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Photoelectric Measurements of Lunar Occultations. V. Observational Results

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Observational timings of 254 lunar occultations, almost all disappearances, made between December 1968 and April 1971 with the McDonald 36-inch reflector, using equipment and techniques previously described, are reported. A number of observers have participated in this, now semiroutine, program, and their contributions are acknowledged with gratitude. For some 40% of the observations (a total of 98 cases) in which the observational noise was sufficiently small and the diffraction pattern well enough defined, a lunar limb slope has been derived. An ambiguity in this has been noted and discussed, and is considered likely to be of minor importance, pending further observations. For the tabulated determinations of slope, 70% are numerically below 10° and only three in excess of 30° . The determination of limb slopes is closely bound up with the use of occultation observations for astrometry of double stars. Seven cases of discovery of double stars are included in notes to the main table of results. Six other cases of possible duplicity requiring confirmatory observations are noted. One certain case of a perceptible angular diameter, that of λ Aqr, has been discussed in detail in a separate publication. Three other cases marginally capable of yielding diameters are noted, and will be examined more closely later. The main table of results forms the basis of the file of traces—which we intend to establish—to which other observers are invited to contribute, so that the advantages of duplicate observations may be made available to those interested. The present listing is by SAO numbers, possessed by all the occulted stars, but other designations are more useful for astrophysical purposes. To facilitate reference cross-indices in terms of SAO, HD, DM, and HR, Bayer and Flamsteed designations have been prepared and are available on application to the author.

GENERAL CONDUCT OF THE PROGRAM

THE essential part of this paper is a consolidated list of all occultation observations made at McDonald Observatory by the techniques of observation and reduction described in previous papers in this series and elsewhere (Nather and Evans 1970; Nather 1970; Evans 1970; Nather and McCants 1970; Nather *et al.* 1970). They are, with only two exceptions, disappearances at the dark limb. In most cases the observations have been made by two-man teams, but it is hoped to bring this down to single-handed work soon. Of the reported observations, the author has participated in about 75% and R. E. Nather in about 40%. Other significant contributions have been made, roughly in order of numerical importance, by Dr P.A.T. Wild of the University of Cape Town, South Africa, while a McDonald Postdoctoral Fellow, by John E. Elliott and Thomas J. Moffett, graduate students in the Department of Astronomy of the University of Texas at Austin, and by Charles Cobb, Technical Staff Assistant at McDonald Observatory. In recent months, a very important contribution has been made by Paul Bartholdi and Mrs. Irene Bartholdi, of the Observatory

of Geneva, Switzerland, who are currently visiting the Department at Austin through the courtesy of Professor M. Golay, Director of the Geneva Observatory.

The reductions were initially undertaken by M. M. McCants according to the system described in an earlier paper (Nather and McCants 1970), but the entire body of data has been reviewed and most of the later observations reduced by Bartholdi. All cases of doubt, arising from excessive noise, doubt of the reality or position of an occultation, convergence of the reduction program onto a false fringe pattern, or other difficulties have been eliminated or corrected. It is thus hoped that all the results given may be used with confidence for celestial mechanical and similar purposes.

DETERMINATION OF LUNAR SLOPES

The topic of lunar slopes has been discussed several times before (Evans 1955, 1970, 1971) from which it would appear that some kind of average slope over a range of about 20 meters around the point of geometrical occultation can be determined. This is found by comparing the time scale of the observed occultation trace with that predicted from the rate of motion of

TABLE I. Slopes for angles off over 45° .

Slope range:	-25/-20	-20/-15	-15/-10	-10/-5	-5/0	0/5	5/10	10/15
Number:	1	0	0	6	7	13	1	1

the Moon against the star background, assuming the limb to be level and smooth.

We adopt the convention that a slope counts positive if its effect is to compress the scale of the occultation phenomenon as compared with what it would have been in the absence of the slope. This convention is convenient for discussing the effect of various limb structures on the traces (Evans 1971) but is less convenient in certain aspects of the reduction.

If the Moon is moving in position angle θ_1 at angular rate V , and the occultation takes place at position angle θ_2 on a slope θ_4 , then the rate of advance of the actual limb normal to itself is $R = V \cos(\theta_1 - \theta_2 + \theta_4)$ with R determined from the fit of the observed trace to a standard theoretical one, and with the stretch or contraction of the time scale left to be determined as one of the parameters.

The determination of the value of the cosine leaves us with an ambiguity of sign for the angle itself, while the convention adopted for the sign of the slope introduces a further ambiguity. The situation will be clear from Fig. 1 where we see the obvious fact that the actual rate of description of the occultation fringe pattern is determined by the angle between the actual limb and the direction of lunar motion. In every case there are two formal solutions, represented by lines antiparallel to the direction of motion of the lunar center. One of these corresponds to what we think is a plausible solution, while the other usually corresponds

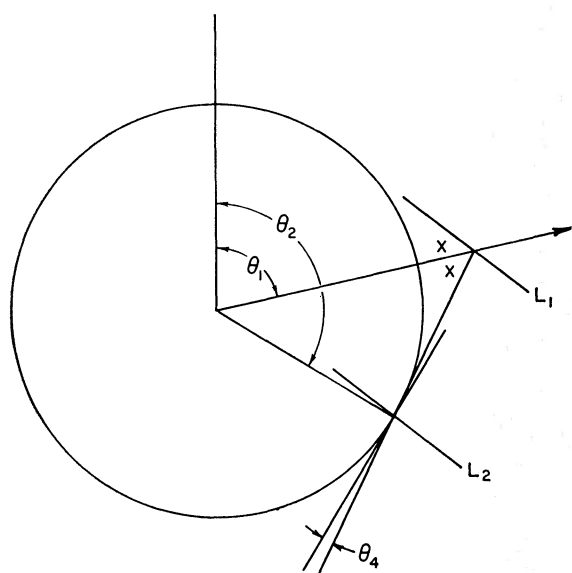


FIG. 1. Ambiguity of lunar slopes. The same result can be produced by the slope θ_4 at position angle θ_2 and by the line L_2 which is parallel to L_1 .

to an extremely steep slope which we can, in most cases, rule out. For example, if the computed $\theta_4 = 0$, and the difference $\theta_2 - \theta_1$ (which we call the "angle off") $= 45^\circ$, then the results can be equally represented either by the adopted level limb or by a vertical precipitous edge, which we do not think very plausible. Still less plausible are the results for larger angles off, where the second solution corresponds to an overhang. It has already been noted elsewhere (Evans 1971) that the uncertainty of determination of the slope is smaller for large angles off, so that we can get the best idea of the range of slope angles by considering the results for angles off numerically in excess of 45° , where we do not have any real ambiguity or serious error of determination.

