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223 Variables in the Andromeda Nebula

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The variables, investigated on 73 plates taken with the 200-inch Palomar telescope, consisted of 59% classical Cepheids, 29% reddish and red irregulars, 8% eclipsing variables, and the rest of indefinite character. The study gives the following results. (1) An approximate confirmation of the period–luminosity relation found in the Magellanic Clouds. (2) A striking duplication of the period–amplitude relation found in the Galaxy. (3) An approximate uniformity of color for Cepheids having periods up to 13 days with a consistent increase in color thereafter. (4) A new three-dimensional diagram for period, amplitude, and luminosity seems to indicate that the range increases for each period with luminosity and that the fainter Cepheids have smaller ranges throughout. (5) All eclipsing variables found are of β Lyrae type and relatively blue. (6) A few of the irregular variables are as bright as the brightest Cepheids. (7) Placing the Cepheids in coils and lanes of the Nebula affords the possibility of establishing a suggestive dependence of the increasing brightness of a Cepheid on its decreasing distance from the center of the Nebula.

I. INTRODUCTION

THE Great Andromeda Nebula represents the richest extragalactic nebula, with the exception of the Milky Way and the Magellanic Clouds, that is easily accessible to a powerful telescope. The importance of this nebula is increased further by the fact that we cannot observe the Milky Way from outside and that the Magellanic Clouds belong to a rather esoteric group of galaxies.

One of the ways to study a galaxy is to study its variables. A dozen years ago, Baade had taken many plates of M31 with the 200-inch Hale mirror at the Palomar Observatory for this purpose. Four fields were selected on the nebula. In 1952 Baade offered me the material on Variable Field No. 2, which is situated about 7000 pc south from the center in projection.

TABLE I. International photographic magnitudes and step readings of the comparison stars of SA No. 68.[a]

Star	I_{pg}	Reading	Remark
4	18.56	910	Standard
224a	18.97	848	Standard
52	18.90	845	
57	18.93	842	Standard
7	18.94	830	Standard
e1	19.04	838	
8	19.23	776	Standard
e8	19.24	784	
e2	19.64	728	
e4	19.66	740	
65	19.72	721	
e5	19.82	706	
e6	19.95	672	
e7	20.05	665	Standard
e3	20.10	611	
e18	20.18	611	
e11	20.19	624	
e16	20.30	570	
e19	20.40	562	
e24	20.46	564	
e12	20.55	561	
e14	20.83	506	Standard
e10	20.87	491	Standard
e23	21.06	422	
e25	21.12	462	
e13	21.14	461	Standard
e21	21.15	461	
e22	21.17:	423	
e15	21.19	468	Standard
e20	21.19	446	
e26	21.21	443	
e17	21.41	395	
e9	21.58	392	
e103	21.60	362	Standard
e27	21.85	334	
e104	21.86	340	
e102	22.13	316	Standard
e105	22.18	308	
e106	22.30:	294	
e108	22.38:	265	
e101	22.47	264	Standard
e107	22.82	189	

[a] *Standard* determined photoelectrically: others determined photographically.

II. PHOTOMETRIC OBSERVATIONS

With one exception, all variables investigated here on 73 plates were discovered by Baade (see Chart, Fig. 1). For each variable I have selected a few comparison stars (usually three) and estimated the brightness of the variables in reference to those stars after having established a definite physical relation between the brightness of the comparison stars and the degrees of brightness used here. Later this relation was determined by means of magnitudes, based on Selected Area No. 69 ($0^h13^m7, +15°32'$; 1945). Baade intended this Selected Area to represent a prime photometric system of magnitudes for both hemispheres.

I have used 42 stars (Table I and Fig. 2) in this Selected Area, 13 of which have magnitudes determined photoelectrically at the Mt. Wilson and Palomar Observatories in the forties and fifties by Stebbins, Whitford, and Baum. The rest were determined later by photographing the Nebula and SA 68 each of nine times with the same exposure time and the same emulsion. The resulting nine pairs of plates were then measured with an instrument especially constructed at Mt. Wilson to determine magnitudes of comparison stars. The graphical application of this relation is illustrated in Fig. 3.

When I determined the magnitudes of comparison stars I also determined those of the variables and made a comparison with previous determinations of bright-

