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PHOTOELECTRIC OBSERVATIONS OF THE LONG-PERIOD ECLIPSING SYSTEM AZ CASSIOPEIAE

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Summary. — Photoelectric observations in *V* and *B* light of AZ Cas performed at the Teramo Observatory from 1966 to 1978 are reported. The temporary parameters *P, D* and *d,* the amount of the eclipse light dimming and also the *V* and *B-V* values for the single components of the system are derived. An attempt is made to estimate the colour excess, the distance of the system and the ratio between the star radii.

Key words : Binaries (eclipsing) — Photometry, *UBV.*

AZ Cassiopeiae, discovered as variable by Beljawski in 1931, was recognized as a 9-year period eclipsing system by Ashbrook (1956) on the basis of the Harvard patrol plates. Other photometric information available up to now in the literature is :

a) Some photographic and visual observations performed by Richter (1957, 1966) during the eclipses of 1938, 1947, 1956-1957 and 1966 ; *b*) a few measurements made between 1942 and 1965 by Weber (1966) at the astrographic station of Mainterne and a series of magnitudes given by the same observer (1967) and covering the eclipse of 1966 ; *c*) a number of plates taken by B. S. Whitney in 1956-1957 and bracketing the ingress phase (Bonnell and Herczeg, 1976) ; *d*) a series of photoelectric observations in *V* and *B* light carried out in 1957 by Larsson-Leander (1959) who made the first photoelectric timing (egressing phase) ; *e*) a preliminary photoelectric timing of the fourth contact in the 1966 eclipse obtained ty Tempesti (1968) ; *f*) a set of magnitudes in the system UBVRIJHKL (Lee, 1970).

The observations presented here, performed from January 1966 to September 1978 with the photoelectric photometer attached to the 40-cm refractor of the Teramo Observatory, cover more than an entire cycle of the variable. BD + 60° 306 was used as comparison star and its constancy, checked by the star BD + 60° 317, appears verified within $0^{\rm m}.01$. The photometric values of these stars, determined by means of several comparisons with Johnson's standard stars (Johnson and Harris, 1954), are given in Table I.

The main bulk of the observations has been made in *V* light (EMI 9502 multiplier with 2 mm-GG14 Schott filter) ; a few *B* magnitudes (2 mm-BG12 + 1 mm-GG13 Schott filters) have been determined for deriving a colour index at maximum and at minimum brightness. The 328 *V* magnitudes so obtained are listed in Table II ; each tabulated value has been averaged from the number of single measures indicated in the column labelled *n* and its typical (internal) mean error is $\pm\ 0^{\rm m}.005$. The general lightcurve derived from these observations is drawn in figure 1 ; the few observations of 1978 have not been plotted. There appear to be erratic brightness fluctuations of a few hundredths of amplitude, rapid variations on a time scale of a score of days and slow drifts on a time scale of several months ; typical examples of the rapid variations are shown on a proper scale in figures 4 and 5. A particularly interesting feature of the lightcurve is the drift observed after the 4th contact in 1966 (a brightnening of $0^{\rm m}.07$ from J. D. about 39 350 to 39 575) ; it might be a photometric effect of the interaction phenomena between the two stars, an inference strengthened by the fact that the eclipse occurs in the very proximity of the periastron (Cowley *et al.,* 1978). Unfortunately it was not possible to ensure observations during the same phase of the following cycle in 1975-1976. A search for fluctuations on a time scale of hours, carried out on a few nights both during the totality and out of the eclipse, revealed no such variations ; only a 4-hour night run on July 13, 1966, plotted in figure 6, showed a brightness weakening at $0^{\rm m}.15$/day rate.

Considering the stretches of the lightcurve where the brightness shows no drifts, one obtains the mean *V* magnitude at maximum as $9^{\rm m}.27$ from J. D. 39 638 to 39 831 (phase 0.10 to 0.16) and $9^{\rm m}.30$ from 41 860 to 42 485 (phase 0.76 to 0.94 of the same cycle). The minima of 1966 and 1975 appear to have the same mean magnitude : $9^{\rm m}.50$. There is an indication that the brightness just before the first contact in 1966 was $9^{\rm m}.30$, whereas at the end of the eclipse it was estimated as $9^{\rm m}.27$; in 1975, at the time of the first contact, the magnitude was $9^{\rm m}.29$. It appears therefore safe to assume $0^{\rm m}.22$ as the decrease in brightness due to the occultation.