For angles off numerically greater than 45° we have 29 results according to the histogram shown in Table I. That is, all except one lie in the range -10° to $+10^\circ$, a result which confirms an often-expressed opinion that most lunar slopes are small, with a few cases of exceptionally large ones.

We are in difficulty over stating what we think the largest admissible slope can be, since we are dealing with features too small to be seen with certainty from the Earth directly, and possibly only with difficulty on orbiter photographs taken at the correct line-of-sight angle.

Perhaps worth reiterating is that if steep lunar slopes were common, then for cases of angle off greater than the complement of the slope, we should see fairly commonly the phenomenon of disappearance of a star, followed by brief reappearance, and again disappearance. This does happen at grazing occultations, but we have no such case in our records for nongrazing phenomena.

If the angle off is zero, then the two alternative cases count the same in our convention, since a left-rising slope and a right-rising slope produce the same effect, and we count both negative (Evans 1971). Also, the error of numerical determination is much greater because of the large differential of the inverse cosine. In the computer program for the determination of slopes, the ambiguity was arbitrarily resolved by taking the numerically smaller alternative. This was given a sign in accordance with our convention. The range of values in which a plausible ambiguity can arise is thus for angles off less than 45° and we can compute the alternative θ_4' by the following rules, using the tabulated θ_4 :

Case I. $\theta_2 > \theta_1$: Compute $2\theta_2 - 2\theta_1 - \theta_4$ and assign the same sign as θ_4 .

Case II. $\theta_1 > \theta_2$: Compute $2\theta_1 - 2\theta_2 - \theta_4$ and assign the same sign as θ_4 .

From the results for angles off numerically greater than 45° it is probably safe to exclude slopes numerically in excess of 40° . If we do this and compute alternative slopes according to the criteria above, we have cases where a real ambiguity might arise; see Table II. In computing Table II we have additionally ruled out a few cases on the grounds that in our convention a positive slope greater than the angle off is geometrically impossible.

We can do little more than state our opinion that in the majority of these cases the choice of the numerically smaller slope seems more reasonable, and that in the few cases where there does seem to be a genuine ambiguity (e.g., as in Runs 705 and 712), the error of determination pretty much spans the ambiguity range. We do note, however, that there are three cases (Runs 1404, 1601, and 1837) where the slope does exceed 30° and the error of determination seems rather small. We leave this problem as one whose existence should not be ignored, but which may become clearer with additional observations. The slopes as determined are illustrated in Fig. 2, as a function of the angle off, $|\theta_1 - \theta_2|$.

OBSERVATIONS OF DOUBLE STARS

Consider a double star with angular separation Δ in position angle θ_3 , and suppose Δ to be so small that curvature of the lunar limb can be neglected, and further (a perhaps more serious assumption) that the lunar limb slope is the same for both components. Then, from Fig. 3, we see that the time interval between occultation of the two components corresponds to the movement of a point on the limb along S_1X , and we readily have

$$S_1X = V\Delta t = \Delta \cos(\theta_2 - \theta_3 - \theta_4) / \cos(\theta_1 - \theta_2 + \theta_4)$$

and from previous arguments giving the fitted rate R , we have

$$R\Delta t = \Delta \cos(\theta_2 - \theta_3 - \theta_4)$$

that is, for a level limb, the time interval between events converted into angular measure through the fitted rate

TABLE II. Possible ambiguities in slope determination.

Run No.	θ_4	θ_4'
700A	-21	-25
705	-20	-24
707	-9	-37
712	-17	-21
1220	-18	-26
1225A	-1	-35
1404	-34	-36
1408	-8	-32
1526	-12	-28
1633	-8	-24
1805	-6	-32
1808	-9	-39
1832	-9	-31
1859	-4	-36

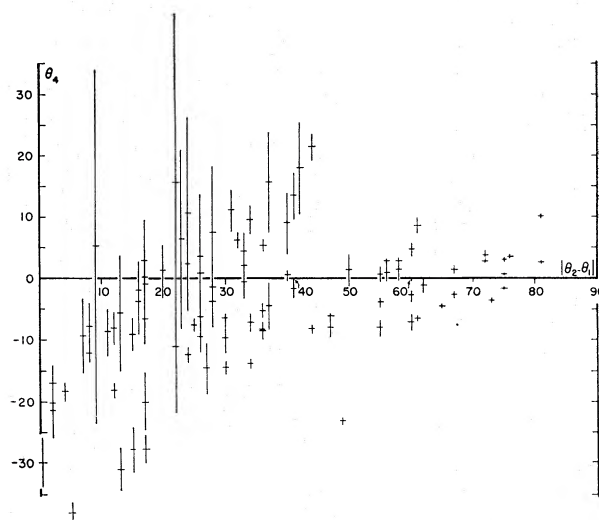


FIG. 2. Statistics of slopes determined as a function of angle off. In each case the value given is the numerically smaller of the two values permitted by the ambiguity.

gives the angular separation projected onto the direction defined by the position angle at which the occultations took place. If a slope is present, then from the discussion given above, this direction is $\theta_2 - \theta_4$ if $\theta_2 > \theta_1$ and $\theta_2 + \theta_4$ if $\theta_2 < \theta_1$. In the Notes to Table III for the cases of duplicity, this rule has been followed, using the tabulated values of the slopes. These are subject to the ambiguity already discussed, which might in some cases lead to a plausible alternative choice in the angle adopted. Where an imaginary slope is involved, we usually consider that this results from a small slope and an experimental fitted rate subject to slight observational error. In such cases we can probably adopt a zero slope. If no slope is determined, then the position angle of projection of the separation between the components can be uncertain, in most cases over $\pm 10^\circ$, with the chance in exceptional cases that this range might be $\pm 30^\circ$. Clearly, if one wishes to use this type

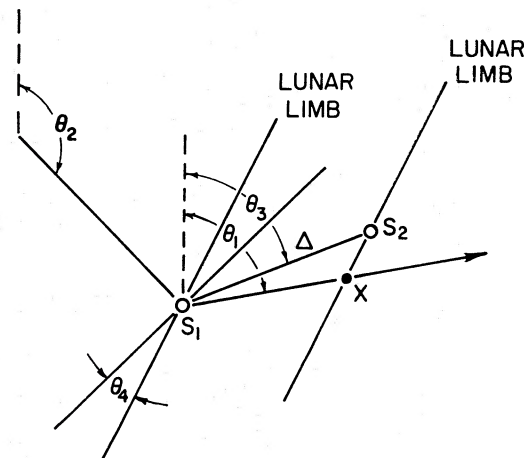


FIG. 3. Geometry of occultation of a close double star in the presence of a slope on the lunar limb.

