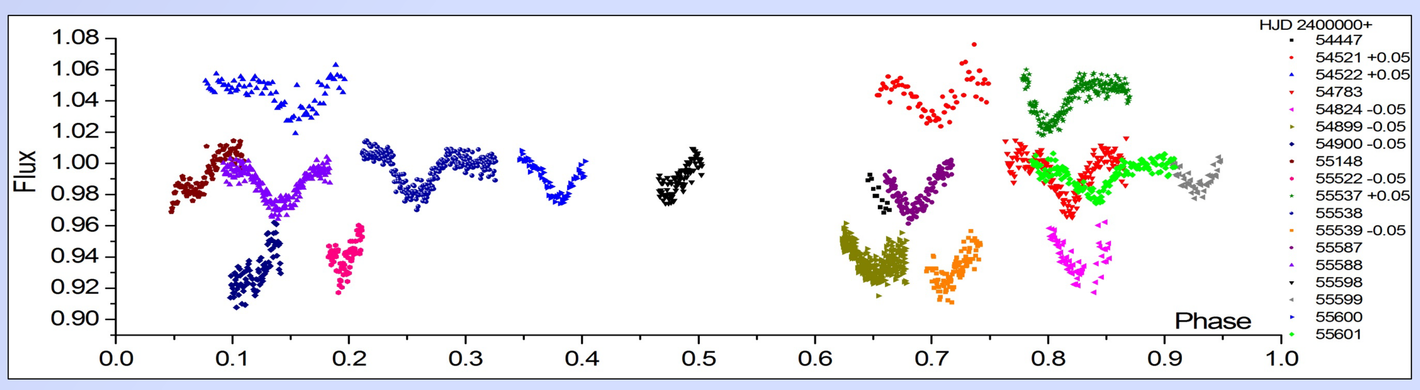
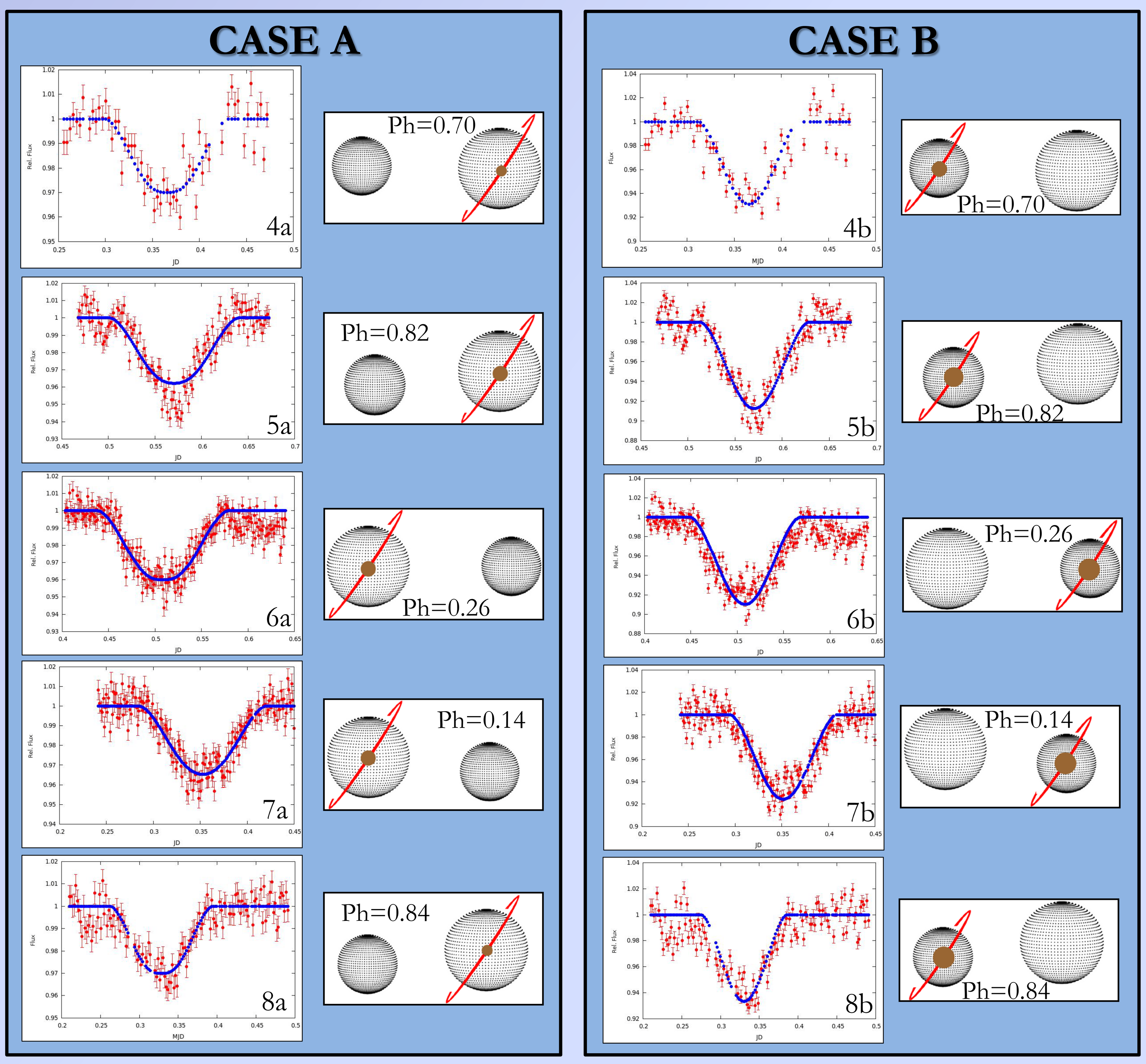