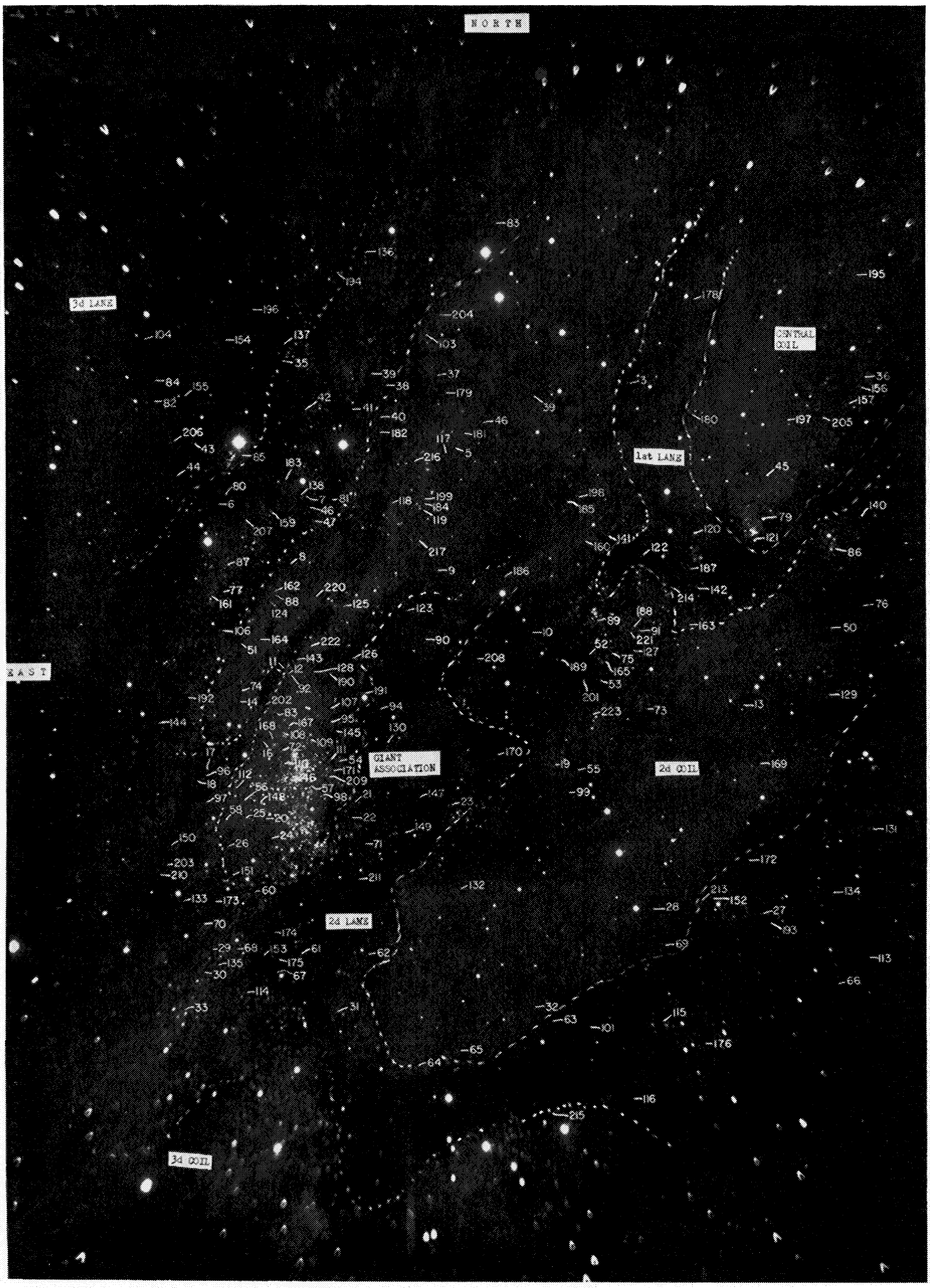

FIG. 1. A southern section of the Andromeda Nebula with the variables indicated. The dotted lines represent the divisions between coil and lane.

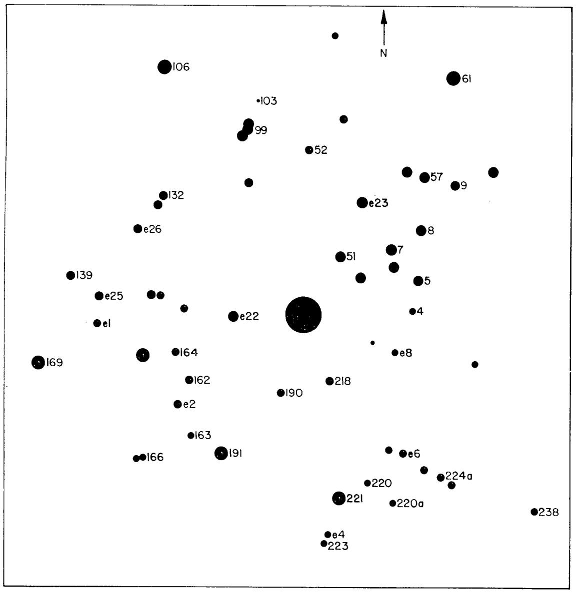

FIG. 2. Chart of Selected Area No. 68. The stars employed are marked numerically.

ness, thus obtaining an independent check of the light variation. The two determinations were usually quite consistent.

Two red plates were taken without reference to the red standards; these plates served mainly to determine the relative color of both the comparison and the variable stars.

III. EVALUATION OF VARIABLES

The nature of the plate material showed clearly that only the intrinsically bright variables could be observed and investigated, that is, only the bright eclipsing binaries, the Cepheids, the irregulars and the (rare) novae. A surprisingly large number of irregulars or semi-irregulars were discovered in the Andromeda Nebula region.

The preponderance of the Cepheids is obvious. These stars having periods of a few days or weeks are the easiest variables to investigate. That is why even our few plates were sufficient to demonstrate the rarity of a spurious period.

