The new photometric study of a possible three-body system AV CMi

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Abstract

We present new results from photometric study of an eclipsing object AV CMi. Liakos & Niarchos (2010) obtained preliminary parameters of the system from photometric measurements and discovered possible low-mass third body which they placed on an unusual inner orbit around one of the main stars. We confirmed depressions in the light curve and analysed observable changes in the whole light curve. The third body system explanation was tested but new alternative – blend of two eclipsing binaries with period 1.03843 d is more realistic. Astrometric measurements of position of centroid unfortunately bring any information about their angular separation.

1 Introduction

AV CMi = 2MASS J07091084+1211190, an eclipsing system of Algol type, was discovered by Hoffmeister (1968). Subsequently Gessner (1973) determined provisional light curve elements (variation between 11.8-12.1 mag (*pg*) and orbital period which is half of real one). This wrong period was adopted by Svechnikov & Kuznetsova (1990) to find the system absolute parameters from statistic dependencies between binary stars and their photometric light curves, e.g. incorrect spectral types (F0)+[G5IV].

The system was for a long time practically neglected. First detailed analysis of photometric changes was made by Liakos & Niarchos (2010) and their results were updated Liakos, Mislis & Niarchos (2011). They obtained complete phase light curves in Bessel bands V, R, I and modeled them by a code PHOEBE 0.29d (Prša & Zwitter 2005). Liakos & Niarchos (2010) used for modelling incorrect value of surface temperature of primary star ($T_1 = 7\,000\,\mathrm{K}$) estimated from Svechnikov & Kuznetsova (1990) and results from Liakos, Mislis & Niarchos (2011) based on B-V index ($T_1 = 7\,900\,\mathrm{K}$, $T_2 = 7\,897\,\mathrm{K}$) are more believable for this reason. On the other hand, Liakos, Mislis & Niarchos (2011) determined absolute parameters of the system without spectroscopic measurements and without any additional information about their process and therefore their results should be adopted with circumspection too.

The eclipsing system consists of two detached components orbiting with period $P = 2.277751$ day in eccentric orbit with $e = 0.11(1)$ (Liakos & Niarchos 2010) and it has an apsidal motion with period ~ 200 years (Liška et al. 2012). Liakos & Niarchos (2010) discovered unexpected small dips in the light curve (amplitude $\sim 2.6\,\%$ in the whole flux with duration $\sim 3.3\,\mathrm{h}$) projected on the main changes. They called them transits of a third body and found its orbital period (actual value $P_3 = 0.519215(1)$ Liakos, Mislis & Niarchos 2011). The third body in a accordance with size of periods $P_3 < P$ has to rotate around one of the stars. There is difficult to decide which star is the third body's host star because both stars have similar temperatures and radii (depths of primary and secondary eclipses are practically same).

Liakos, Mislis & Niarchos 2011 tried to identified host star by modelling shapes of transits. They set the third body on a path around the first component (case A) and around the secondary component (case B). After subtraction flux of the no-host component from the total flux the same measurements by program PhoS-T were analysed (Mislis et al. 2011). Their results are inconclusive due to low amplitude and variation of transits' shapes and mainly due to similar temperatures of main components. Nevertheless they determined radius of the third body $(4.1 - 4.7)\,\mathrm{R}_{Jup}$ in case A and $(5.4 - 6.9)\,\mathrm{R}_{Jup}$ in case B and also found low values of inclination $(53 - 62)^\circ$. Disputed point is distance of the third body from host star $a = 0.016\,\mathrm{AU} = 3.42\,\mathrm{R}_\odot$ (case A, radius $R_1 = 2.38\,\mathrm{R}_\odot$) and $a = 0.015\,\mathrm{AU} = 3.21\,\mathrm{R}_\odot$ (case B, radius $R_2 = 1.72\,\mathrm{R}_\odot$) because surfaces of host star and third body are separated no more than $0.64\,\mathrm{R}_\odot$ (case A) and $0.89\,\mathrm{R}_\odot$ (case B).

2 Observations

Our CCD photometric measurements in bands – B,V,R,I were obtained on different observations sides but most of them was observed in Masaryk University Observatory in Brno (MUO) by 62cm Newtonian reflector with CCD ST-8 Sbig. All reduction steps and differential aperture photometry were done by software C-Munipack ver. 1.1.28 (Motl 2009) based on DAOPHOT (Stetson 1987). CCD frames were standard calibrated (appropriate darks frames, flat fields). AV CMi was compared with stars GSC 770-929 (comparison star) and GSC 770-911 (check star) that were chosen as stars with good ratio S/N and with similar color for suppression influence of extinction. A lot of observations were systematic oriented for orbital phase binary around primary or secondary mid-eclipses and simultaneous phase of transit close to mid-transits. This set-up was planned to capture of situation when transit would not come or would be deformed due to hiding by covering no-host star.

