COMMISSIONS G1 AND G4 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Volume 63 Number 6227 DOI: 10.22444/IBVS.6227

Konkoly Observatory
Budapest
11 December 2017

HU ISSN 0374 – 0676

NEW LIGHT-TIME CURVE OF ECLIPSING BINARY AM Leo

GORDA, S. YU.[1]; MATVEEVA, E. A.[2]

[1] Kourovka Astronomical Observatory of the Ural Federal University; e-mail: stanislav.gorda@urfu.ru

[2] Ural Federal University, 51, Lenin av., Ekaterinburg, Russia, 620000

The eclipsing variable star AM Leo (BD +10°2234 A) is a bright component ($V = 9.1$–9.7 mag) of the visual binary system ADS 8024 ($\rho = 11''.4$, $\theta = 270°$)(Hiller et al. 2004). The most comprehensive survey of the photometric observations of AM Leo were given in the studies of Hiller et al. (2004) and Albayrak et al. (2005a). Many authors noted temporal variations in the light curve of AM Leo. Along with the light curve variations, orbital variations have been observed too. Various hypotheses were proposed to explain this phenomenon. The most likely reason for the period change in AM Leo is now considered to be the presence of a third body in the system. This hypothesis was first suggested by Demircan & Derman (1992). Later Albayrak et al. (2005a) and Qian et al. (2005) have determined the parameters of the light-time curve based on the analysis of the moments of minima from data obtained using photomultiplier and CCD detectors only.

Albayrak et al. (2005a) obtained the mutual orbital period of AM Leo and the third body by the very eccentric orbit to be about 45 years, they also estimated the mass of the third body to be $M_3 = 0.18 M_\odot$. These results have been obtained on the basis of the data collected from $JD_\odot = 2435570$ to $JD_\odot = 2453106$. In the paper of Qian et al. (2005) the values of the period 51.8 years and $M_3 = 0.20 M_\odot$ were listed. But these values were obtained with less data compared to the paper of Albayrak et al. (2005a).

Since this research a number of new values of the moments of minima of AM Leo have been received. In the paper of Albayrak et al. (2005a) the moments of minima were used which have been distributed on an interval of time, corresponding only to ~ 1.1 of the 45-year period. Now this interval comprises ~ 1.4 times of the period, and the moments of minima are distributed regularly enough throughout. Differences O–C calculated with the new moments of minima, already do not correspond to the light-time curve received by Albayrak et al. (2005a). Thus, now it is the time to define again the parameters of a light-time curve of AM Leo.

We have obtained 72 photoelectric and CCD moments of minima of the eclipsing binary AM Leo generally between 1996–2017 at Kourovka Astronomical Observatory of the Ural Federal University in Russia, which have not been published earlier. Data were obtained by one of the authors with a reflector telescope ($D = 0.45$ m), equipped with a photoelectric photometer, placed in the Cassegrainian focus ($F = 11.0$ m), and by a CCD-camera, placed in the Newtonian focus ($F = 2.0$ m).

The CCD observations data were reduced using the $MaxImDL$ and *Muniwin* (http://c-munipack.sourceforge.net) packages. The minima time were computed by a parabola fitting method and averaged from all filters used during the night. Values of the moments of minima of AM Leo, obtained from our observations, are listed in Table 1. Abbreviation in the column named “Rem.” corresponds to the detector used for observations:

- PE — scanning photoelectric photometer (it is not used now);
- CCD1 — CCD camera Apogee Alta-U6 (Kodak KAF-1001E, 1048×1048, 24-micron chip);
- CCD2 — CCD camera FLI PL230 (e2v CCD230-42-1-143, 2048×2048, 15-micron chip).

Additional seven moments of minima obtained by one of the authors in 2015 have been published by Gorda (2016).