Table II contains the results of studies on all variables. Under *Range*, the first number of the second line for each star denotes color of the star expressed in an arbitrary scale but in such a way that the largest negative number (−40) corresponds to the reddest color, probably around spectral class M, and the largest positive number (30) corresponds to the bluest star, probably around spectral class O or early B. The letter next to the color indicates the phase at which a red plate was taken: m—minimum, M—maximum, R—rising, and F—falling branch. In the *Remarks* column, n. i. c. means that the variable was not within the circular region of the field where correction of the stellar images by means of a correcting lens was effective. Originally these variables on the periphery of the field were not on the program, but in many respects, they proved to be as easily estimated as the stars within the corrected area; they represent about 30%, and the Cepheids more than 40%, of the total number. Figure 4 shows the light curve of all periodic variable stars found and studied in this field.

IV. GENERAL REMARKS

The 223 variables investigated are distributed over the classes as follows. There are 120 Cepheids with well-determined periods and 11 with uncertain periods. Thus the Cepheids amount to about 59% of the whole number of variables. The shortest period is $2\overset{d}{.}0$ (No. 155) and the longest, $42\overset{d}{.}3$ (No. 76), or, possibly $48\overset{d}{.}2$ (No. 33). Cepheid No. 3 is apparently the brightest variable ($19\overset{m}{.}23$ at the maximum). It has the period $23\overset{d}{.}3$ and is also situated in the first (central) lane and coil formation. The second brightest Cepheid (No. 73) has the period $17\overset{d}{.}5$ and is situated in the same lane and coil formation. The two faintest Cepheids, Nos. 61 and 97, have the periods $7\overset{d}{.}3$ and $5\overset{d}{.}3$, respectively, and the minimal magnitudes 23.22 and 23.26, respectively. One of them is situated in the second land and coil formation and the other in the third. Here we have an indication that possibly the "supergiantness" (being or becoming absolutely brighter) of the Cepheid depends on its location. I shall refer to this question later.

The next brightest variable is the semiregular, No. 23, with maximal magnitude $19\overset{m}{.}39$. The faintest star of the whole group is also an irregular variable, No. 41, with minimal magnitude $23\overset{m}{.}45$. These values of brightness, $19\overset{m}{.}23$ and $23\overset{m}{.}45$, exhibit the interval of magnitude investigated here. The irregular and the semi-irregular variables surprise us not only by the

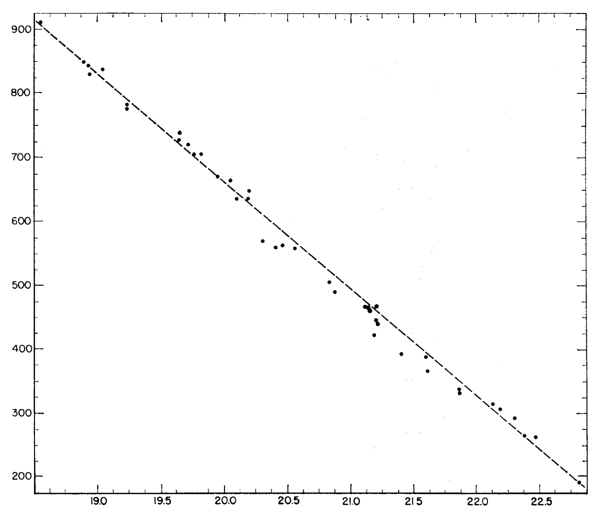

FIG. 3. Determination of photographic magnitudes. Abscissa—Photographic magnitudes on the international scale. Ordinates—Star brightness expressed numerically.

TABLE II. Elements of 223 variable stars in the Andromeda Nebula.

