PHOTOMETRIC STUDY OF MM CAS

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Abstract. The U, B, and V photometric observations of the eclipsing binary MM Cas have been presented and discussed. The photometric elements have been derived. By use of the colour indices $U - B$ and $B - V$, the spectral types of the systemic components are estimated. An examination of all available times of minimum light of MM Cas does not reveal any change in its orbital period.

1. Introduction

The photographic light curve of the eclipsing binary MM Cas has been given by Perova (1958). Lichtenknecker (1981) observed the star photovisually and derived a time of primary minimum light. There has been no radial velocity study done. We selected MM Cas for three-colour photoelectric photometry in 1980 because neither photoelectric light curve nor photoelectric times of minimuml light of it had ever been published to date to our knowledge.

Furthermore, the steep slope and a relatively large duration of totality ($A = 0^{\mathrm{m}}.6$, $D = 5^{\mathrm{h}}.0$, and $d = 2^{\mathrm{h}}.2$) of the primary eclipse, as can be seen in the photographic light curve, given by Perova (1958), made MM Cas an interesting eclipsing binary system for carrying out photoelectric photometry. It has already been reported that the hotter component of MM Cas may be an intrinsic variable (Chaubey, 1983). The aim of this paper is to present our UBV observations, solve the light curves and to discuss some further findings on the system.

2. Observations

During October 1980 to September 1982, a three-colour photometry of MM Cas was carried out with a 104-cm telescope of Uttar Pradesh State Observatory on 13 nights. The telescope was equipped with an EMI 6094S photomultiplier, thermo-electrically cooled to − 20 °C, and UBV filters of Johnson and Morgan. The comparison star used as an anonymous nearby star ($\alpha_{1980} = 0^{\mathrm{h}}53^{\mathrm{m}}.6$ and $\delta_{1980} = +54°20'.6$). Figure 1 is a finding chart showing the location of both MM Cas and that of the comparison star.

The variable star was observed alternately with the comparison star, generally two observations of the variable star were made between two observations of the comparison star. After correcting for atmospheric extinction, all the observations were transformed to the standard UBV system. The differential magnitudes ΔU, ΔB, and ΔV in the sense variable minus comparison against phase are displayed in Figure 2, wherein the phases have been comptued with the ephemeris

$$M(E)\ \text{J.D. (Hel.)} = 2\,444\,544.154 + 1^{\mathrm{d}}.1584705E\,. \tag{1}$$

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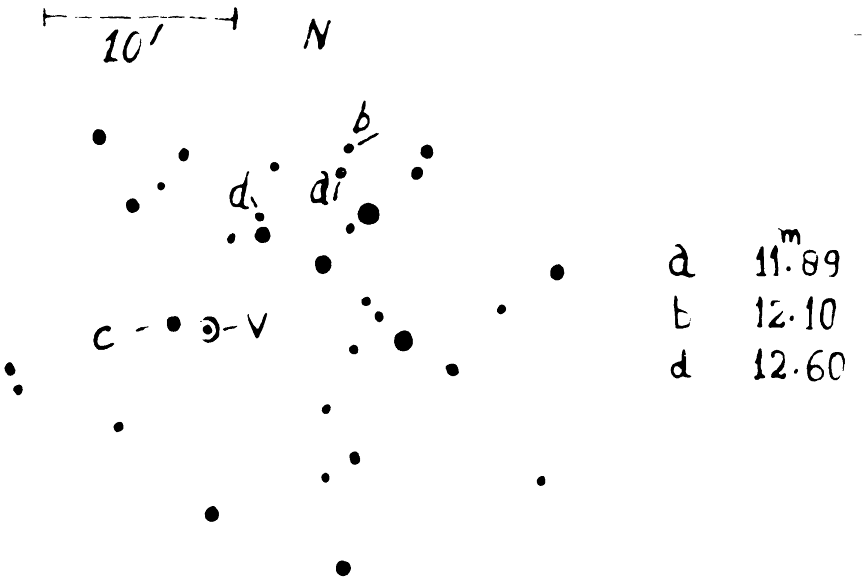

Fig. 1. Finding chart of MM Cas and the comparison star.

In the above, the epoch is the time of primary minimum light observed by us and period is also determined by us.