The intrinsic variability, originating in the red supergiant and in the interaction phenomena, much diminishes the accuracy of the determination of the contact

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times ; anyhow the estimated times are given in Table III, last column. Following the procedure of Bonnell and Herczeg (1976), in order to derive the period, instead of these times I have considered the mid-points of the ingress and egress partial phases, defined as being equidistant in magnitude from the maximum and minimum brightness. The observations cover an ascending branch (eclipse of 1966) and a descending one (eclipse of 1975) ; the duration of the egress phase may be estimated 11 ± 1.5 days, that of the ingress phase 12 ± 2 days. The difference between the two durations appears hardly meaningful, nevertheless it has the same sense noticed by Cowley *et al.* (1978) in old photographic observations. The observed mid-egress took place at J. D. 39 334.5 ± 0.5 ; the mid-ingress at J. D. 42 639.5 ± 0.5, the uncertainty being mostly caused by the light fluctuations. All the available mid-point times are reported in Table III. These data are essentially the same as given by Bonnell and Herczeg : but the accuracy of the ingress time of 1966 has been greatly improved here by adding to the observations of Richter (1966) the photographic observations of Weber (1967) ; the data derived from the observations of Larsson-Leander and of Tempesti have undergone minor changes. The mid-egress time of 1975 has been derived from 124 visual estimates performed by a network of amateur observers from November 21 to 30 ; Romoli (1976) who processed these observations, determined the 4th contact to be at J. D. 42 745 : assuming the photoelectrically observed shape for the ascending branch, the tabulated time has been found. It should be noted that the time of the 2nd contact in the eclipse of 1975 used by Cowley, Hutchings and Popper in the already quoted paper and attributed to Tempesti in wrong by 8 days ; there has been evidently a misunderstanding about the statement « ... (AZ Cas) entered eclipse on August 11. » which appeared in the IAU Circular 2825 and by which the author meant to indicate the *first* contact.

The photoelectric timings of Table III allow us to compute the « instantaneous » period P and the duration D of the eclipse ; it is known that both quantities show sensible variations from one cycle to the other, but the period so determined shows better agreement with the times of Table III from 1947 on. The photometrically derived parameters of the eclipsing system are given in Table IV ; the B-V value at maximum has been obtained from 7 determinations carried out from August 13, 1966, to September 25, 1968, and the value at minimum from 6 determinations made during the totality in 1966.

The brightness fluctuations, which in a few days may reach some 25 % of the amplitude of the eclipse, make it impossible to compute preliminary values of the parameters p_0 and k by the shape of the lightcurve in the partial phases. Cowley *et al.* (1978) have derived a set of spectroscopic orbital elements, but they have not been able to obtain blue star velocities of sufficient reliability to derive the mass ratio ; nevertheless, assuming convenient values for this ratio, making the hypothesis that the red star fills its Roche lobe and using the photometric parameters D and d they found a range of possible values for the orbital inclination ($80° \leq i \leq 85°$) and for the ratio of the radii ($0.05 \leq R_B/R_R \leq 0.08$). Since the values of P and D in Table IV pratically coincide with those assumed by the quoted authors (respectively 3 404 and 109 days), the orbital elements and particularly the range of the values of i remain unchanged. However the length of the partial phase assumed here (11 days) differs rather noticeably from the length they assumed (9 days) : using the spectroscopic orbital elements with 81° as the most reliable value of the inclination (Cowley *et al.*, 1978), the present values of D and d give $R_B/R_R = 0.07$.

As regards the spectrum, Lee (1970) classified it as M0 Ib + Be ; according to Mendez *et al.* (1975), Bidelman judged the spectral type « certainly at least as late as K0 or later » ; the same authors, using a plate taken during the totality in 1956, estimated the type as F8 Ib. From the strength of the HeI line at 3 819 Å on spectra taken well outside of eclipse they suggest for the blue component a type close to B0 or B1. By means of wide band photometry Wawrukievicz and Lee (1974) found for the epoch December 1967 the equivalent types K3.8 Iab + B0.2 V. On spectra obtained during the totality in 1975 with the 180 cm reflector of the Asiago Observatory at a dispersion of 115 Å/mm the spectral type appears as K5/6 (Rosino, 1978). It seems clear therefore that there are noticeable changes with time in the spectral features of the red supergiant.