No.	Type	Epoch JD 2433000+	Period	Maxima or minima	Range	Remarks
1	Cepheid	$511^{\mathrm{d}}877$	$6^{\mathrm{d}}47662$	$479^{\mathrm{d}}96$; 505.85; 836.93; 894.98; 978.65	$21^{\mathrm{m}}26$– $22^{\mathrm{m}}44$ 1	n.i.c.
2	Semireg?	Cycle	60.0:	536.85; 590.67	20.40– 22.10 5	n.i.c.
3	Cepheid	591.674	23.307	569.71; 894.98	19.23– 20.95 – 4, R	
4	Cepheid	512.847	6.75296	470.93; 505.24; 593.66; 894.80; 978.64	21.18– 22.02 10, M	
5	Faint				22.39– 23.24 5	
6	Cepheid	977.650	14.1634	481.93; 510.86; 566.71; 836.93	21.31– 22.76 – 2, M	
7	Cepheid	866.869	4.94168	481.93; 510.86; 540.83; 565.71; 896.80	20.83– 21.72 1, M	
8	Cepheid	570.810	23.0833	478.93; 503.89; 594.78; 867.88; 894.81	20.52– 21.88 – 5, R	
9	Cepheid	898.922	13.1229	478.93; 504.86; 570.88; 832.73; 977.65	20.70– 22.43 3, R	
10	Cepheid	565.711	5.66723	480.73; 508.90; 865.90; 899.93	21.29– 22.20 4, F	
11	Variable?	cycle	400.0:	Max: 539.77 Min: 565.71	20.90– 21.41 16	
12	Cepheid	590.674	4.00971	514.86; 538.77; 566.71; 570.81; 594.78	21.28– 21.93	
13	Semireg			Max: 924.79 Min: 503.84	21.38– 22.63 8	
14	Cepheid	590.674	13.0510	510.86; 537.77; 836.93; 954.74	21.12– 23.22	
15	Cepheid	868.869	5.76724	503.89; 514.85; 537.77; 953.63	21.71– 22.49 5, M	
16	Small Var	590.670		540.83; 954.74	22.10– 22.40 – 5	
17	Cepheid	981.710	12.2858	478.93; 514.86; 539.77; 833.94	20.65– 22.49 3, F	
18	Cepheid	978.653	5.6523	480.93; 503.84; 566.71; 898.92	22.18– 22.76 10, M	
19	Cepheid	953.340	5.6040	482.95; 510.86; 572.87; 981.71	21.67– 22.51 12, M	
20	Cepheid	480.929	$11^{\mathrm{d}}1469$	503.84; 536.86; 592.66; 981.65	20.88– 21.87 5, m	
21	Semireg	cycle	100.0:	Max: 481.93 Min: 564.77	20.99– 22.60 – 2	
22	Irr?		6.0:	Min: 538.77	20.91– 21.50 12	
23	Semireg	Cycle	400	Max: 540.1; 940 Min: 830	19.39– 20.15 –12	
24	Cepheid	981.714	6.52555	511.87; 537.77; 570.81; 896.80	21.18– 22.43 – 7, m	
25	Cepheid	895.833	5.49142	478.93; 505.84; 566.71; 868.89; 923.76	21.62– 22.51 4, M	
26	Irr			Max: 572.87 Min: 833.94	21.87– 22.64 6	
27	Cepheid	830.944	26.28727	541.78; 594.78	20.85– 22.51 –16, F	
28	Semireg?	Cycle	120.0:	Max: 977.65 Min: 951.67	21.16– 22.48 – 3	
29	Cepheid	832.931	6.70806	503.89; 510.86; 564.77; 953.64	21.62– 22.31 4, F	n.i.c.
30	Cepheid?		6.7:	Max: 564.78; 570.82 Min: 481.93	21.65–)22.10 3	n.i.c.
31	Irr?			Max: 503.89 Min: 507.90	21.35– 21.65 0	n.i.c.
32	Cepheid	573.905	4.63685	480.93; 508.90; 564.77; 865.90; 981.71	21.83– 22.37 6, F	n.i.c.
33	Cepheid?	896.803	48.25	509.91	21.16– 22.26	n.i.c.
34	Cepheid	514.855	26.2500	541.78; 567.72; 593.66; 830.94	20.42– 21.59	n.i.c.
35	Cepheid	977.650	12.0674	566.71; 590.67; 868.89; 953.64	21.67–)22.25 – 4, M	n.i.c.
36	Cepheid	894.980	21.7726	480.83; 567.72; 981.70	20.43– 21.48	n.i.c.
37	Irr?	cycle	470.0:	Max: 481.93; 509.87 Min: 867.88; 869.88	22.42– 23.37 –27	

TABLE II. (Continued)