3. Light Curves and Rectification

Figure 2 shows the presence of brightness fluctuations. These brightness fluctuations seem to be enhanced during the secondary minimum and disappear during the central phase of primary minimum. This behaviour may be due to an intrinsic variability of the hotter component which is totally eclipsed during the primary minimum. The fragments of the light curve between the orbital phases from $0^P.15$ to $0^P.35$ and from $0^P.65$ to $0^P.85$ of MM Cas in the V filter are given, respectively, in Figures 3(a) and 3(b). Because of scatter and paucity of observations on the secondary minimum, we feel no reliable statement can be made concerning the displacement of secondary. However, an examination of the points from a single well-observed night from $0^P.33$ to $0^P.54$, we note the secondary minimum light at phase $0^P.51$.

The brightness fluctuations in MM Cas (Figures 3(a) and 3(b)) are quite analogous to those found in AB Cas, in which Tempesti (1971) has noted that the hotter component is a δ Scuti variable. He found an amplitude of $0^m.05$ and we estimate $0^m.08$; he found a period of $0^d.06$ we estimate $0^d.15$. It is worth noting, however, that both, the A3 component in AB Cas and Fe component in MM Cas, lie slightly outside the A5–F2 spectral type range in which the δ Scuti variables usually occur.

After applying the corrections for the intrinsic variability of the primary component, the light I outside the eclipses was expressed as the truncated Fourier series

$$I = A_0 + A_1 \cos\theta + A_2 \cos 2\theta + B_1 \sin\theta + B_2 \sin 2\theta . \qquad (2)$$

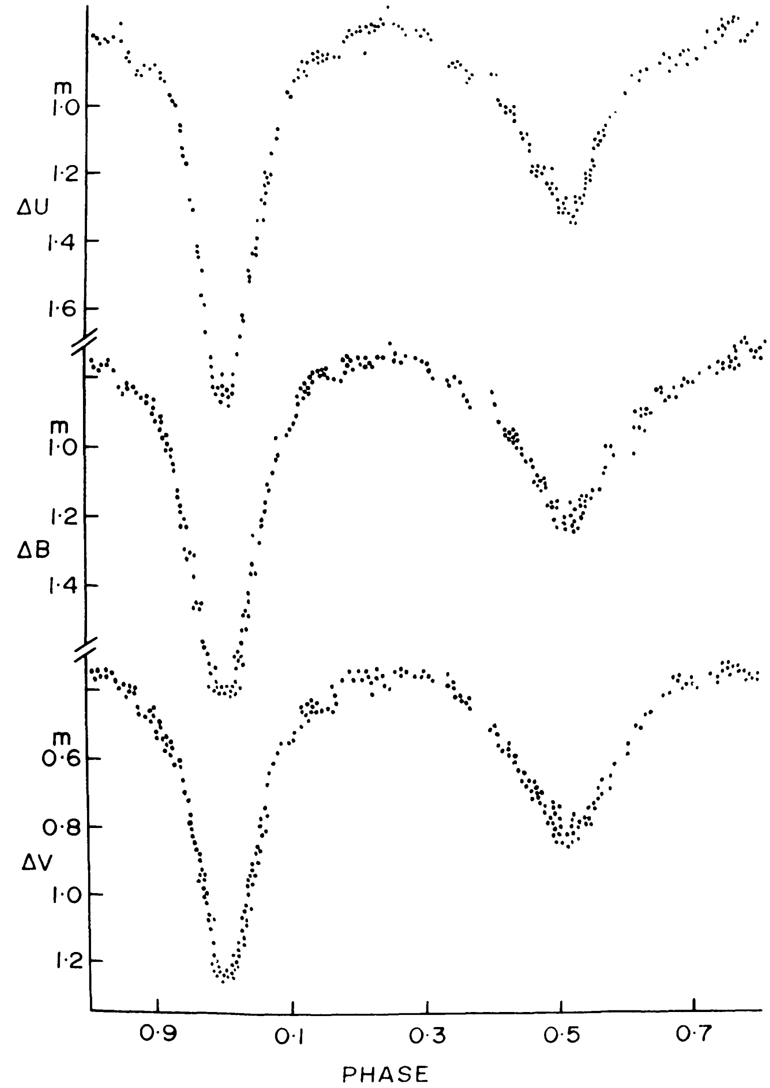

Fig. 2. The U, B, and V light curves of MM Cas.

The coefficients A_0, A_1, A_2, B_1, and B_2 were determined by a least-squares fit. The magnitudes corresponding to unit light and the resulting coefficients in all the three colours are given in Table I.