TABLE III. Observational results.

Run No.	SAO	Mag	Sp.	U.T. date	U.T. observed	Δt	θ_1	θ_2	θ_4	$\Delta\theta_4$	Notes
100	92859	8.1	K5	29 Dec 68	04 34 45.557	1	58	91			A
101	93221	8.0	F0	30 Dec 68	01 22 39.575	2	54	127	-3.5	0.5	
102	76228	3.8	B8	31 Dec 68	01 45 38.275	0	60	56			AB 1
103	76229	5.2	B8p	31 Dec 68	01 55 53.937	1	60	40	1.4	4.2	B
104	158331	6.4	A2	12 Jan 69	12 18 29.381	1	129	210	10.2	0.3	B
105	158331	6.4	A2	12 Jan 69	12 31 27.072	1	129	228	4.5	0.2	BR
212	76460	8.2	A0	24 Feb 69	02 09 47.064	1	74	57	-6.5	4.1	B
301	76682	6.5	F0	24 Mar 69	01 21 07.890	1	82	131			
303	76714	8.9	G5	24 Mar 69	03 31 38.842	1	90	131	13.6	3.9	
400	78398	9.0	A0	25 Mar 69	01 41 58.094	1	98	68	-14.4	1.1	B
402	78440	6.8	A2	26 Mar 69	03 33 06.152	1	104	138	9.6	2.5	B 2
404	78461	8.1	A0	26 Mar 69	04 11 14.581	1	106	80	-6.2	2.4	B
405	78478	9.0	F2	26 Mar 69	04 56 28.519	1	106	72			B
406A	78483	7.6	A2	26 Mar 69	05 08 11.795	0	106	128	-11.0	1.3	B
406B	78488	8.7	A5	26 Mar 69	05 14 32.567	1	106	123	0.2	5.9	B
407	78496	7.8	K2	26 Mar 69	05 35 42.028	0	106	144			V
409	78524	5.0	A0	26 Mar 69	06 10 38.939	0	106	110			AB
501	79369	9.0	K5	27 Mar 69	04 26 09.119	2	113	180			V
502	79379	8.7	G5	27 Mar 69	04 41 07.091	1	113	148			V
506	79422	8.9	G5	27 Mar 69	06 16 31.050	1	113	82	11.2	3.5	V
600	80035	7.9	M5g	28 Mar 69	01 51 10.882	2	111	38			V 3
601	80040	8.9	K7	28 Mar 69	02 03 41.932	2	112	133			V
603	80089	7.0	G5	28 Mar 69	05 06 25.872	1	120	59	-6.5	0.4	
604	80105	8.0	A0	28 Mar 69	05 41 59.073	1	120	119			AB
605	80113	5.9	A0	28 Mar 69	06 13 17.460	1	120	39	2.7	0.1	B
606	80113	5.9	A0	28 Mar 69	06 25 02.600	0	120	20	4.9	0.1	BR
607	80133	8.8	F8	28 Mar 69	07 06 02.260	2	119	123			
608	80146	8.3	A2	28 Mar 69	07 44 57.650	1	118	82	-8.5	1.4	B
700A	80634	7.7	G0	29 Mar 69	02 32 47.964	1	119	121	-21.4	4.5	
700B	80637	8.9	K0	29 Mar 69	02 43 25.416	2	120	93	-14.5	4.2	
701A	80662	9.0	F2	29 Mar 69	04 47 07.748	1	125	146			B
701B	80667	9.1	A7	29 Mar 69	05 17 36.159	1	126	151			B
705	98874	7.6	G5	30 Mar 69	04 43 25.627	0	129	131	-20.2	3.0	
706	98914	7.9	A0	30 Mar 69	07 56 27.215	0	127	98			BD
707	99257	7.3	K5	31 Mar 69	01 34 41.379	1	121	114	-9.3	6.1	V
712	118929	5.8	F5	1 Apr 69	05 44 19.152	0	134	136	-16.9	2.9	B
900	138763	9.4	G8	27 May 69	02 46 28.282	2	134	112			
901	138777	8.0	F5	27 May 69	04 00 45.738	1	133	141			A 4
902	138798	6.0	F2	27 May 69	05 08 49.643	0	130	100	-6.4	0.8	B
903	157811	7.2	K5g	28 May 69	03 14 57.462	2	132	65	1.5	0.7	V
904	157819	8.9	G5	28 May 69	04 19 10.217	1	131	151			
905	157836	6.7	A2	28 May 69	06 07 20.150	1	126	181	0.8	1.3	BC
906	157860	7.1	A2	28 May 69	07 14 05.422	1	121	138	3.0	6.8	B
907	183168	6.9	K0g	30 May 69	03 54 33.233	1	123	143			V
908	183176	6.1	K0g	30 May 69	04 04 24.975	1	122	46	3.6	0.3	V
909	183234	8.1	F5	30 May 69	06 09 07.203	1	118	103	-27.7	3.7	
1008	76140	4.4	B5	6 Aug 69	08 48 31.588	2	63	348	3.1	0.5	B 5
1078	189903	7.8	G0	13 Dec 69	01 13 26.320	1	57	45			A
1080	164789	8.5	K0	14 Dec 69	02 55 59.604	1	54	91	15.7	8.2	
1081	146320	9.1	A5	15 Dec 69	01 23 39.185	2	48	348	-7.7	1.0	
1082	146362	3.8	M2g	15 Dec 69	04 09 10.424	1	54	21	4.5	2.4	EV 6
1201	146822	9.3	G2	16 Dec 69	01 11 18.374	1	46	87			
1202	146838	8.8	K0	16 Dec 69	02 19 23.599	1	47	80	2.2	5.5	
1203	146837	9.2	K2	16 Dec 69	02 21 23.876	1	47	67			
1204	146839	9.3	F8	16 Dec 69	03 01 13.420	1	49	24			A
1205	146851	9.0	K0	16 Dec 69	04 01 13.965	1	52	30			
1206	146862	8.4	G5	16 Dec 69	05 18 33.113	1	56	358			V
1207	109219	9.1	K	17 Dec 69	02 08 35.384	1	47	21			
1208	109239	8.7	F0	17 Dec 69	04 07 08.101	0	52	37			
1209	92792	8.4	F5	19 Dec 69	03 34 49.423	1	54	14	9.1	5.1	
1210	92810	6.4	F5	19 Dec 69	05 40 31.396	0	62	37	-7.5	1.1	B
1211	75635	8.7	F2	20 Dec 69	01 20 45.195	1	56	95			C
1212	75646	9.1	G0	20 Dec 69	01 49 19.239	1	56	70			
1213	75652	8.6	A5	20 Dec 69	03 06 15.326	1	57	22			
1214	75671	6.7	A3	20 Dec 69	04 30 05.411	1	61	45	-1.8	4.7	B 7