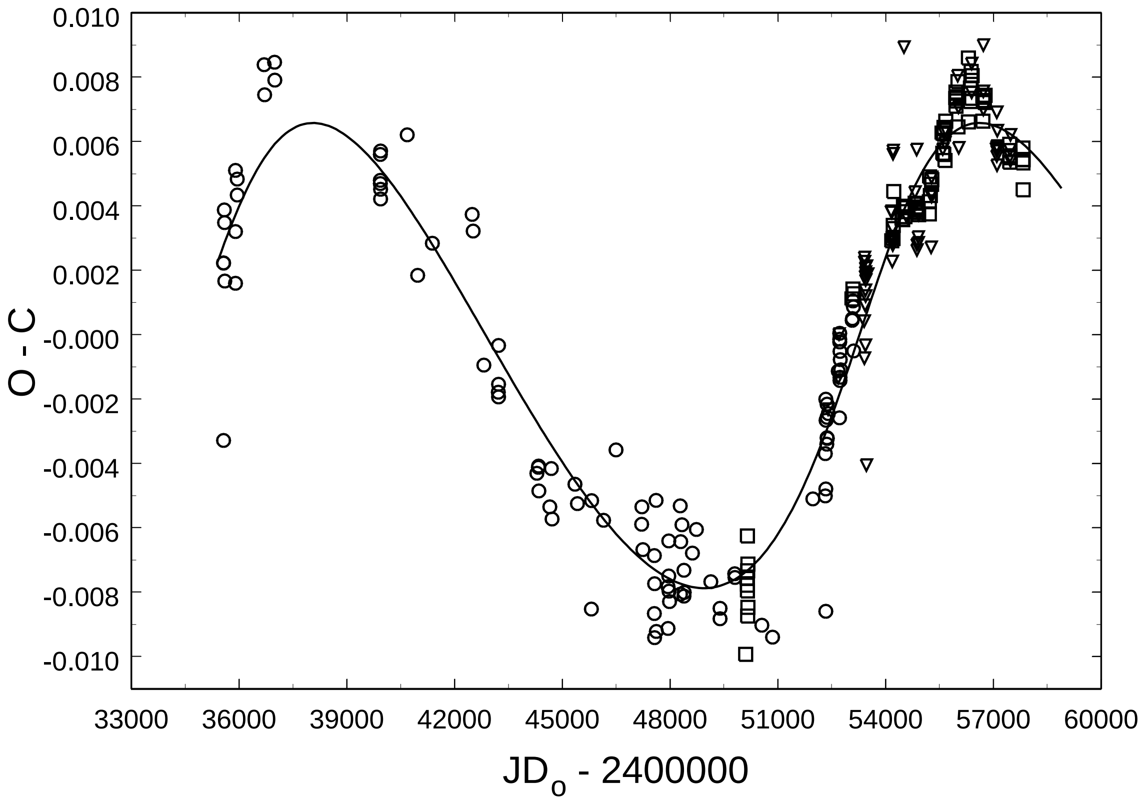

Figure 1. The light-time curve of the variable star AM Leo (solid line); open circles denote values of the O–C calculated from the times of minima from Albayrak et al. (2005a); open triangles represent ones from IBVS (see page 3); open squares denote O–C calculated from our data (see Table 1).

For calculating the O–C differences and the parameters of the light-time curve we used our data (see Table 1), data from the paper of Albayrak et al. (2005a), and also the moments of minima published in *IBVS* from 2002 to 2017 (Pribulla et al. 2002, Gürol et al. 2003, Dvorak 2004, Hübscher 2005, Albayrak et al. 2005b, Hübscher et al. 2005, Kotková & Wolf 2006, Şenavci et al. 2007, Kiliçoğlu et al. 2007,Hübscher 2007, Ogłoza et al. 2007, Hübscher et al. 2008, Nelson 2009, Diethelm 2009, Parimucha 2009, Hübscher et al. 2010, Diethelm 2010, Hübscher & Monninger 2011, Diethelm 2011, Hübscher et al. 2012, Diethelm 2012, Parimucha 2013, Hübscher et al. 2013, Nelson 2013, Hübscher 2013, Zasche 2014, Hübscher & Lehmann 2015, Hübscher 2016a, Hübscher 2016b, Zasche et al. 2017).