In order to rectify the light within the eclipse for ellipticity and reflection, we carried out calculations by the equation (Russell and Merrill, 1952) as

$$I^r = \frac{I + C_0 + C_1 \cos\theta + C_2 \cos 2\theta}{(A_0 + C_0) + (A_2 + C_2)\cos 2\theta} . \tag{3}$$

where the C terms were calculated with the method given by Binnendijk (1970). The phases in all the three colours were also rectified with the procedure given by Binnendijk

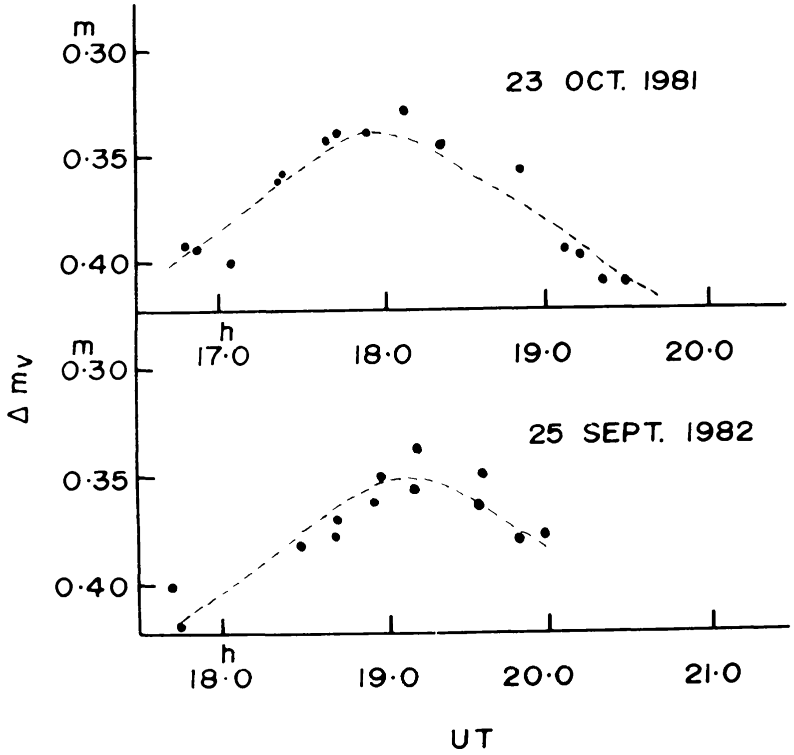

Fig. 3a. A representation of the light curve of MM Cas between the phases 0.ᵖ15 and 0.ᵖ35 in V filter.

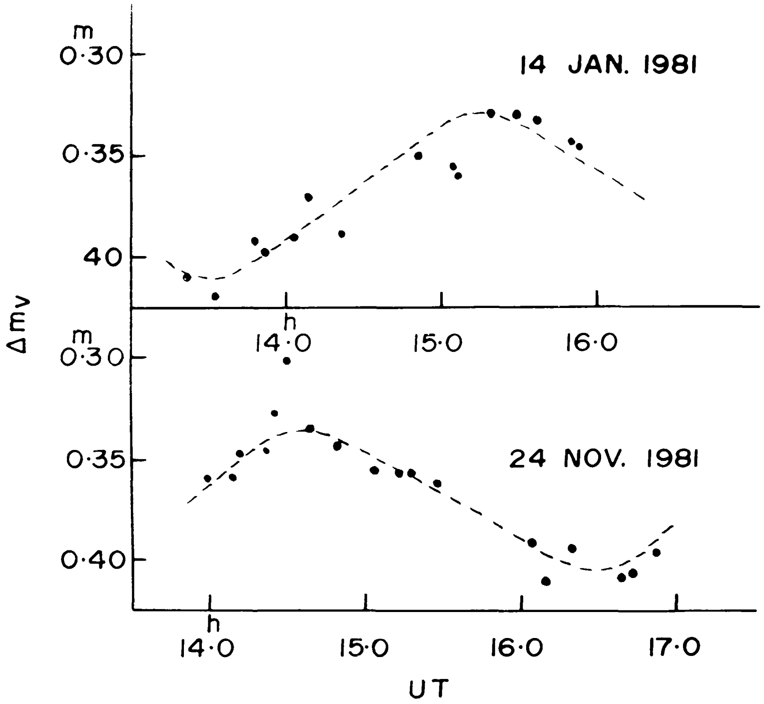

Fig. 3b. Same as Figure 3(a), but for the phases between 0.ᵖ65 and 0.ᵖ85.