LUNAR OCCULTATIONS. V

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TABLE III (continued)

Run No.	SAO	Mag	Sp.	U.T. date	U.T. observed	Δt	θ_1	θ_2	θ_4	$\Delta\theta_4$	Notes
1215	75675	8.7	F0	20 Dec 69	04 53 22.294	1	62	83			
1216	75704	7.9	K2	20 Dec 69	07 26 05.008	1	74	51			V
1217	75717	8.5	K2	20 Dec 69	08 30 33.056	4	77	145			V
1218	76131	3.8	B5p	20 Dec 69	23 47 57.002	0	65	101			U 8
1219	76140	4.4	B5	20 Dec 69	00 14 09.779	0	64	32	6.3	1.4	BD 9
1220	76155	4.0	B5	21 Dec 69	00 19 57.840	0	64	68	-18.3	1.6	B 10
1221	76159	5.8	B8	21 Dec 69	00 38 14.803	0	63	30	-0.5	1.4	B 11
1223	76319	8.4	A2	21 Dec 69	06 45 02.757	1	76	119			B
1224	76345	7.8	A5	21 Dec 69	08 01 16.713	2	82	97			
1225A	75991	8.7	B9	17 Jan 70	01 46 01.171	1	62	45	-0.8	5.8	B
1225B	75989	9.0	F8	17 Jan 70	01 50 12.111	3	62	152			V
1226	75999	5.9	A2	17 Jan 70	02 44 52.445	1	65	4	-6.3	0.3	B 12
1227	76041	8.3	F0	17 Jan 70	05 09 37.516	1	76	60			B
1228	76046	7.5	A0	17 Jan 70	05 39 12.861	1	78	42	-8.2	0.9	BD
1300A	76672	8.4	K2	18 Jan 70	07 38 38.345	2	91	79			V
1301	77121	6.3	B9	19 Jan 70	00 24 38.200	2	74	90			U 13
1302	77170	9.0	A0	19 Jan 70	03 58 03.891	2	83	67			B
1304	77267	8.1	K2	19 Jan 70	09 24 07.647	3	100	138			V
1305	78154	8.0	A0	20 Jan 70	00 47 00.477	1	82	34			B
1306	78191	7.4	A0	20 Jan 70	01 34 46.339	1	82	97			B
1307	78206	8.0	K0	20 Jan 70	02 02 18.992	1	83	91			V
1310	78334	7.7	A0	20 Jan 70	06 22 38.720	1	101	88			B
1311	78410	7.7	K2	20 Jan 70	08 53 54.324	1	107	129			V
1313	79142	6.8	K0	21 Jan 70	01 56 33.291	7	90	172			V
1314	79164	7.8	K0	21 Jan 70	02 01 22.567	1	90	110			V
1316	79200	8.8	G0	21 Jan 70	03 21 27.332	1	94	86			
1318	79243	7.5	K0	21 Jan 70	05 21 43.270	1	103	134			V
1319	79253	7.9	K0	21 Jan 70	05 50 32.321	1	106	132			V
1320	79316	7.9	G0	21 Jan 70	08 23 44.926	1	114	102			
1321	79319	8.2	K2	21 Jan 70	09 05 14.972	3	114	170			V
1401	77509	8.6	B9	15 Mar 70	02 37 54.678	1	96	21	-1.5	0.2	
1402	77546	8.8	A0	15 Mar 70	03 23 59.711	1	99	140	-1.6	1.7	
1403	77551	8.1	B9	15 Mar 70	03 33 50.526	1	99	34	-4.4	0.3	
1404	77582	8.4	B8	15 Mar 70	04 10 14.504	0	101	102	-34.2	1.1	
1405	77638	8.0	A0	15 Mar 70	05 51 17.808	1	102	124	15.6	37.4	C
1406	77625	5.6	K0	15 Mar 70	06 00 29.582	1	102	177	0.8	0.1	EV
1407	78660	8.9	K7	16 Mar 70	03 51 41.119	2	107	165			
1408	78685	8.2	B9	16 Mar 70	04 30 06.925	0	109	121	-8.1	2.7	D
1409	78710	6.8	K0	16 Mar 70	05 33 16.876	1	110	38	2.9	0.2	V
1410	78725	9.0	K0	16 Mar 70	05 55 04.411	1	110	71			
1411	78740	8.2	K0	16 Mar 70	06 32 52.729	1	110	147	-4.4	3.9	
1412	78770	6.6	A2	16 Mar 70	07 16 15.546	0	109	97	-18.1	1.3	D
1413	79529	8.5	K0	17 Mar 70	03 03 28.339	2	111	136			
1415	79568	8.9	M0	17 Mar 70	05 57 18.027	3	117	178			
1416	80174	8.9	A2	18 Mar 70	02 34 29.150	1	115	135			
1417	80172	8.3	G5	18 Mar 70	03 01 11.280	2	117	176			
1418	80189	9.0	G0	18 Mar 70	03 42 28.158	1	119	135			
1419	80206	8.9	F5	18 Mar 70	05 23 31.458	1	123	83			
1420	80212	9.1	M0	18 Mar 70	06 02 56.081	1	123	103			V
1421	80218	8.7	K5	18 Mar 70	06 25 48.394	2	123	81			
1502	185996	8.7	B9	7 Oct 70	02 00 36.251	2	86	141	-7.9	1.5	
1503	186025	6.0	B5	7 Oct 70	02 19 44.380	1	78	86			AD
1504	187531	8.8	F5	8 Oct 70	01 36 24.719	1	73	121			
1505	187536	9.2	A0	8 Oct 70	02 15 40.637	1	71	15			
1507	188877	8.5	F5	9 Oct 70	04 25 05.380	1	61	91			
1508	164014	9.2	G0	10 Oct 70	01 23 53.755	4	62	34			
1509	189893	9.2	A3	10 Oct 70	01 39 48.436	5	61	127			
1510	164045	8.7	F8	10 Oct 70	02 35 27.388	1	58	50			
1511	164073	8.8	G0	10 Oct 70	04 03 13.159	2	55	43			
1512	164087	7.1	K0	10 Oct 70	04 23 42.964	1	55	66			AV
1513	164095	8.3	G0	10 Oct 70	04 33 18.513	1	55	90			
1514	164750	7.8	M2	11 Oct 70	02 17 29.285	1	55	80			CV
1516	164780	7.3	G5	11 Oct 70	04 30 43.192	1	51	23	7.5	10.9	D
1517	146340	8.7	A3	12 Oct 70	02 07 05.301	1	54	77			
1518	146347	7.3	K0	12 Oct 70	02 31 16.651	1	52	69	-27.6	2.4	