Values of parameters of the light-time curve were obtained by a fitting method described by Gorda et al. (2007). Our fit is plotted in Fig. 1 along with the observed values. The parameters of light-time curves obtained by Qian et al. (2005), Albayrak et al. (2005a) and obtained by us are given in Table 2. Designations in the first column of Table 2 correspond to following parameters: N is the total number of the moments of minima under consideration, $\sum(O - C_{LTC})^2$ is the value of the minimum sum of the squares of the residuals of O–C differences from the light-time curve, $JD_{\odot}I_{min}$ and P_{orb} are reference epochs for the primary minimum and the true period of the AM Leo respectively, $a \sin i$, e, w, T_0 and P_{12} are the semi-major axis, inclination, eccentricity, longitude and epoch of the periastron passage and the period of the orbit of the eclipsing pair around the mass center of the AM Leo system with the third body, respectively. A is the semi-amplitude of the light-time curve and $f(m_3)$ is the mass function of the third body.

As it can be seen, the new values of only three parameters of the AM Leo orbit with the third body, namely e, T_0 and P_{12} differ considerably from the ones received by Albayrak et al. (2005a). Our values can be considered as more reliable at the present time because they were obtained by the use of more data, compared to the paper of Albayrak et al. (2005a) and because our moments of minima are distributed on the time interval exceeding the value of P_{12} nearly one and a half times.

The obtained values of $P_{12} = 50.5 \pm 0.5$ and $a \sin i = 1.30 \pm 0.05$ lead to a very small mass function of $f(m_3) = 0.00086 \pm 0.00023 M_{\odot}$ for the third body. The mass of the third body was computed for different values of the orbital inclination of the third body orbit and the derived values are given in Table 3. In this computation, the masses of the components of the eclipsing pair $M_1 = 1.23 M_{\odot}$, $M_2 = 0.54 M_{\odot}$ (Gorda 2016) were applied.

Below we list the light elements that can be used to compute the period of AM Leo for the nearest epoch of observation. We have determined them by analyzing the moments of minima for the last 5 years. These data can be approximated quite accurately by the following parabolic dependence:

$$\begin{array}{lcccccc} JD_{\odot\, min\, I} & = & 2452397.34402 & + & 0.36580143 \cdot E & - & 1.76 \cdot 10^{-10} \cdot E^2. \\ & & \pm 30 & & \pm 44 & & \pm 32 \end{array}$$

We derive from that the following light elements suitable for computing the times of minima of AM Leo at present time:

$$JD_{\odot\, min\, I} = 24577835.30926 + 0.36579882 \cdot E.$$

Acknowledgements: This work was supported in part by the Ministry of Education and Science (the basic part of the State assignment, RK no. AAAA-A17-117030310283-7) and by the Act no. 211 of the Government of the Russian Federation, agreement 02.A03.21.0006.

References:

Albayrak, B., Selam, S. O., Ak, T., Elmasli, A., Özavci İ. 2005a, *AN*, **326**, 122 DOI
Albayrak, B., Yüce, K., Selam, S. O., et al., 2005b, *IBVS*, **5649**
Demircan, O. , Derman E. 1992, *AJ*, **103**, 593 DOI
Diethelm, R. 2009, *IBVS*, **5894**