With the data of Table IV the best fit of colours, colour excess and difference between the absolute visual magnitudes of the two stars is obtained for $E_{B\text{-}V} = 1.0$ and spectra K2 I and B2 V. Assuming this classification with the pertaining effective temperatures 3 800° and 18 000°, a value $R_B/R_R = 0.03$ is derived for the ratio between the radii of the blue and the red star. The discrepancy with the ratio found using the spectroscopic orbital elements is not too high considering the assumptions made by Cowley *et al.*, the inadequacy of the pure star disc model and the uncertainty in the effective temperatures.

Absolute visual magnitudes of − 4.4 for the K2 star and − 2.5 for the B2 one (Allen, 1965), together with the standard ratio of total-to-selective extinction $A_v/E_{B\text{-}V} = 3$, give fairly consistent values of the distance of the system (1.5 and 1.3 kpc respectively for the red and the blue star). More reliable results may be achieved only by means of appropriate simultaneous multicolor photometry and spectroscopic observation covering atmospheric eclipse and partial phases.

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TABLE I. — *Comparison and check stars.*

BD	V	B-V	Number of determinations
+ 60° 306	$9^{\rm m}.87 \pm 0^{\rm m}.01$	$+ 1^{\rm m}.18 \pm 0^{\rm m}.01$	35
+ 60 317	9.60 ± 0.01	$+ 0.40 \pm 0.01$	16

TABLE IV. — *Temporary and photometric characteristics of AZ Cassiopeiae.*

Min = 2 442 689 + 3 402 E

$D = 110^{\rm d}$ $d = 88^{\rm d}$

$V_{\rm max} = 9.22$ $V_{\rm min} = 9.52$

$\overline{V}_{\rm max} = 9.26$ $\overline{V}_{\rm min} = 9.50$

$(B\text{-}V)_{\rm max} = + 1.78 \pm 0.02$

$(B\text{-}V)_{\rm min} = + 2.20 \pm 0.03$

Amplitude in V light due to star disc occultation 0.22

Blue star $\begin{cases} V = 11.1 \\ B\text{-}V = + 0.8 \end{cases}$

TABLE III. — *Timing of the eclipses of AZ Cassiopeiae.*

Mid-ingress times				Mid-egress times				Photoelectric contact times			
J. D.	Year		Observer	J. D.	Year		Observer				
15 405 ± 5	1901	pg	Ashbrook	22 298 to 318	1919-20	pg	Ashbrook	1957	3th	35 929.5	± 0.5
25 603 to 622	1928	pg	Ashbrook	29 124 to 127	1938	pg	Ashbrook		4th	35 939	± 2
> 29 019	1938	pg	Richter	32 533 ± 1	1947	pg	Ashbrook				
32 433 ± 2	1947	pg	Ashbrook					1966	3th	39 330	± 1
35 806 to 829	1956	pg	B. S. Whitney	35 932.5 ± 1	1957	pe	Larsson-Leander		4th	39 341	± 2
39 233 ± 1	1966	pg	Richter, Weber	39 334.5 ± 0.5	1966	pe	Tempesti	1975	1st	42 632	± 2
42 639.5 ± 0.5	1975	pe	Tempesti	42 739 ± 2	1975	v	Romoli		2nd	42 644	± 1

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TABLE II. — *Photoelectric observations of AZ Cas from 1966 to 1978.*