Fig. 3. Observed transits between 2008-2011.



Figs. 4-8. Fit (blue symbols) on transit data (red symbols) and corresponding 3D plot of the triple system. The third body is indicated with brown colour and its orbit with red circle for cases A and B, respectively. The phase (ph) of the eclipsing binary is also given.

Table 2. Parameters of the third body derived form transit analyses

HJD of transit	Transit in front of	R [R_{Jup}]	R [$R_\odot$]	i [deg]	χ^2	Figure
2454521	Primary component	4.1	0.4	55.5	2.14	4a
	Secondary component	5.4	0.6	61.9	9.13	4b
2454783	Primary component	4.6	0.5	56.1	2.70	5a
	Secondary component	6.1	0.6	62.3	7.36	5b
2455538	Primary component	4.7	0.5	56.8	2.14	6a
	Secondary component	6.9	0.7	60.0	9.96	6b
2455588	Primary component	4.7	0.5	53.7	1.29	7a
	Secondary component	6.9	0.7	58.1	5.52	7b
2455601	Primary component	4.1	0.4	55.6	1.32	8a
	Secondary component	6.6	0.7	57.7	6.01	8b

5. Discussion & conclusions

New light curve modelling of AV CMi and analysis of five transits of the third body in front of one of the components were obtained. The absolute parameters of the eclipsing components were calculated and showed that both components are Main-Sequence stars with almost the same temperature and eccentric orbits. Using the 18 transit observations we calculated the updated ephemeris of the transits: **$T_{transit}$ = HJD 2454899.354 (1) + 0.519215 (1)^d ×E.**

The results of transit analyses showed that both inclination and radius of the third body for each case are varying. However, the errors of the observed points are relatively large, and one should take into account that the eclipsing components are not perfect spheres due to tidal distortions, especially the primary one. Hence, this can affect both the duration and the depth of the transit. However, as a first approach to understand the third body's nature, some of its absolute characteristics were calculated. A mean value for its radius yielded as 4.4(3) R_{Jup} and 6.4(6) R_{Jup} for cases A and B, respectively. However, the χ^2 value of case B was found to be systematically greater than that of case A, indicating that the solution of case A is more realistic.

The present results, although they offer a first step for the investigation of the third component in AV CMi, cannot provide a final conclusion about its nature. The "Hot Jupiter" scenario seems to fail due to the big value of the radius. On the other hand, the "Brown dwarf" hypothesis is probably the solution for the nature of the tertiary companion, although again the resulted radius is not very consistent with the typical ones (~R_{Jup}). Moreover, the light curve analysis of AV CMi showed that a third light contribution of ~2% maybe exists. This value is impossible for planets but not for low-luminosity stars.

High accuracy spectral observations are certainly needed for: (a) spectral classification of the eclipsing components, (b) radial velocity measurements of the components for the derivation of the spectroscopic mass ratio, and (c) determination of the third body's orbit and shedding some light on its nature.

6. Acknowledgements

This work has been financially supported by the Special Account for Research Grants No 70/4/9709 of the National & Kapodistrian University of Athens, Hellas.

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