Diethelm, R. 2010, *IBVS*, **5945**
Diethelm, R. 2011, *IBVS*, **5992**
Diethelm, R. 2012, *IBVS*, **6029**
Dvorak, S.W. 2004, *IBVS*, **5502**
Gorda, S. Yu., Balega, Yu. Yu., Pluzhnik E. A., Shkhagosheva Z. U. 2007, *AstBu*, **62**, 352 DOI
Gorda, S. Yu. 2016, *AstBu.*, **71**, 64 DOI
Gürol, B., Gürdemir, L., Çaglar, A., Kirca, M., Akçay, U., Tunç, A., Elmas, T. 2003, *IBVS*, **5443**
Hiller, M. E., Osborn, W., Terrell, D., 2004, *PASP*, **116**, 337 DOI
Hübscher, J. 2005, *IBVS*, **5643**
Hübscher, J., Paschke, A., Walter, F, 2005, *IBVS*, **5657**
Hübscher, J. 2007, *IBVS*, **5802**
Hübscher, J., Steinbach, Hans-Mereyntje, Walter, F. 2009, *IBVS*, **5874**
Hübscher, J., Lehmann, P. B., Monninger, G., Steinbach, Hans-Mereyntje, Walter, F. 2010, *IBVS*, **5918**
Hübscher, J., Monninger, G. 2011, *IBVS*, **5959**
Hübscher, J., Lehmann, P. B., Walter, F. 2012, *IBVS*, **6010** e Hübscher, J., Braune, W., Lehmann, P. B. 2013, *IBVS*, **6048**
Hübscher, J. 2013, *IBVS*, **6084**
Hübscher, J., Lehmann, P. B. 2015, *IBVS*, **6149**
Hübscher, J. 2016a, *IBVS*, **6156**
Hübscher, J. 2016b, *IBVS*, **6196**
Kiliçoğlu, T., Baştürk, Ö., Şenavci, H., et al., 2007, *IBVS*, **5801**
Kotková, L., Wolf, M. 2006, *IBVS*, **5676**
Nelson, R. H. 2009, *IBVS*, **5875**
Nelson, R. H. 2013, *IBVS*, **6050**
Ogłoza, W., Niewiadomski, W., Barnacka, A., Biskup, M., Małek, K., Sokołowski, M. 2008, *IBVS*, **5843**
Parimucha, Š., Dubovský, P., Baluďanský, D., Pribulla, T., Hambálek, Ľ., Vaňko, M., Ogloza, W. 2009, *IBVS*, **5898**
Parimucha, Š., Dubovský, P., Vaňko, M. 2013, *IBVS*, **6044**
Pribulla, T., Vaňko, M., Parimucha, Š., Chochol, D. 2002, *IBVS*, **5341**
Qian, Sh-B., He, J., Xiang, F., Ding, X., Boonrucksar, S. 2005, *AJ*, **129**, 1686 DOI
Şenavci, H.V., Tanriverdi, T., Törün, et al., 2007, *IBVS*, **5754**
Zasche, P., Uhlař, R., Kučáková, H., Svoboda, P., Mašek, M. 2014, *IBVS*, **6114**
Zasche, P., Uhlař, R., Svoboda, P., Kučáková, H., Mašek, M., Juryšek, J. 2017, *IBVS*, **6204**

Table 1: Moments of minima of AM Leo.