TABLE III (continued)

Run No.	SAO	Mag	Sp.	U.T. date	U.T. observed	Δt	θ_1	θ_2	θ_4	$\Delta\theta_4$	Notes
1519	146360	9.0	G5	12 Oct 70	03 46 13.328	3	49	66			
1520	146411	8.7	F0	12 Oct 70	07 53 44.838	1	53	57			
1521	146419	8.7	K5	12 Oct 70	08 05 47.418	3	54	69			D 14
1522	146860	8.4	A0	13 Oct 70	02 24 08.584	1	53	23			
1523	146891	7.8	F8	13 Oct 70	04 02 10.913	3	49	47			V
1524	128375	7.4	G5	13 Oct 70	04 43 53.727	1	48	25	6.5	14.6	D
1525	128391	9.0	A3	13 Oct 70	06 20 18.649	2	48	26			
1526	128401	5.8	A2	13 Oct 70	06 43 22.181	0	49	41	-12.0	1.6	B
1527	128428	9.0	K5	13 Oct 70	08 23 39.208	3	53	58			
1528	128429	8.4	F0	13 Oct 70	08 28 12.594	1	54	65			
1600	188470	6.6	A5	5 Nov 70	01 19 57.188	1	64	352			C
1601	188494	8.9	A2	5 Nov 70	01 33 59.574	1	64	51	-30.9	3.5	
1602	188491	8.2	G5	5 Nov 70	02 03 18.412	1	63	1	-1.0	1.2	
1603	188547	7.6	F0	5 Nov 70	02 57 14.203	1	63	105	18.1	7.5	22
1604	189609	8.8	F8	6 Nov 70	02 10 57.452	1	57	76			15
1605	189619	9.1	A0	6 Nov 70	02 49 41.174	3	57	38			
1607	189663	8.9	F8	6 Nov 70	03 55 38.535	2	58	104			16
1608	164517	8.7	K0	7 Nov 70	01 51 40.901	2	53	350			
1609	164542	8.9	G5	7 Nov 70	02 05 26.470	2	52	88			
1611	164579	7.1	F0	7 Nov 70	04 18 29.946	0	53	9	21.5	2.3	
1613	164591	9.0	G0	7 Nov 70	04 52 33.922	1	54	74			
1614	164600	6.0	A5	7 Nov 70	05 34 00.755	0	56	20	-5.2	1.4	D
1617	146695	9.0	K2	9 Nov 70	03 44 32.137	6	48	9			
1618	146715	8.7	A0	9 Nov 70	05 47 15.329	1	51	32			
1619	146730	8.7	K2	9 Nov 70	06 11 01.511	2	52	65			
1620	146735	7.1	G0	9 Nov 70	07 09 05.177	1	56	356	4.6	2.3	
1621	109120	8.9	K2	10 Nov 70	04 20 54.145	5	48	30			
1622	92307	8.8	G5	11 Nov 70	04 44 24.199	2	51	74			
1623	92318	8.2	G0	11 Nov 70	05 43 04.723	1	53	81			
1624	92313	8.6	G5	11 Nov 70	06 03 17.847	2	54	14			
1630	189270	8.9	F2	3 Dec 70	00 35 29.793	1	59	44			A
1633	164346	4.3	K0	4 Dec 70	00 32 59.699	0	53	61	-7.7	3.9	E
1634	164349	9.0	K0	4 Dec 70	01 15 26.111	1	53	24			
1635	164361	9.4	K2	4 Dec 70	01 50 01.616	2	54	44			
1636	164376	9.0	A2	4 Dec 70	02 26 58.307	1	54	76			BC
1637	164971	8.8	K0	5 Dec 70	01 33 56.909	4	50	27			17
1638	165001	8.5	K0	5 Dec 70	03 59 06.373	1	54	354			
1639	146514	8.6	F2	6 Dec 70	00 52 25.586	3	50	351			
1640	128501	9.0	G0	7 Dec 70	00 45 33.150	1	48	63			
1641	128524	8.0	K2	7 Dec 70	02 22 00.146	1	48	76	-1.3	6.5	
1642	108987	9.2	G0	7 Dec 70	04 26 09.573	2	52	71			
1643	108985	8.6	F5	7 Dec 70	04 32 55.732	1	53	49			
1644	109004	6.9	G5	7 Dec 70	05 57 06.281	1	57	83	-9.4	2.5	
1646	109520	8.5	K5	8 Dec 70	04 27 41.988	2	53	8			
1647	92621	8.7	...	9 Dec 70	04 13 59.874	2	55	51			
1648	92663	8.2	K0	9 Dec 70	07 41 19.049	1	68	48			
1649	76102	7.9	A2	11 Dec 70	07 08 55.151	1	77	27	1.5	2.8	
1650	76137	5.6	B8	11 Dec 70	07 39 24.116	0	79	113	-13.7	0.8	D
1651	76184	8.4	A2	11 Dec 70	08 49 08.531	3	83	121			
1655	92505	8.8	K0	5 Jan 71	04 33 30.520	3	62	87			
1656	92530	6.2	B9	5 Jan 71	06 12 25.508	0	68	112	-8.1	0.9	D
1658	92940	7.9	K0	6 Jan 71	03 47 45.387	2	63	88			
1660	92979	6.1	F0	6 Jan 71	06 56 02.459	1	75	122	-7.8	1.7	
1661	76514	7.6	G5	8 Jan 71	00 38 24.194	1	68	36			
1662	76530	8.1	K5	8 Jan 71	01 43 00.164	3	69	56			
1663	76547	8.0	A0	8 Jan 71	03 34 14.003	4	73	138			
1665	77121	6.3	B9	9 Jan 71	05 10 12.871	1	88	27	8.7	1.4	D
1666	78196	6.7	K0	10 Jan 71	03 49 04.523	1	89	116			
1667	78309	7.8	A0	10 Jan 71	07 13 28.308	1	104	107			22
1800	109155	8.7	G5	31 Jan 71	01 26 38.414	1	55	82			
1801	109145	7.2	K0	31 Jan 71	01 50 18.985	1	56	344	4.1	0.5	
1802	109169	8.7	A3	31 Jan 71	03 05 08.017	1	60	41			
1804	76400	8.9	K2	4 Feb 71	01 48 12.151	3	71	75			
1805	76407	8.1	A0	4 Feb 71	02 18 18.358	1	74	87	-5.6	9.4	
1806	76431	8.0	M0	4 Feb 71	03 52 47.688	1	81	48			V

LUNAR OCCULTATIONS. V

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TABLE III (continued)