TABLE I

Rectification constants
$(I = A_0 + A_1 \cos\theta + A_2 \cos 2\theta + B_1 \sin\theta + B_2 \sin 2\theta)$

	U	B	V
$\Delta m = 0\overset{m}{.}0$	0.785	0.776	0.385
A_0	0.9673	0.9661	0.9718
A_1	0.0102	0.0120	0.0093
A_2	0.0273	0.0308	0.0256
B_1	0.0011	0.0016	0.0012
B_2	0.0015	0.0020	0.0011
z	0.038	0.046	0.043
N	3.2	3.0	2.6

(1970), with the equation

$$\sin\theta^r = \frac{\sin\theta}{1 - z\cos^2\theta}, \tag{4}$$

where the oblateness coefficient z was computed with equation

$$Nz = \frac{-4(A_2 - C_2)}{(A_0 - C_0) - (A_2 - C_2)} \tag{5}$$

and $N = 2.2$, 2.6, and 3.2 for $x = 0.4$, 0.6, and 0.8, respectively.

4. Orbital Elements

It is difficult to devise a satisfactory procedure for removing the light, produced by the intrinsic variability from the light curve within the eclipse. Fortunately it does not have a disastrous effect on our ability to solve primary eclipse for the elements. As the primary eclipse progresses and the primary star gets occulted, the variability become progressively less important. In U, for example, single night observational data should show deviations on the eclipse branches amounting to typically $\pm 0\overset{m}{.}05$ around $\alpha = 0.0$, $\pm 0\overset{m}{.}02$ around $\alpha = 0.5$, and $\pm 0\overset{m}{.}00$ around $\alpha = 1.0$.

By use of the rectified light and with no corrections for the intrinsic variability of the primary component, the shape of the primary eclipse was solved for the photometric elements. For this total eclipse we have used the ψ functions (Merrill, 1950) varying not only k but also A and B until an optimum fit was achieved for each colour separately. The leeway in deciding on the best k was such that k is probably uncertain by about ± 0.05 in each filter.

The value of the limb-darkening coefficients used in these calculations were taken from Grygar *et al.* (1972). The resulting elements are given in Table II, wherein the subscript h refers to the hotter star which is eclipsed at the primary minimum and the subscript c refers to the cooler star which is eclipsed at the secondary minmum.

TABLE II

Photometric solution of MM Cas

	U	B	V
x	0.8	0.7	0.6
k	0.85	0.85	0.85
r_h	0.226	0.224	0.225
r_c	0.266	0.264	0.265
L_h	0.618	0.583	0.563
L_c	0.382	0.417	0.437
θ_e	28°2	28°0	28°1
θ_i	2°5	2°6	2°6
i	86°1	86°2	85°9

5. Spectral Types and Period Variation

From the observed colour indices, $U - B$ and $B - V$ outside the eclipses and within the eclipses, we have determined the colour indices of the individual systemic components. A plot of the colour indices $U - B$ and $B - V$ of both stars, the colour-colour diagram suggest that both stars are equally reddened, $E(B - V) = 0^m.12$, F3 and G2 stars, respectively. This spectral type of the hotter star is in good agreement with F: the classification listed by Wood *et al.* (1980).

In order to study the variations in the orbital period of the system MM Cas, we have compiled a list of the 45 minima (Table III) ranging from 1900 to 1982 from the literature known to us and examined the O–C residuals computed with the ephemeris given in