3 Light curve analysis

We verified existence of the transit effect in the light curve and tried to determine host star in a situation when transit and eclipse take the same place, but without success (Liška et al. 2012). Our contemporary aim is testing of two possibilities – binary with third body orbiting one of the main components (case 1A, 1B) same as (Liakos, Mislis & Niarchos 2011) and two eclipsing pairs blended in one object on the sky (case 2). Both of cases are still unusual between known eclipsing systems and for this reason two procedures were written. Main ideas were adopted from Cagaš & Pejcha (2012) and Lehmann et al. (2012).

3.1 Case 1A, 1B – three body system

Variation of the total brightness m in time t_i for case 1A respective 1B is modelled as a sum of individual fluxes (F_1, F_2, F_3) for all of three components. Their properties and orbital movement were described by parameters included in vector $\mathbf{a}$. The third body (low mass) is placed in an circular orbit with a center in the host star – primary component (case 1A) respective in secondary one (case 1B). Covering of both stars by third body is allowed in this algorithm. All of the bodies are computed as projection circular sphere on 2D circles and have not equipotential surface but linear limb darkening is included. This approximation should be sufficient for our purpose.

Finding correct parameters for the models is a necessary part of calculations. We used gradient-development algorithm (Marquardt 1963, Djuraševič 1992) based on nonlinear least-square method for minimization process and Monte Carlo method for generation a lot of possible input parameters. After that we chose the median parameters (the most probable value) as the best result.

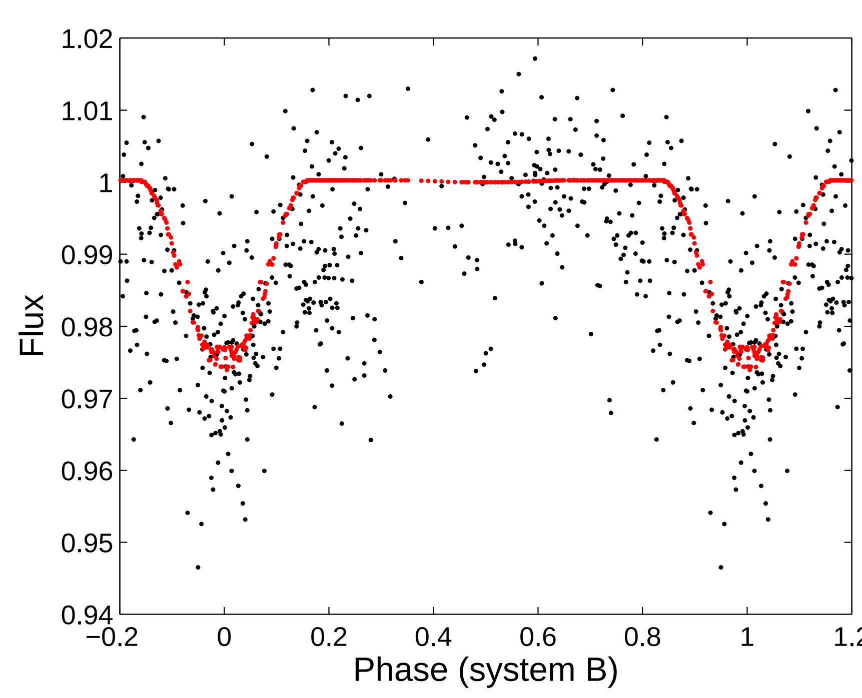

FIGURE 1: The separate phase light curve of transit – observation in R-band (black dots) and model for case 1A (red dot)