Run No.	SAO	Mag	Sp.	U.T. date	U.T. observed	Δt	θ_1	θ_2	θ_4	$\Delta\theta_4$	Notes
1808	76941	6.5	A2	5 Feb 71	04 24 26.588	0	90	75	-9.0	2.7	
1809	76998	6.9	F5	5 Feb 71	07 28 46.592	1	98	81	-20.0	4.6	
1810	77798	8.3	B9	6 Feb 71	01 34 28.313	1	85	102			
1811	77804	7.6	B9p	6 Feb 71	01 44 24.972	1	86	114	-3.7	2.7	18
1812	77837	6.1	B8p	6 Feb 71	02 59 47.680	0	91	115	2.5	1.3	B 18
1813	77870	9.1	A2	6 Feb 71	04 06 08.806	3	96	135			
1814	77894	8.8	F2	6 Feb 71	04 35 39.410	1	98	89			
1815	77909	7.8	A0	6 Feb 71	04 59 50.423	1	100	100	-29.8	4.0	
1816	78000	8.2	G0	6 Feb 71	07 26 42.999	1	106	84			
1817	78041	8.0	K0	6 Feb 71	08 16 34.076	1	106	115			
1818	78853	7.5	A0	7 Feb 71	01 09 26.039	1	91	33	1.6	1.9	
1819	78929	6.1	F5	7 Feb 71	03 44 01.439	0	101	125	-12.3	1.2	
1820	78947	6.3	B9	7 Feb 71	04 39 05.676	1	105	163	2.9	0.7	
1821	78973	8.8	A2	7 Feb 71	05 24 38.471	2	109	67			
1822	78979	8.6	G5	7 Feb 71	05 44 33.372	2	110	44			
1823	79026	8.5	G0	7 Feb 71	07 41 11.590	3	113	159			
1824	80361	7.0	K0	9 Feb 71	02 30 06.333	1	107	83	10.6	15.9	
1825	98645	8.7	...	10 Feb 71	06 27 06.650	1	127	101	3.7	10.2	19
1826	98651	8.9	...	10 Feb 71	06 56 16.597	1	128	119	5.2	28.9	19
1827	98662	6.2	A0	10 Feb 71	07 51 14.765	0	130	83	-6.0	0.5	B 19
1828	98654	7.6	B9	10 Feb 71	07 58 18.052	0	130	170	0.6	0.6	B 19
1830	76204	8.1	A2	3 Mar 71	03 49 27.289	1	85	45			
1831	76206	6.8	K5	3 Mar 71	04 04 20.109	2	85	145	-2.7	0.9	B
1832	77478	7.9	A0	5 Mar 71	02 12 09.064	1	93	104	-8.7	4.0	D
1833	77514	8.9	K0	5 Mar 71	03 07 18.210	2	97	69			V
1834	77563	8.0	A3	5 Mar 71	04 23 20.978	2	101	101			
1835	77588	8.1	B8	5 Mar 71	05 23 26.281	2	103	157			20
1836	77604	7.3	K0	5 Mar 71	05 27 32.948	1	103	100			B
1837	77619	7.1	F5	5 Mar 71	05 59 52.577	1	103	98	-38.1	2.0	B
1838	77621	7.8	M0	5 Mar 71	06 12 02.748	2	103	50			V
1839	79523	7.9	M0	7 Mar 71	01 21 33.241	2	103	155			V
1840	79562	6.3	F0	7 Mar 71	03 18 56.541	1	112	78	-7.1	1.6	DV
1841	79580	6.0	A0	7 Mar 71	04 02 44.263	1	114	88	0.9	2.6	V
1842	79657	7.8	K5	7 Mar 71	07 56 15.742	1	117	140			V
1843	80243	5.5	K0	8 Mar 71	06 00 08.875	1	124	68	2.8	0.5	DV
1844	80242	8.5	F5	8 Mar 71	06 08 02.009	3	124	133			V
1845	97941	8.3	A2	8 Mar 71	08 13 21.327	1	122	114			V
1846	98517	6.5	A0	9 Mar 71	07 29 31.174	2	128	184	1.0	1.5	V
1850	79332	8.9	F2	3 Apr 71	03 29 29.458	1	115	73			
1851	79384	9.0	K0	3 Apr 71	06 04 17.326	2	114	95			V
1852	80047	9.1	F5	4 Apr 71	03 53 51.894	2	122	127			
1853	80053	8.8	A0	4 Apr 71	04 06 17.257	4	122	73	-22.8	1.5	21
1854	80049	8.8	K7	4 Apr 71	04 12 17.709	3	122	142			
1855	80063	7.5	G5	4 Apr 71	04 48 21.081	1	122	124			V
1856	80067	8.7	A2	4 Apr 71	05 07 46.406	1	122	120			
1857	80075	8.5	M0	4 Apr 71	05 28 28.714	3	121	103			E
1858	80091	8.9	G0	4 Apr 71	06 28 23.328	5	120	50			
1859	80099	7.9	B9	4 Apr 71	06 39 14.136	1	120	104	-3.6	6.3	
1861	98315	8.6	G0	5 Apr 71	02 29 37.125	1	123	113			
1862	98362	7.6	G5	5 Apr 71	05 09 54.238	1	127	97	-9.7	2.5	
1863	98373	9.0	M0	5 Apr 71	06 32 11.198	5	125	151			
1864	98384	7.9	K0	5 Apr 71	06 54 19.611	1	124	99			
1865	98386	9.2	G5	5 Apr 71	07 22 51.847	2	123	147			
1866	118376	5.2	K0	7 Apr 71	04 42 19.724	0	133	169	5.4	1.1	V
1867	118389	7.9	K0	7 Apr 71	05 12 03.903	2	133	101			V
1868	118404	8.5	G5	7 Apr 71	07 20 41.723	2	130	113			
1869	118764	5.4	K5	8 Apr 71	03 38 25.696	1	132	77	-3.8	0.6	V
1870	118778	6.0	K0	8 Apr 71	05 23 02.675	2	134	67	-1.6	0.6	V
1871	138523	8.3	K5	9 Apr 71	04 11 51.378	3	133	155			