No.	Type	Epoch JD 2433000+	Period	Maxima or minima	Range	Remarks
38	Cepheid	571.793	4.57179	479.96; 539.77; 594.78; 955.80; 978.65	21.24– 22.43 4, m	
39	Irr?	cycle	240.0:	Max: 860	21.76– 22.86 0:	
39a	Eclipse	869.881	4.2303	590.67	21.97– 23.32 4, M	excentr?
40	Cepheid	894.817	4.1682	506.89; 511.87; 565.72;	21.90– 22.58 0, F	
41	Irr. Ecl?			Max: 479.96; 567.72; 924.79 Min: 867.88; 897.78	22.64– 23.45	faint
42	Cepheid	980.704	7.90510	506.895; 593.66; 898.926	21.70– 22.53	
43	Irr? Ecl?			Max: 536.86; 897.78 Min: 482.95; 863.85	21.70– 22.15 0	n.i.c.
44	Semireg?			Max: 953.64 Min: 980.70	22.15–)22.85 0	n.i.c.
45	Cepheid	894.978	10.5044	506.90; 569.71; 863.95; 979.65	21.75– 22.39 4, m	
46	Irr? Ceph?			Max: 503.89 Min: 514.86	22.09– 22.37 5	
47	Cepheid	923.770	12.0676	513.84; 537.77; 573.91; 863.85; 899.93	20.90– 22.40 – 8, m	
48	Cepheid	536.860	13.5391	481.93; 509.87; 590.67; 833.94; 955.80	21.16– 22.68	n.i.c.
49	Cepheid	864.860	4.59917	503.89; 507.90; 512.84; 590.67; 898.92	21.97– 22.66	n.i.c.
50	Cepheid	869.886	11.6518	508.90; 590.67; 927.87; 951.67	21.32– 22.59 2, M	n.i.c.
51	Cepheid	952.672	9.08527	806.90; 536.86; 570.88; 590.67; 863.85; 869.88; 88.898; 923.76	21.49– 22.23 – 3, m	
52	Cepheid	592.662	5.93675	479.96; 503.89; 514.86; 895.83; 978.65	21.65– 22.72 0, m	
53	Irr			Max: 865.90 Min: 570.88; 866.87	21.55– 22.15 1	
54	Cepheid	955.790	11.76575	509.87; 567.72; 591.67; 897.78; 980.70	20.88– 22.54 0, R	
55	Irr? Cep?		20.0:	Max: 478.93 Min: 954.74	21.44– 22.37 – 4	
56	Cepheid	923.764	6.53000	505.84; 538.77; 564.77; 590.67	21.70– 22.37 7, F	difficult
57a	Irr			Max: 896.80 Min: 954.74	21.98– 22.64 – 5:	not Baade's
58	Cepheid	978.649	4.83223	480.93; 514.86; 572.87; 954.74	21.78– 23.04 4:, m	
59	Irr			Max: 540.84 Min: 981.71	21.98– 22.37 – 6:	
60	Cepheid	866.943	9.87000	511.87; 540.83; 570.81; 896.80	21.09– 22.22 6, m	n.i.c.
61	Cepheid	833.940	7.3643	480.93; 509.87; 538.77; 952.67; 981.70	22.11– 23.22 – 2, M	n.i.c.
62	Cepheid	571.794	28.5625	514.86	21.82– 23.02	n.i.c.
63	Cepheid	952.672	4.96568	480.93; 505.84; 541.78; 590.67; 867.88; 952.67	21.79– 22.42 5, M	n.i.c.
64	Cepheid	951.671	18.3250	478.93; 511.87; 896.80	20.64– 22.00 – 5, R	n.i.c.
65	Eclipse?	593.658	4.878:	505.84; 510.86	21.73– 22.31 5, m	n.i.c.
66	Cepheid	950.796	13.9953	479.96; 507.90; 591.67; 927.87	20.68– 21.83	n.i.c.
67	Cepheid	981.714	2.93172	478.96; 512.84; 539.77; 594.78; 869.88	21.40– 22.23 – 3, m	n.i.c.
68	Cepheid	594.781	9.67755	479.96; 537.77; 894.81; 954.74	21.30– 22.09 4, M	n.i.c.
69	Nova?	decrease of two mag. in three weeks		Max: 478.93	20.47–(23.35	
70	Cepheid	952.672	7.46343	482.95; 512.84; 572.87; 594.78; 863.85	21.62– 22.78 2, m	n.i.c.
71	Cepheid	894.978	19.7421	480.93; 539.77; 836.93; 954.74	21.52– 22.64 2, m	
72	Cepheid	899.927	10.4609	481.93; 512.84; 836.93	20.73– 22.19 3, M	
73	Cepheid	866.943	17.52732	480.93; 569.71; 954.74	19.68– 21.67	

TABLE II. (Continued)

No.	Type	Epoch JD 2433000+	Period	Maxima or minima	Range	Remarks
74	Cepheid	593.658	13.9659	481.93; 509.86; 537.77	20.45– 21.67	
75	Semireg	Cycle	90.0:	Max: 506.90 Min: 564.77; 572.87	21.55– 22.31 0	
75a	Ecl[a]	978.653	4.805	Min: 507.89; 954.74	20.60– 21.44 30, M	
76	Cepheid	927.870	42.310	505.8; 590.7	19.89– 21.21	
77	Cepheid	923.764	4.61512	480.93; 503.89; 540.83; 863.85; 951.67	21.35– 22.39 4, m	
78	not seen			Min: 22^{m}9	no data	
79	Cepheid	512.842	7.35456	505.85; 594.78; 836.93; 894.954; 954.74	21.88– 22.42 4, M	
80	Cepheid	895.810	3.82661	504.86; 512.84; 570.81; 573.91; 864.86; 952.67	22.15– 22.66	
81	Eclipsing?			Min: 569.71; 924.79; 927.87	21.60– 21.80	
82	Irr?	cycle	60.0:	480.93; 536.86; 594.78; 977.65	20.80– 22.40 0	n.i.c.
83	Semireg?		90.0:	Min: 923.77	21.70– 22.60	n.i.c.
84	Cepheid	866.940	6.46584	504.86; 510.86; 956.67	21.74– 22.38 3, m	n.i.c.
85	Cep? Irr?		6.6:	Max: 513.84; 981.65 Min: 566.71; 830.94	21.38– 22.92 8	n.i.c.
86	Cepheid	514.855	18.18279	478.93; 569.71; 951.68	20.80– 22.14 4, m	n.i.c.
87	Cepheid	927.868	8.39285	507.90; 591.67; 894.90; 977.65	21.50– 22.30 0, R	
88	Cepheid	980.700	3.78191	503.89; 507.89; 594.78; 836.93	21.93– 22.72 3, m	
89	Irr?	only one	max.	Max: 480.93 Min: 478.93; 830.94	20.52– 21.33 10	
90	Cepheid	869.881	3.45336	579.96; 503.89; 593.66; 866.94; 980.70	21.80– 22.35 5, m	
91	Irr?			Max: 479.96; 507.90 Min: 832.93	21.82– 22.20 10:	
92	Cepheid	867.880	6.10142	482.95; 507.89; 513.84; 830.94; 953.64	21.08– 22.16 7, R	
93	Ecl?	514.855	4.95:	504.86; 509.86; 569.71; 863.85	20.82– 21.40	
94	Cepheid	832.931	6.49795	507.89; 514.86; 592.66; 897.77; 923.76	21.90– 22.62 3, m	
95	Cepheid	898.92	13.02069	480.93; 507.90; 832.93; 977.65	21.60– 22.38	
96	Cepheid	863.850	6.10634	478.93; 509.87; 570.81; 924.79; 955.80; 979.65	21.47– 22.59 3, m	
97	Cepheid	978.649	5.35183	480.93; 507.90; 512.84; 593.66; 851.67	22.25– 23.23 1, M	
98	Irr?			Max: 571.79 Min: 979.65	21.90– 22.69 4	
99	RV Tau?	866	46.86:	Max: 510.80; 564.80; 896.80 Min: 538.80	21.54– 22.48 4, m	epoch fr. minimum
100	Cepheid	867.879	5.21811	481.93; 507.90; 570.88; 894.81; 898.92; 977.65	21.12– 21.88	
101	Irr			Max: 478.93 Min: 953.64	21.70– 22.10 0	n.i.c.
102	Cepheid	894.812	22.706	508.90; only two max.	21.05–)21.90	n.i.c.
103	Cepheid	979.646	4.2452	478.94; 503.89; 830.94; 482.95; 507.90	21.50– 22.52	n.i.c.
104	Irr			Max: 514.86; 590.68 Min: 536.86; 869.93	21.20– 21.50 – 2	n.i.c.
105	Cepheid	977.646	3.27615	482.95; 505.84; 541.78; 895.83; 954.74	21.88– 22.83	n.i.c.
106	slow			Max: 864.86 Min: 542.81; 573.91	20.50– 21.28 15	
107	Cepheid	536.858	13.02172	510.86; 953.64; 979.65	21.45– 22.55 – 8, m	
108	Cepheid	981.710	5.0:	508.90; 513.84; 897.77; 953.64	21.45– 22.31 4	
109	Cepheid	955.796	10.85814	509.86; 564.77; 923.76; 977.65	20.72– 21.93 4, R	
110	Cepheid?	573.905	4.9:	Max: 508.90 Min: 594.78	21.20– 22.00 5	