J. D.	V	n	J. D.	V	n	J. D.	V	n	J. D.	V	n
39			39			39			42		
155.29	9.259	10	437.38	9.242	6	787.46	9.290	3	361.48	9.306	5
172.28	9.260	10	444.23	9.249	7	808.26	9.272	4	363.26	9.292	4
176.25	9.250	5	446.41	9.262	4	818.47	9.309	3	367.26	9.290	4
211.34	9.311	11	451.33	9.256	7	820.50	9.307	5	371.45	9.311	4
215.30	9.303	9	454.22	9.236	9	821.38	9.315	4	386.24	9.290	4
216.30	9.293	9	455.22	9.248	7	827.28	9.296	4	390.38	9.302	6
220.31	9.297	9	456.46	9.273	4	830.27	9.272	7	391.38	9.294	4
221.29	9.304	7	458.21	9.256	7	831.28	9.297	3	398.37	9.290	4
267.58	9.492	9	460.22	9.268	6	895.24	9.295	5	402.51	9.302	4
272.57	9.510	8	463.44	9.243	9	906.24	9.261	6	404.42	9.293	4
289.56	9.476	9	469.19	9.254	9	911.28	9.271	5	417.25	9.294	4
293.56	9.495	13	470.30	9.228	7	912.37	9.285	3	418.43	9.291	4
294.56	9.483	6	474.24	9.258	11	921.31	9.271	5	419.46	9.292	6
295.56	9.488	16	475.44	9.258	5	938.29	9.242	5	422.40	9.295	5
298.56	9.506	15	476.23	9.251	6	939.30	9.262	3	423.41	9.302	6
299.56	9.505	7	477.27	9.266	6	940.29	9.267	2	430.40	9.297	5
300.56	9.513	21	480.23	9.238	7	941.29	9.267	4	432.39	9.297	6
301.56	9.506	6	482.51	9.243	7	40			443.25	9.288	6
304.57	9.503	11	483.46	9.264	5	015.54	9.249	6	444.27	9.295	7
305.57	9.502	8	484.35	9.237	7	028.57	9.277	4	446.25	9.304	6
306.61	9.514	15	486.29	9.239	5	029.57	9.267	3	451.28	9.302	6
307.54	9.508	10	491.25	9.230	12	034.56	9.272	4	453.30	9.310	4
308.56	9.517	13	498.25	9.223	4	035.54	9.269	3	454.25	9.282	6
309.51	9.523	19	504.43	9.237	7	038.48	9.266	5	455.31	9.289	2
310.53	9.514	20	505.28	9.243	9	039.48	9.265	4	461.22	9.309	4
311.53	9.508	8	506.43	9.228	6	041.51	9.267	2	462.27	9.296	8
314.52	9.521	10	508.23	9.249	5	042.55	9.261	2	471.29	9.297	4
317.47	9.466	7	518.26	9.240	7	043.45	9.283	3	485.29	9.280	4
319.52	9.492	15	520.44	9.224	6	052.45	9.274	4	597.46	9.270	6
320.50	9.486	59	525.24	9.235	6	055.42	9.271	5	600.40	9.257	4
321.54	9.501	12	532.28	9.200	3	058.46	9.289	2	601.44	9.267	5
323.55	9.496	12	536.31	9.223	5	060.46	9.254	3	603.47	9.266	6
324.53	9.506	10	537.29	9.335	6	061.42	9.257	2	607.46	9.260	7
326.52	9.484	15	538.29	9.229	4	089.63	9.247	2	608.42	9.266	4
327.50	9.496	7	544.26	9.233	7	095.44	9.268	4	609.45	9.291	4
330.45	9.490	12	545.40	9.213	4	125.37	9.271	3	610.54	9.270	4
331.50	9.470	14	547.28	9.210	4	153.55	9.253	2	612.45	9.271	6
332.45	9.471	18	552.30	9.220	6	189.50	9.287	2	620.41	9.305	4
336.41	9.319	19	553.30	9.219	8	41			621.40	9.295	4
337.42	9.291	18	554.31	9.224	6	860.53	9.321	5	622.40	9.287	4
338.46	9.285	20	555.31	9.213	7	861.53	9.333	6	623.54	9.280	7