Notes to Table III

1. Run No. 102. SAO 76228: HD 23850: BD +23°557: HR 1178: 27 Tau: Atlas (Pleiades). $V=3.62$, $B-V=-0.083$, $U-B=-0.36$, B8III, ADS 2786, companion 6.8, at 0°.4. Also spectroscopic binary, not identifiable with this pair (Abt *et al.* 1965), with $P=1254.68$ days. The trace can be interpreted as that of a double star, the fainter component ($\Delta m=2.0 \pm 0.4$ mag) having been occulted first at U.T. 1h 45m 38.257s ± 0.003 s, corresponding to a separation of 0.006 ± 0.001 arc sec in direction 56°, the lunar slope being imaginary and taken as zero. The visual duplicity is stated to be doubtful. Our confidence that this trace indicates a definite double has been diminished by the impression that other Pleiades traces show similar peculiarities, all corresponding to about the same separation and magnitude difference, and we are not disposed to insist on this interpretation at the present time.
2. Run No. 402. SAO 78440: HD 45721: BD +28°1138. Double star, occultation of second component at U.T. 3h 33m 06.236s ± 0.011 s. Separation 0.023 ± 0.001 arc sec in direction 128° (slope 9.6°) with $\Delta m=0.0 \pm 0.1$ mag.
3. Run No. 600. SAO 80035: HD 45337: BD +25°1880. Variable star RX Cnc, SRb 9.2-10.7, $P=120$ d $\pm$. High noise level makes it impossible to be sure that an indication of a hesitation at mid-fall on the trace is real.
4. Run No. 901. SAO 138777: HD 108240: BD -3°3289. Double star; the first (and fainter) component was occulted at U.T. 4h 00m 45.683s ± 0.001 s with $\Delta m=0.6 \pm 0.2$ mag and a separation of 0.021 ± 0.001 arc sec in direction 141°. The slope is imaginary, and hence probably close to zero.
5. Run No. 1008. SAO 76140: HD 23338: BD +24°547: HR 1145: Taygeta (Pleiades). Not closely analyzed, because the trace is believed instrumentally distorted by improper background level setting. The timing is not seriously affected. See Run 1219 of the same star for Remarks [Fig. 4(a)].
6. Run No. 1082. SAO 146362: HD 216386: BD -8°5968: HR 8698: λ Aqr. $V=3.74$, $B-V=+1.64$, M2III. Angular diameter for fully darkened disk 0.0082. For full discussion see Nather *et al.* (1970).
7. Run No. 1214. SAO 75671: HD 18484: BD +21°397. Binary, Orbit Worley (1963) No. 73. Timing presumed to be for the following component according to the ephemeris of Balze (1958).
8. Run No. 1218. SAO 76131: HD 23302: BD +23°507: HR 1142: 17 Tau: Electra (Pleiades). $V=3.69$, $B-V=-0.11$. Claimed as a spectroscopic binary by Abt *et al.* (1965). This trace, obtained in U with the Sun above the horizon is too noisy to warrant inference of duplicity from its somewhat peculiar shape.
9. Run No. 1219. SAO 76140: HD 23338: BD +25°547: HR 1145: 19 Tau: Taygeta (Pleiades). See also Run No. 1008. $V=4.29$, $B-V=-0.11$, B6V. Claimed as double from occultation observations by Povenmire (1969) and by de Veig (1969) and, doubtfully, as a spectroscopic binary (Abt *et al.* 1965) (rejected from Batten's catalogue). This trace is of better quality than Run No. 1008 of the same star, but is still somewhat noisy. It shows peculiarities which might be attributed to close duplicity, but on the evidence available we have reservations [Fig. 4(b)].
10. Run No. 1220. SAO 76155: HD 23408: BD +23°516: HR 1149: Maia (Pleiades). $V=3.86$, $B-V=-0.07$, B7III.
11. Run No. 1221. SAO 76159: HD 23432: BD +24°553: HR 1151: Asterope (Pleiades). $V=5.75$, $B-V=-0.04$, B8V.
12. Run No. 1226. SAO 75999: HD 22091: BD +23°473: HR 1086: 7 Tau: ADS 2616 $V=5.90$, $B-V=+0.13$, A3V. Visual binary, Orbit Worley (1963) No. 83. The timing is for the second star to be occulted, the first having gone 1.5 sec sooner and failed to trigger the stop.
13. Run No. 1301. SAO 77121: HD 34762: BD +27°758: HR 1750. $V=6.26$, $B-V=+0.04$, B8V. Observed in w with Sun above the horizon. Run No. 1665 is of the same star. Spectroscopic binary, Stillwell (1944).
14. Run No. 1521. SAO 146419: HD 217145: BD -6°6112. It is possible that a second star was occulted at U.T. 8h 05m 47.499s ± 0.002 s near the end of the trace. If so, the separation is 0.040 ± 0.002 in direction 69° (no slope determined) with $\Delta m=0.2 \pm 0.4$ mag.
15. Run No. 1604. SAO 189609: HD 197256: BD -21°5805. A second occultation occurred at U.T. 2h 10m 57.750s ± 0.002 s, giving a separation of 0.117 ± 0.001 in direction 76° (no slope determined) with $\Delta m=0.6 \pm 0.3$.
16. Run No. 1607. SAO 189663: HD 197691: BD -21°5820. A fainter component was occulted first at U.T. 3h 55m 38.469s ± 0.003 s with separation 0.022 ± 0.002 in direction 104° (no slope determined) and $\Delta m=0.4 \pm 0.4$ mag.
17. Run No. 1637. SAO 164971: HD 211358: BD -11°5792. A second occultation occurred at U.T. 1h 33m 56.943s ± 0.002 s, giving separation 0.013 ± 0.002 in direction 27° (no slope determined) with $\Delta m=0.7 \pm 0.4$ mag.
18. Run No. 1811. SAO 77804: HD 40297: BD +27°938. $V=7.27$, $B-V=0.29$, A0Ib. Run No. 1812. SAO 77837: HD 40589: BD +27°945: HR 2111. $V=6.05$, $B-V=+0.25$, B9Iab? Both traces may show some signs of an extended shell in the form of an abnormally long toe.
19. Runs No. 1825, 1826, 1827, 1828. All made during a total lunar eclipse, showing very low noise and background, and numerous fringes. Run No. 1825. SAO 98645: BD +15°2071. Run No. 1826. SAO 98651: BD +15°2074. Run No. 1827. SAO 98662: HD 83023: BD +15°2077: HR 3818: 7 Leo. $V=6.18$, $B-V=+0.04$, A1V. Run No. 1828. SAO 98654, HD 82906, BD +14°2113.
20. Run No. 1835. SAO 77588: HD 38689: BD +27°874. Occultation of a fainter companion took place first at U.T. 5h 23m 26.210s ± 0.003 s with separation 0.017 ± 0.001 in direction 157° (no slope determined) with $\Delta m=1.0 \pm 0.4$ mag.
21. Run No. 1853. SAO 80053: HD 69868: BD +21°1812. The large numerical slope derived must be treated with caution. A different fit to the fringe pattern gives a solution with a smaller mathematical probability but with a small positive slope ($<+5^\circ$).
22. (Added in proof after preliminary reduction of data by H. M. Nautical Almanac Office). Run No. 1603 SAO 188547: HD 186600: DM -25°14325: ADS 12883 (8.1, 9.1, 0.9, 287°, 1959). A faint component ($\Delta m \sim 1.5$) disappeared earlier but failed to trigger the stop. Run No. 1667. SAO 78309: HD 44541: BD +27°1092. Occurred very early. No obvious trace defect. Star is a rejected double in Index Catalogue.

of data for astrometric purposes, restriction to those cases where a slope has been determined is desirable.