TABLE II. (Continued)

No.	Type	Epoch JD 2433000+	Period	Maxima or minima	Range	Remarks
111	Semireg	cycle	100.0:	Max: 510.86 Min: 830.94	20.92– 22.43 −40, m	
112	Cepheid	981.710	5.36055	503.89; 509.87; 541.78; 836.93	21.85– 22.47 5:, m	
113	Small var			Max: 479.96 Min: 567.72	21.35– 21.55 5	
114	Cepheid	867.879	15.625	478.93; 507.94; 570.86; 836.89; 898.90	21.20– 21.99 0, m	n.i.c.
115	Cepheid	981.649	28.75	836.93; 866.94; 984.81	20.80– 22.39	n.i.c.
116	Cepheid	894.812	32.2285	508.90; 572.87; 863.85; 927.87	20.56– 22.54 − 5:, m	n.i c.
117	Cepheid	981.649	5.06791	479.96; 570.87; 869.88; 951.67	21.80– 22.90	
118	Cepheid	951.671	6.31291	508.90; 514.86; 566.71; 591.67; 894.81	21.50– 22.58 0, M	
119	Cepheid	863.851	17.41553	480.93; 567.72; 898.92	20.36– 21.95 0:, R	
120	Irr			Max: 898.92 Min: 573.91; 868.89; 979.65	21.82– 23.03 0	
121	Irr			Max: 561.79 Min: 868.89; 869.88	21.04– 21.29 11	
122	Semireg	cycle	80.0:	Max: 480.90; 566.70; 863.81; 951.67 Min: 927.87	20.85– 21.65 − 1	
123	Cepheid	591.669	12.3879	481.93; 505.84; 567.72; 864.86; 951.67	21.75– 22.70 − 4, m	
124	Cepheid	830.944	4.0813	479.96; 565.71; 924.79; 981.71	22.10–)23.16	
125	Cepheid	895.833	6.46424	482.95; 507.90; 514.86; 566.71; 869.88	21.80– 22.40 2, M	
126	Cepheid	565.711	9.05963	482.95; 511.87; 865.90; 955.80	21.90– 22.97 3, F	
127	Cepheid?	868.886	31.0:	only one max.	21.50– 22.20 − 3	
128	Cepheid	895.833	12.82054	510.86; 536.86; 573.90; 869.88	20.76– 21.77 0, m	
129	Cepheid	977.650	32.48	590.67	21.13– 22.49 7, F	n.i.c.
130	Cepheid	867.880	20.4783	478.93; 539.77; 951.67	21.90– 23.14 −10, m	
131	Irr?			Min: 951.68	21.25– 21.70	n.i.c.
132	Cepheid	571.788	25.850	only one max.	21.61–)22.77 − 5, m	
133	Cepheid	977.650	12.28421	482.95; 510.86; 594.78; 894.98	20.74– 21.44 − 2, m	
134	Cepheid	980.700	10.9455	478.93; 511.87; 564.77	20.92– 21.85 − 2, F	n.i.c.
135	Cepheid	953.630	12.358	510.86; 532.87; 830.94	20.99– 22.04 8, M	n.i.c.
136	Cepheid	955.796	21.891	540.83; 868.89; 978.65	21.44–)22.80 − 6, m	n.i.c.
137	Cepheid	897.780	3.21513	497.96; 508.90; 511.87; 540.83; 868.89; 955.80	21.73– 22.34 6, M	n.i.c.
138	Ecl?			Min: 570.81	21.85– 22.18 4	
139	Irr?			Max: 509.87 Min: 512.84	21.88– 22.30	
140	Cepheid	538.766	8.31250	480.93; 504.86; 953.64; 979.65	21.35– 21.92 8, F	n.i.c.
141	Ecl	868.886	5.1840	894.81; 899.93	21.45– 21.97	
142	slow			Max: 505.84; 538.77 Min: 898.92	21.93– 22.53 −12	
143	Ecl?	540.00	110ᵈ:	Min: 870.00; 980.00	20.40– 21.39 22	remarkable
144	Var?			503.89; 504.86; 592.66; 977.65	21.85– 22.20 10	
145	Cepheid	867.880	6.63663	482.95; 509.86; 927.87; 980.70	21.46– 22.28 0, m	
146	Irr? Cep?		8.0:	Max: 836.93 Min: 923.76	21.72– 22.71 4	faint
147	Irr?		30.0:	Max: 506.90 Min: 565.71; 864.80	21.77– 23.19 − 6	strange