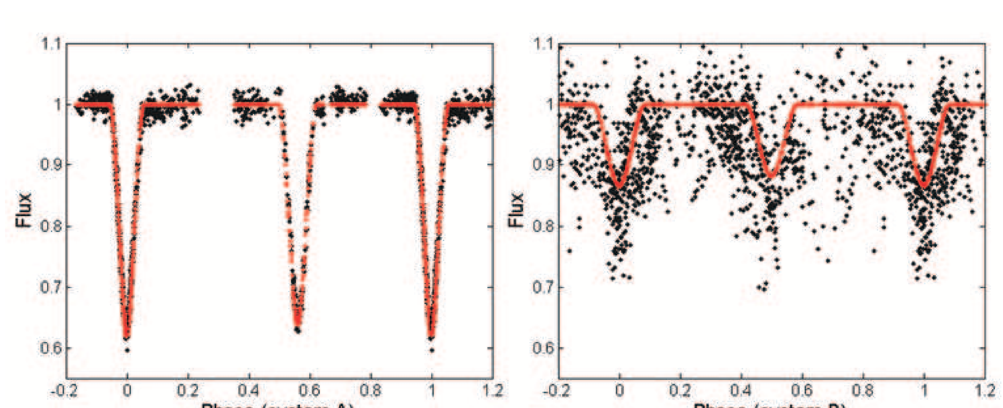

FIGURE 2: The separate phase light curves for system A (left) and system B (right) - observed curves (black dots) and modeled as a case 2 (red dot) with value $\beta = 0.1$

3.2 Case 2 – two eclipsing binary systems

Total brightness in case 2 can be calculated similarly, an independence of both eclipsing systems is expected (any mutual orbit and eclipses). Total brightness is dependent on a sum of fluxes for system A an B (F_A, F_B). Vectors $\mathbf{a}_A$, $\mathbf{a}_B$, contain parameters described individual objects and their orbits in each system. There was included parameter β in the model which marked ratio of fluxes between system A and B (Cagaš & Pejcha 2012).

4 Discussions and conclusions

We introduced two possible explanations of observed variations in the light curve – a mutual eclipsing triple system or two eclipsing pairs and we presented results of our modelling. First of them includes presence of the low-mass third body – exoplanet or brown dwarf (Liakos & Niarchos 2010, Liakos, Mislis & Niarchos 2011). The third component is placed in a inner orbit around primary or secondary star (due to low value of period $P_3 \sim 0.52\,\mathrm{d}$) and object has to orbit regularly between both of the main stars. This orbital path looks unusual and can be strongly unstable. We suppose that tides force caused by host star plays large role. When we adopted results from Liakos, Mislis & Niarchos 2011 ($M_1 = 1.9\,\mathrm{M}_\odot$, $a_3 = 0.016\,\mathrm{AU}$, $M_2 = 1.6\,\mathrm{M}_\odot$, $a_3 = 0.015\,\mathrm{AU}$) then Lagrange point L1 for system star 1-third body (case 1A) or star 2-third body (case 1B) lies under the surface of the third body (for exoplanet) or just above (brown dwarf). A high amplitude of transit, which is more than most of a known transiting exoplanets, is other problematic point. Only three transiting exoplanets cause amplitude of transit more than 0.03 mag (WASP-10 0.039 mag, Quatar-2 0.037 mag, CoRoT-2 0.032 mag). Furthermore observed amplitude of transit in AV CMi is lower than amplitude which would be observed in the system with isolated star and exoplanet. When we take into account brown dwarf as a creator of transits then we expect observable eclipse of brown dwarf by host star. For these reasons we adopt this explanation as less realistic than second one.

Idea of two eclipsing systems (A and B) (the same situation as e.g. V994 Her (Lee et al. 2008), CzeV343 (Cagaš & Pejcha 2012)) brings more realistic explanation. Depressions in the light curve are better described by eclipsing system because their shapes are too pointed in "mid-transits". We also noted that amplitudes of dips in the light curve are different between primary and secondary minimum of the system B and we used and modified ephemeris for system B from Liakos, Mislis & Niarchos (2011) T_{min} = HJD 2454899.873 + 1.03843 d × E. The different amplitude of primary and secondary eclipses of the system B is visible also in measurements of Liakos, Mislis & Niarchos 2011. Independent eclipses of the binary B also explained why is it possible observed "transit" in primary and also in secondary eclipses (Liška et al. 2012) and dependence amplitude of "transit" to a wavelength.

Explanation by two binary pairs does not require strictly gravitational boundary of both systems. The two eclipsing systems could be projected on the same position in the sky. This alternative was tested by astrometric measurements of the AV CMi and awaited shift in the position of the centroid on the frames during main eclipses was not observed (Liška et al. 2012). We supply that used main instrument has quite short focal length ($f = 2.8\,\mathrm{m}$) and chance for detection was low, angular resolution 0.7"/pixel and observed variation around central position was 0.1 pixel. Nevertheless a new photometric and especially spectroscopic observations are necessary.

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