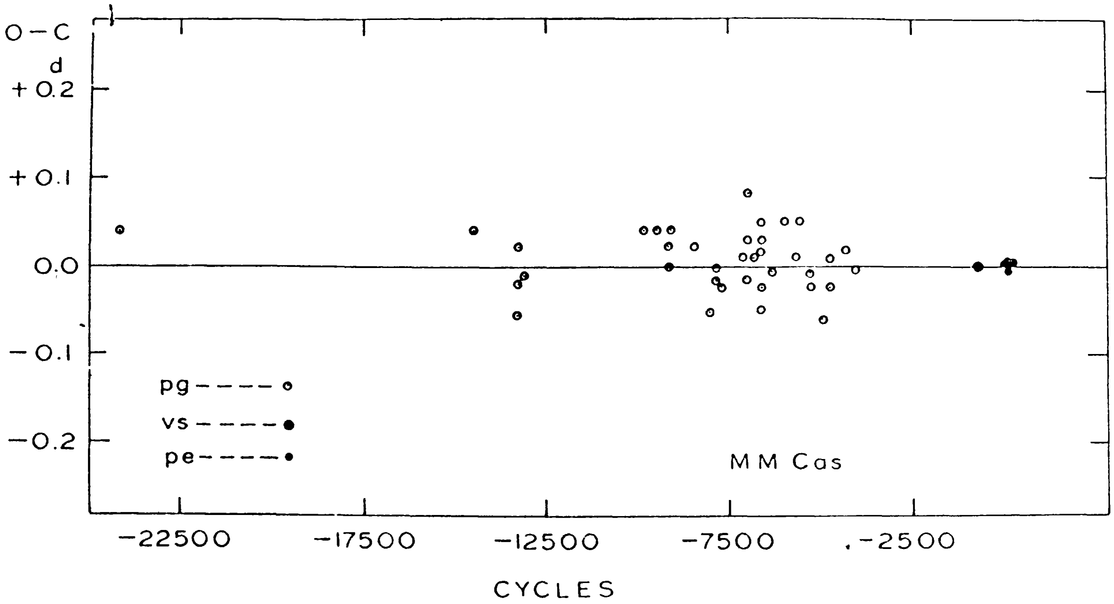

Fig. 4. The O–C curve of MM Cas. Points are the residuals of the observed minima of MM Cas based on the ephemeris $M(E)$ J.D. (Hel.) = 2444544.154 + $1^d.15870E$.

TABLE III

Times of minimum light of MM Cas

n	J.D. (Hel.) 2400000.0 +	Cycles	O–C	Observing method[b]	Type of minima[c]	Reference[a]
1	16737.357	−24003	$0^{\mathrm{d}}.040$	pg	P	1
2	27755.293	−14475	+0.041	pg	P	1
3	29165.365	−13275	−0.055	pg	P	1
4	29172.452	−13269	−0.019	pg	P	1
5	29288.240	−13169	+0.022	pg	P	1
6	29487.469	−12997	−0.002	pg	P	1
7	33156.402	−9830	+0.041	pg	P	1
8	33543.331	−9496	+0.040	pg	P	1
9	33895.490	−9192	+0.023	pg	P	1
10	33901.301	−9187	+0.042	pg	P	1
11	33953.393	−9142	+0.002	pg	P	1
12	34683.251	−8512	+0.023	pg	P	1
13	35343.503	−7942	−0.005	pg	P	1
14	35350.486	−7936	−0.023	pg	P	1
15	35394.512	−7898	−0.019	pg	P	1
16	35401.483	−7892	+0.001	pg	P	1
17	36395.462	−7034	+0.010	pg	P	2
18	36399.533	−7030	−0.027	pg	S	2
19	36402.491	−7028	−0.088	pg	P	2
20	36461.471	−6977	−0.014	pg	P	2
21	36599.253	−6858	−0.010	pg	P	2
22	36790.539	−6693	−0.048	pg	P	2
23	36812.520	−6674	−0.018	pg	P	2
24	36895.363	−6602	+0.030	pg	S	2
25	36899.363	−6599	−0.025	pg	P	2
26	36903.397	−6595	−0.045	pg	S	2
27	37192.473	−6346	−.008	pg	P	2
28	37579.462	−6012	+0.050	pg	P	2
29	37883.529	−5749	+0.018	pg	S	2
30	37945.501	−5696	+0.012	pg	S	2
31	37970.446	−5674	+0.050	pg	S	2
32	38412.332	−5293	−0.022	pg	P	2
33	38441.303	−5268	−0.013	pg	P	2
34	38910.531	−4863	−0.066	pg	P	2
35	38998.510	−4787	−0.031	pg	P	2
36	39034.454	−4756	+0.000	pg	P	2
37	39179.311	−4631	+0.048	pg	P	2
38	39406.346	−4435	+0.022	pg	P	2
39	39414.484	−4428	+0.051	pg	P	2
40	39443.393	−4403	−0.002	pg	P	2
41	44466.532	−267	−0.007	v	P	3
42	44544.154	0	0.000	pe	P	4
43	44581.227	+32	+0.002	pe	P	4
44	44881.270	+291	+0.002	pe	P	4
45	44917.183	+322	+0.002	pe	P	4

[a] (1) Perova (1958); Halle (1972); (3) Lichtenknecker (1981); (4) Present paper.

[b] pg is photographic; v is visual; pe is photoelectric.

[c] P is primary minimum; S is secondary. minimum.

Section 2. A plot of these O–C residuals against cycles, given in Figure 4, shows that the orbital period of the the system remained constant at least during the last eighty years.

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