TABLE II. (Continued)

No.	Type	Epoch JD 2433000+	Period	Maxima or minima	Range	Remarks
148	Irr?		4.0:	480.93; 513.84; 564.77; 899.93; 951.67	20.83– 21.67 8	
149	Irr?			572.87; 863.85	21.77– 22.22 0	
150	Cepheid	593.668	15.2158	503.85; 564.77; 836.93; 867.88	20.60– 21.74 6, F	n.i.c.
151	Cepheid	894.812	6.64507	508.90; 541.78; 867.88; 927.87; 980.70	21.27– 22.32 4, R	n.i.c.
152	Cepheid	952.670	5.997	508.90; 564.78; 597.66; 899.93; 981.71	21.56– 22.58 0, F	queer
153	Cepheid	868.890	5.72057	479.96; 508.90; 594.78; 954.74; 977.65	21.98–)22.45 5, M	n.i.c.
154	Long p.?		265.0:	observed on: 564.80; 590.75 rise: 835; 570	21.65– 22.31 –10	n.i.c.
155	Cepheid	571.798	2.05032	507.90; 510.86; 565.71; 864.86; 867.88; 980.70	21.65– 22.31 6, F	n.i.c.
156	Cepheid:		28.1	506.90; 897.78; 980.70	20.40– 21.30 6, M	n.i.c.
157	Irr?			Max: 506.90; 895.94 Min: 481.93; 567.72	20.95– 21.30 7	n.i.c.
158	Cepheid	898.922	5.65798:	480.93; 509.87; 514.86; 864.86; 955.80	21.85– 22.45	
159	close to a bright star			Max: 980.70 Min: 594.78	21.90– 22.57 12	unknown
160	slow	cycle	400.0:	Max: 952.67; 980.70 Min: 565.71	21.72– 22.98 (– 5	
161	Irr? Ceph?		5.0:	Max: 508.90; 895.83 Min: 981.71	21.23– 21.87 14	
162	Irr			Max: 592.66 Min: 978.65	22.10– 22.50 0	
163	Cepheid	571.790	7.01014	480.93; 508.90; 537.77; 866.94; 894.81	22.11– 22.83 2, m	
164	Irr?			Max: 503.89; 570.88 Min: 953.64; 977.65	21.40– 21.97 – 6	
165	Cepheid	896.803	7.70137	480.93; 511.87; 573.91; 927.37	20.78– 21.80 8, M	
166	flash:	567.716		Min: all the rest of obs.	21.95– 22.40	
167	Cepheid	866.943	5.2627	503.89; 508.90; 540.83; 977.65	21.54–)22.13 0, M	
168	Cepheid	977.650	5.1380	479.96; 510.86; 592.66; 833.94	21.66–)22.19 0, M	
169	Var?				22.55– 22.70	
170	Irr?			Max: 479.96 Min: 590.67	22.38– 22.88 8	
171	Irr?	close to another[a]		Max: 570.88 Min: 539.77	21.22– 21.91 10	difficult
172	Cepheid	897.775	4.76634	506.90; 573.91; 864.86; 868.89; 978.65	22.07– 23.06 5, F	
173	Cepheid	505.844	5.73585	482.95; 539.77; 896.80; 953.64	21.72– 22.48 2, F	n.i.c.
174	Cepheid	923.764	5.34452	479.96; 506.90; 565.71; 977.65	21.70– 22.44 0, F	n.i.c.
175	Cepheid	981.710	6.07449	507.90; 513.84; 592.66; 896.80	21.33– 22.36 – 4, m	n.i.c.
176	Slow			Max: 951.67; 981.71	21.90– 22.20 8	n.i.c.
177	Cepheid	977.650	6.107407	482.95; 507.90; 537.78; 836.93; 977.65	21.70– 22.41 3, R	n.i.c.
178	Cepheid:		32.0:	514.86; 572.87; 898.93	21.80– 22.30 5, R	n.i.c.
179	Eclipsing	865.902	20.7094:	Min: 513.84	21.70– 22.38 6, M	
180	Eclipsing	894.817	9.4126	Min: 508.91; 593.66; 977.66	21.30– 22.40 15, M	
181	Irr?			Max: 537.86 Min: 981.65	21.10– 21.43 16	
182	Cepheid	567.716	3.61089	512.84; 537.78; 571.79; 833.94; 979.65	21.80– 22.50 6, R	
183	Irr?	faint		Max: 511.87 Min: 573.91	21.80– 22.27 3	
184	Cepheid	980.700	3.8598	478.93; 536.86; 567.72; 953.64	21.88– 22.45 0, m	

[a] Discovered by S. G.