339.45	9.275	10	560.26	9.214	6	865.52	9.326	6	624.47	9.280	7
340.47	9.279	7	565.27	9.202	8	884.44	9.282	8	625.39	9.285	4
341.42	9.275	9	571.27	9.198	5	900.54	9.315	6	626.40	9.274	3
343.45	9.260	9	572.26	9.223	7	902.58	9.304	4	627.39	9.276	5
348.49	9.280	12	574.28	9.206	10	915.48	9.280	6	628.40	9.290	9
349.34	9.261	4	575.28	9.201	5	928.56	9.288	4	629.43	9.288	5
350.41	9.284	20	638.58	9.266	5	929.60	9.295	5	630.38	9.318	4
351.44	9.297	23	641.56	9.287	8	931.58	9.278	6	631.42	9.292	4
352.41	9.284	26	645.55	9.267	6	979.39	9.292	5	632.40	9.286	7
353.50	9.282	10	647.54	9.279	7	985.32	9.296	4	633.42	9.310	4
357.42	9.296	7	651.53	9.278	4	986.27	9.313	4	634.39	9.289	4
361.50	9.274	8	657.50	9.275	6	987.39	9.315	4	635.46	9.305	6
370.35	9.274	10	688.43	9.242	4	989.58	9.304	6	636.47	9.329	7
371.40	9.272	9	702.46	9.238	6	990.29	9.324	10	637.44	9.342	13
373.41	9.286	5	703.45	9.240	7	991.48	9.302	6	638.42	9.374	12
375.37	9.274	6	704.55	9.273	3	42			639.47	9.381	6
376.38	9.290	6	705.50	9.266	6	006.50	9.293	3	641.50	9.480	7
377.39	9.276	11	706.52	9.279	5	007.34	9.302	4	642.54	9.506	6
378.44	9.270	10	709.44	9.296	4	012.40	9.294	4	643.47	9.511	6
379.35	9.292	14	714.47	9.305	3	030.27	9.301	5	644.40	9.516	6
382.35	9.286	7	718.46	9.297	5	037.38	9.302	4	645.41	9.501	10
383.42	9.274	7	730.47	9.258	4	044.26	9.298	12	646.40	9.496	8
384.41	9.278	10	731.62	9.251	4	220.53	9.264	5	647.38	9.493	6
391.45	9.259	6	732.69	9.271	5	224.56	9.296	3	651.40	9.511	10
392.60	9.242	8	734.43	9.261	4	238.54	9.271	4	652.43	9.474:	3
393.44	9.249	16	735.37	9.262	5	241.47	9.285	4	655.50	9.493	6
394.65	9.246	7	740.41	9.255	3	244.49	9.277	4	656.53	9.492	6
395.43	9.258	8	741.46	9.274	3	254.42	9.280	4	660.44	9.486	10
400.39	9.262	9	743.44	9.270	10	270.43	9.301	4	661.36	9.477	6
402.41	9.279	9	744.42	9.254	3	272.43	9.298	4	663.41	9.483	5
403.46	9.293	10	746.41	9.265	4	273.54	9.319	6	667.60	9.498	10
404.48	9.267	11	757.38	9.277	4	274.54	9.318	5	742.25	9.322	4
409.61	9.272	9	758.49	9.251	4	276.49	9.326	4	746.27	9.326	4
412.25	9.307	10	759.30	9.260	3	278.44	9.324	5	43		
413.28	9.272	7	.65	9.282	3	279.51	9.314	5	716.43	9.236	6
414.31	9.283	12	761.64	9.271	3	280.44	9.301	5	717.43	9.241	6
417.29	9.252	7	767.39	9.238	5	302.41	9.280	5	723.41	9.255	8
420.24	9.251	10	770.50	9.271	5	304.39	9.273	6	727.43	9.256	6
422.28	9.243	7	771.49	9.275	4	306.36	9.272	4	773.36	9.307	4
424.24	9.250	5	772.46	9.272	5	318.51	9.301	4	775.34	9.305	4
426.43	9.251	12	774.47	9.260	3	338.59	9.328	5	776.44	9.307	4
435.24	9.241	7	786.33	9.283	4	344.57	9.320	5	777.39	9.304	4