Time of min. HJD 2400000+	Error	Type	Filter	Rem.	Time of min. HJD 2400000+	Error	Type	Filter	Rem.
50106.54068	0.00061	II	BV	PE	55594.43435	0.00031	I	BVR	CCD1
50142.39120	0.00205	II	BV	PE	55617.48019	0.00005	I	BVR	CCD1
50156.29112	0.00041	II	BV	PE	55623.33233	0.00084	I	BVR	CCD1
50156.47572	0.00061	I	BV	PE	55625.34501	0.00033	II	BVR	CCD1
50157.38869	0.00054	II	BV	PE	55630.46622	0.00040	II	BVR	CCD1
50159.21672	0.00085	II	BV	PE	55659.36320	0.00114	II	BVR	CCD1
50159.40102	0.00050	I	BV	PE	55679.30038	0.00026	I	BVR	CCD1
50168.36193	0.00025	II	BV	PE	55953.46636	0.00011	II	BVR	CCD1
50169.27776	0.00015	I	BV	PE	55958.40439	0.00029	I	BVR	CCD1
53066.40291	0.00052	I	BV	PE	55960.41672	0.00017	II	BVR	CCD1
53090.36297	0.00013	II	BV	PE	55973.40238	0.00014	I	BVR	CCD1
53123.28460	0.00075	II	BV	PE	55978.34052	0.00041	II	BVR	CCD1
54172.39374	0.00010	II	BVR	CCD1	56016.20116	0.00025	I	BVR	CCD1
54208.24196	0.00011	II	BVR	CCD1	56016.38267	0.00038	II	BVR	CCD1
54214.27804	0.00021	I	BVR	CCD1	56309.38667	0.00037	II	BVR	CCD1
54459.54551	0.00016	II	BVR	CCD1	56309.57155	0.00010	I	BVR	CCD1
54475.45769	0.00021	I	BVR	CCD1	56365.35475	0.00035	II	BVR	CCD1
54497.40597	0.00012	I	BVR	CCD1	56366.26882	0.00012	I	BVR	CCD1
54537.46047	0.00005	II	BVR	CCD1	56385.29096	0.00026	I	BVR	CCD1
54552.27559	0.00043	I	BVR	CCD1	56386.38863	0.00093	I	BVR	CCD1
54571.29691	0.00025	I	BVR	CCD1	56400.28810	0.00008	I	BVR	CCD1
54578.24718	0.00033	I	BVR	CCD1	56412.36013	0.00015	I	BVR	CCD1
54586.29474	0.00027	I	BVR	CCD1	56710.30083	0.00005	II	BVR	CCD1
54825.52650	0.00015	I	BVR	CCD1	56710.48448	0.00030	I	BVR	CCD1
54882.40781	0.00027	II	BVR	CCD1	56770.29242	0.00032	II	BVR	CCD1
54887.52890	0.00031	II	BVR	CCD1	56742.30875	0.00016	I	BVR	CCD1
54888.44357	0.00011	I	BVR	CCD1	56751.27073	0.00046	II	BVR	CCD1
54909.29397	0.00041	I	BVR	CCD1	57458.35613	0.00020	II	BVR	CCD2
54923.19396	0.00026	I	BVR	CCD1	57459.27007	0.00009	I	BVR	CCD2
55217.47827	0.00013	II	BVR	CCD1	57463.29403	0.00008	I	BVR	CCD2
55218.57605	0.00023	II	BVR	CCD1	57463.47687	0.00018	II	BVR	CCD2
55223.51509	0.00016	I	BVR	CCD1	57822.32412	0.00014	II	BVR	CCD2
55246.37686	0.00021	II	BVR	CCD1	57827.26249	0.00008	I	BVR	CCD2
55281.31090	0.00013	II	BVR	CCD1	57828.36025	0.00015	I	BVR	CCD2
55288.26110	0.00034	II	BVR	CCD1	57829.27344	0.00010	II	BVR	CCD2
55570.47523	0.00105	II	BVR	CCD1	57835.31003	0.00015	I	BVR	CCD2

Table 2: Parameters of the light-time curve.

	Qian et al., 2005		Albayrak et al., 2005a		This paper	
Parameter	Value	Error	Value	Error	Value	Error
N	74		103		243	
$\sum(O-C_{LTC})^2$	0.00016		0.00020		0.00045	
$JD_{\odot\,min\,I}$	2439936.8260		2452397.35411	0.00006	2452397.35801	0.00009
P_{orb} (day)	0.36579770		0.365797425	0.000000007	0.365797590	0.000000008
$a\sin i$ (AU)	1.69	0.10	1.36	0.10	1.30	0.05
e	0.58	0.07	0.73	0.04	0.28	0.03
ω (°)	54.0	16.6	22.0	3.0	20.6	2.8
T_0 (HJD)	2436021	859	2436346	70	2435320	50
P_{12} (year)	51.4		44.82	0.34	50.5	0.5
A (day)	0.0097	0.0006	0.0058	0.0003	0.0072	0.0008
$f(m_3)$ ($M_\odot$)	0.00182	0.00033	0.00125	0.00028	0.00086	0.00023

Table 3: Mass and semi-major axis of the third body orbit depending on the orbital inclination.

$i(°)$	$m_3(M_\odot)$	a_3(AU)
10.0	1.12 ± 0.13	12.0 ± 1.1
20.0	0.48 ± 0.04	14.2 ± 1.2
30.0	0.31 ± 0.03	15.0 ± 1.3
40.0	0.24 ± 0.03	15.3 ± 1.4
50.0	0.20 ± 0.02	15.5 ± 1.5
60.0	0.17 ± 0.02	15.6 ± 1.5
70.0	0.16 ± 0.01	15.7 ± 1.5
80.0	0.15 ± 0.01	15.8 ± 1.6
90.0	0.15 ± 0.01	15.8 ± 1.5