EXPLANATION OF TABLE III

Table III contains the observational results with the following column designations:

- (1) Run No. Monotonically increasing with time but not always assigned on any very consistent system.
- (2) SAO star number.
- (3) Star magnitude. From prediction list supplied by the U. S. Nautical Almanac Office.
- (4) Spectral type. From prediction list.
- (5) U.T. date of observation.
- (6) U.T.C. of observation. This is determined in the best time system available to us, the McDonald Observatory quartz clock. Comparisons are made periodically with WWV transmissions, but presumably due to mountainous country intervening between McDonald and Fort Collins there is some variation of phase with time of day and with the frequency used. If the observed lag of the WWV signal lies between 3 and 6 msec of time (symmetrically disposed about the best determined travel time), it is assumed that direct reading from the clock provides the best time available.

The time stated refers to the passage through the 25% level of the theoretical curve of best fit.

(7) Error determination of time in milliseconds, Δt . The time is determined by the fitting process described by Nather and McCants (1970) and the error is the error of fit determined in that program. Because of the multiparameter style of the program, the nominal error is not strictly a standard error, and our feeling is that the given values are optimistic but probably not by more than a factor of about 2 or 3.

(8) The direction of lunar motion relative to the star background (θ_1).

(9) Position angle of occultation (θ_2).

(10) Slope θ_4 (see previous discussion), with sign convention as explained.

(11) Error of slope, $\Delta\theta_4$.

(12) Remarks, according to the following code:

A. The slope determined is imaginary. In most cases the cosine is numerically only just in excess of unity, and we might well assume that all such cases are really of zero slope.

U, B, V. Filter used; otherwise no filter used.

C. No detailed analysis, but there may be a double star with separation less than 10 arc msec.

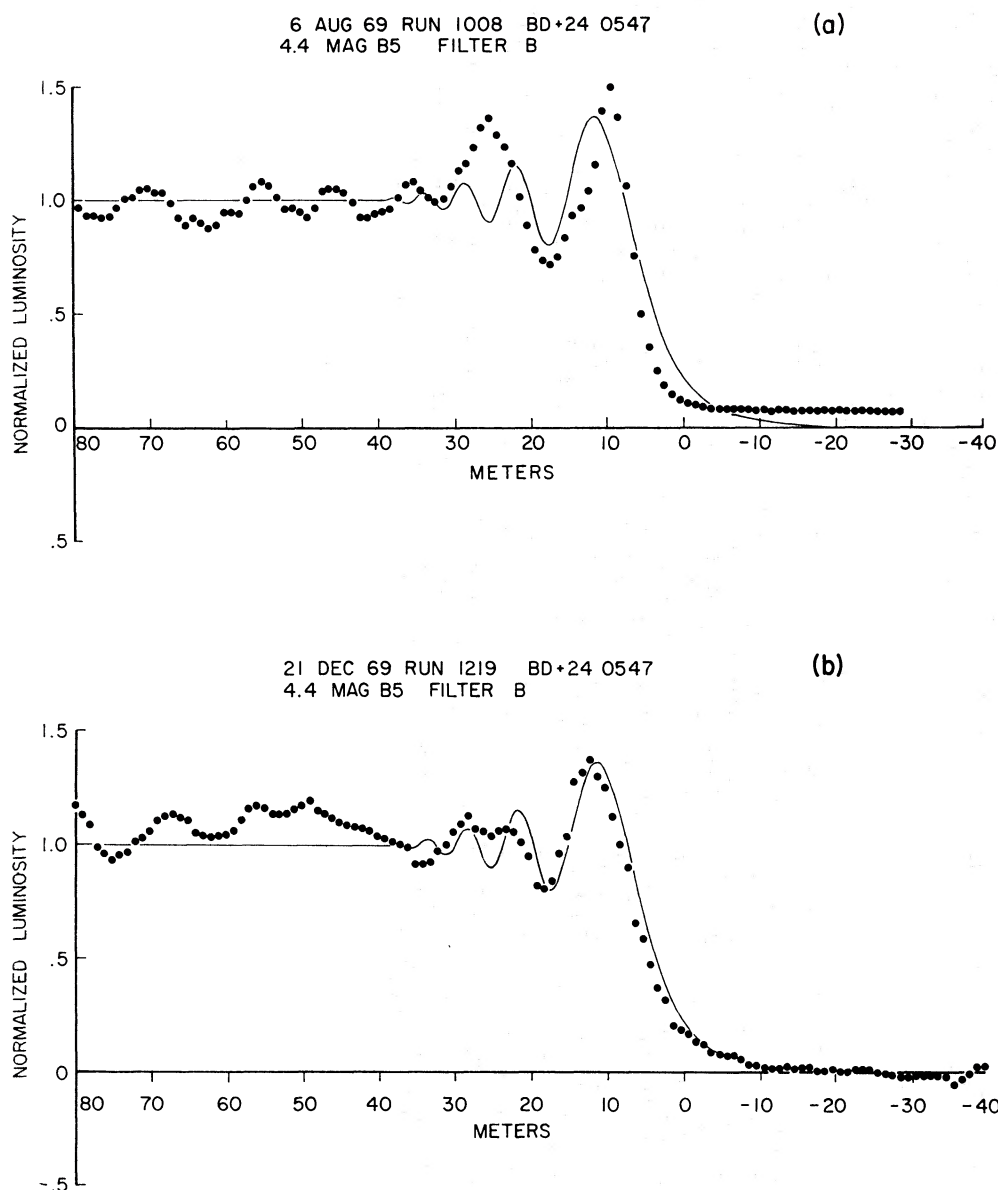


FIG. 4(a) and (b). Observations of the Pleiades star Taygeta for which duplicity has been claimed. Run No. 1008 (a) shows an instrumental cutoff. It is questionable whether the peculiarities in (b) really indicate duplicity.

D. Noticeable distortion of the trace by limb effects.

E. A diameter might be detectable. Applies to four cases, in one of which (λ Aqr) an analysis was made. Preliminary study of some of the others indicates, in accordance with expectation, purely nominal values near 0".001.

R. The phenomenon is a reappearance (two cases) both of disappearance followed by reappearance, both at the dark limb when lunar motion in declination was large.

A number in the last column refers to a special note at the end of Table III.

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