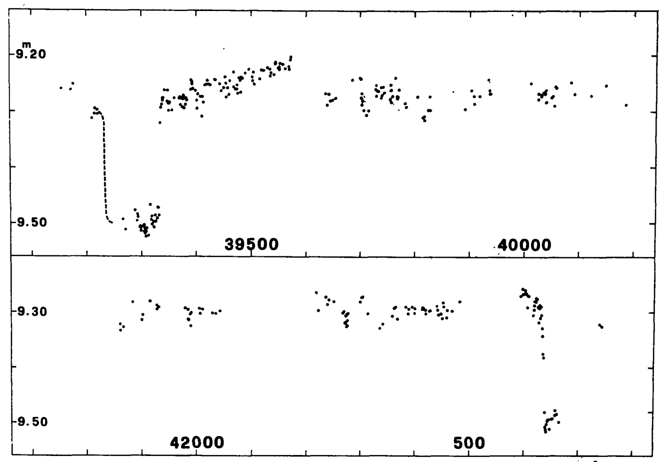

FIGURE 1. — The V lightcurve of AZ Cas from January 1966 to November 1975.

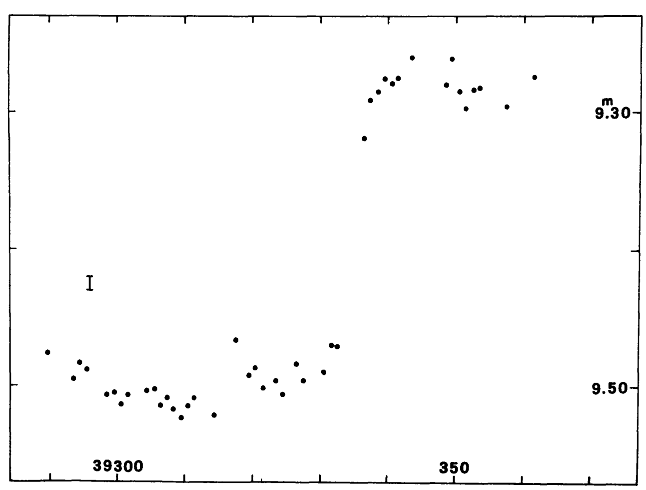

FIGURE 2. — The egress phase of 1966. In this and in the following figures the bar indicates 2 times the mean error.

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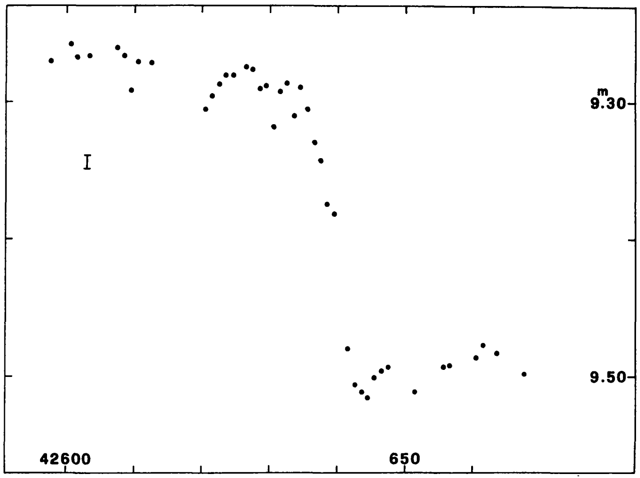

FIGURE 3. — The ingress phase of 1975.

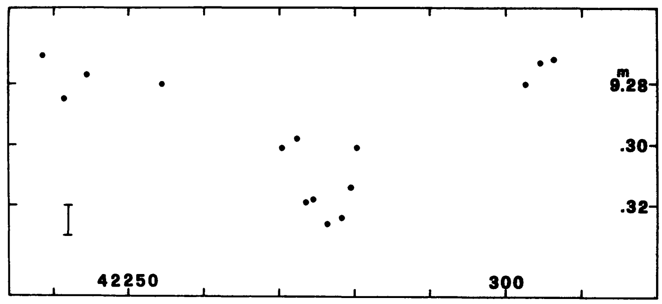

FIGURE 5. — A detail of the lightcurve (phase 0.88).

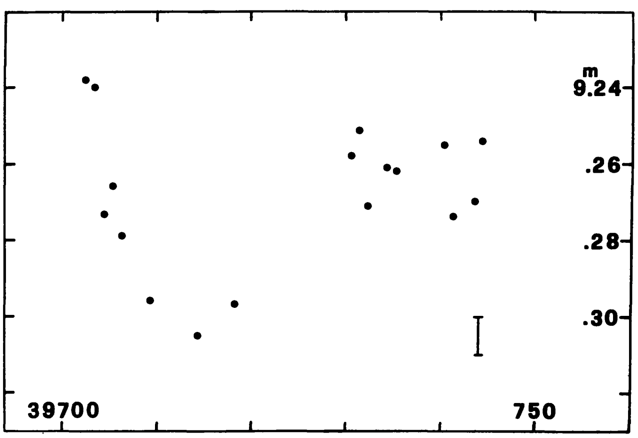

FIGURE 4. — A detail of the lightcurve (phase 0.13).

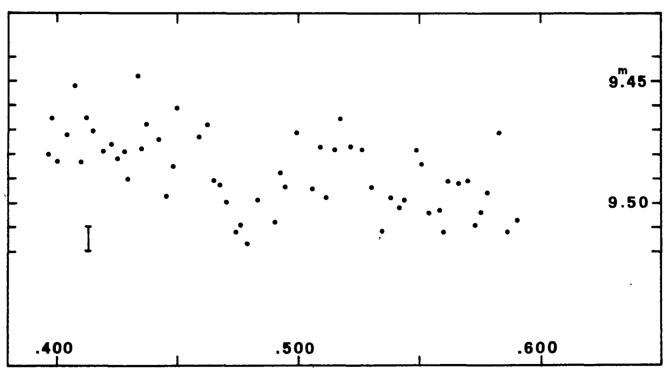

FIGURE 6. — The brightness drift observed during the totality on July 13/14, 1966.

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