Table II. (Continued)

No.	Type	Epoch JD 2433000+	Period	Maxima or minima	Range	Remarks
185	Irr?	flashes:		Max: 540.83; 571.79; 590.67 Min: 594.78	22.48– 23.18	
186	Irr?	only once seen		898.93	22.37–)23.18 0	
187	Eclipsing		10^d:	Max: 867.88 Min: 506.71; 955.80	21.12– 21.47 6, M	small r.
188	Cepheid	511.874	7.69231	481.93; 572.87; 981.65	21.17– 22.03 6, M	
189	Cepheid?	504.9		Max: 504.86 Min: 570.85; 894.81	19.94– 20.88 20:	
190	Cepheid?		5.0:	Max: 479.96; 503.89 Min: 863.85	21.75– 22.25 3	
191	Cepheid	510.864	7.80055	503.89; 573.90; 924.79; 979.65	21.40– 22.43 4, M	
192	Irr?			Max: 979.65 Min: 981.71	22.58– 22.91	
193	Eclipse	982.82	27.9447	Max: 951.67 Min: 594.78	21.93– 23.22 – 4, m	n.i.c.
194	Irr? Var?			508.90; 573.91; 868.88	21.70– 22.00	n.i.c.
195	Cepheid	509.865	22:	592.67; 894.82	21.50–)22.20 – 6	n.i.c.
196	Eclipse	832.931	3.88138	506.90; 541.78; 572.87; 867.88; 898.92	22.26– 22.99 2:	n.i.c.
197	Cepheid	864.90	8.0:	Max: 536.86 Min: 506.90	21.95– 22.25 5	n.i.c.
198	Eclipse	830.944	5.636	509.86; 571.79	21.11– 21.83 8, M	
199	?	cycle	90.0:	Max: 864.86; (19.95); 954.70 Min: 482.95; 573.91	19.95– 22.55 –20, m	color?
200	Cepheid	830.944	9.44792	479.96; 508.86; 536.86; 923.76; 980.70	21.54– 22.43	n.i.c.
201	Cepheid	981.710	11.01865	509.86; 564.77; 894.81; 927.87	22.08– 22.84 – 1, F	
202	Irr			Max: 572.89 Min: 539.77	21.89– 22.34	
203	Cepheid		$30^d/n$	480.93; 509.89; 536.86; 571.79; 863.85	22.45– 23.00 8	n.i.c.
204	Eclipse?		5.0:	Min: 541.78; 566.71; 571.79; 591.67; 896.80	21.35– 21.85 3	n.i.c.
205	Cepheid	977.650	6.87897	511.88; 573.91; 879.88; 924.79; 979.65	21.84– 22.42 0, M	n.i.c.
206	Cepheid	870.543	11.6413	509.87; 541.78; 894.98; 951.67	21.57– 22.33 – 5, m	n.i.c.
207	Cepheid	980.700	4.25423	478.93; 482.95; 512.84; 567.72; 593.66; 865.90	21.68– 22.15 0, R	
208	small				21.60– 21.80 10:	
209	rapid			Max: 898.92; 955.80; 978.65 Min: 566.71; 895.83	21.21– 22.30 –28	
210	Cepheid?		314:	511.86; 536.86; 539.77; 540.80; 569.71; 570.81	22.20– 22.60	n.i.c.
211	very small range			Max: 952.68 Min: 864.86	22.74– 22.90 0	
212	Irr		5.0:	Max: 540.83 Min: 981.71	21.94– 22.92 – 6	
213	Ecl? Irr?		5.0:	Max: 953.63 Min: 507.90; 897.78	21.93– 22.83 8	
215	Irr		29.5:	Max: 833.94; 865.90; 953.64; 981.65	21.30–)22.40	n.i.c.
216	Irr			Max: 514.86 Min: 954.70	21.29– 21.70 12	n.i.c.
217	Eclipse?	895.833	5.355:	Min: 836.93; 863.85; 868.88; 951.67	21.85– 22.40 8	
219	Irr	cycle	500.0:	Max: 480.0; 980.0:	21.78– 22.25	
220	Irr?			480.0; 505.0; 536.0; 831.0; 834.0; 867.0; 900.0	21.90– 22.41 –20	
221	Cepheid	955.80	10.2465	508.89; 514.86; 594.78; 923.76	21.54– 22.20 6, M	
222	Cepheid	981.710	6.36430	478.93; 503.89; 509.87; 923.76; 955.80	21.84– 22.65 0, M	
223	Cepheid	980.700	12.54425	428.93; 592.61; 955.80	21.20– 22.25 2, M	

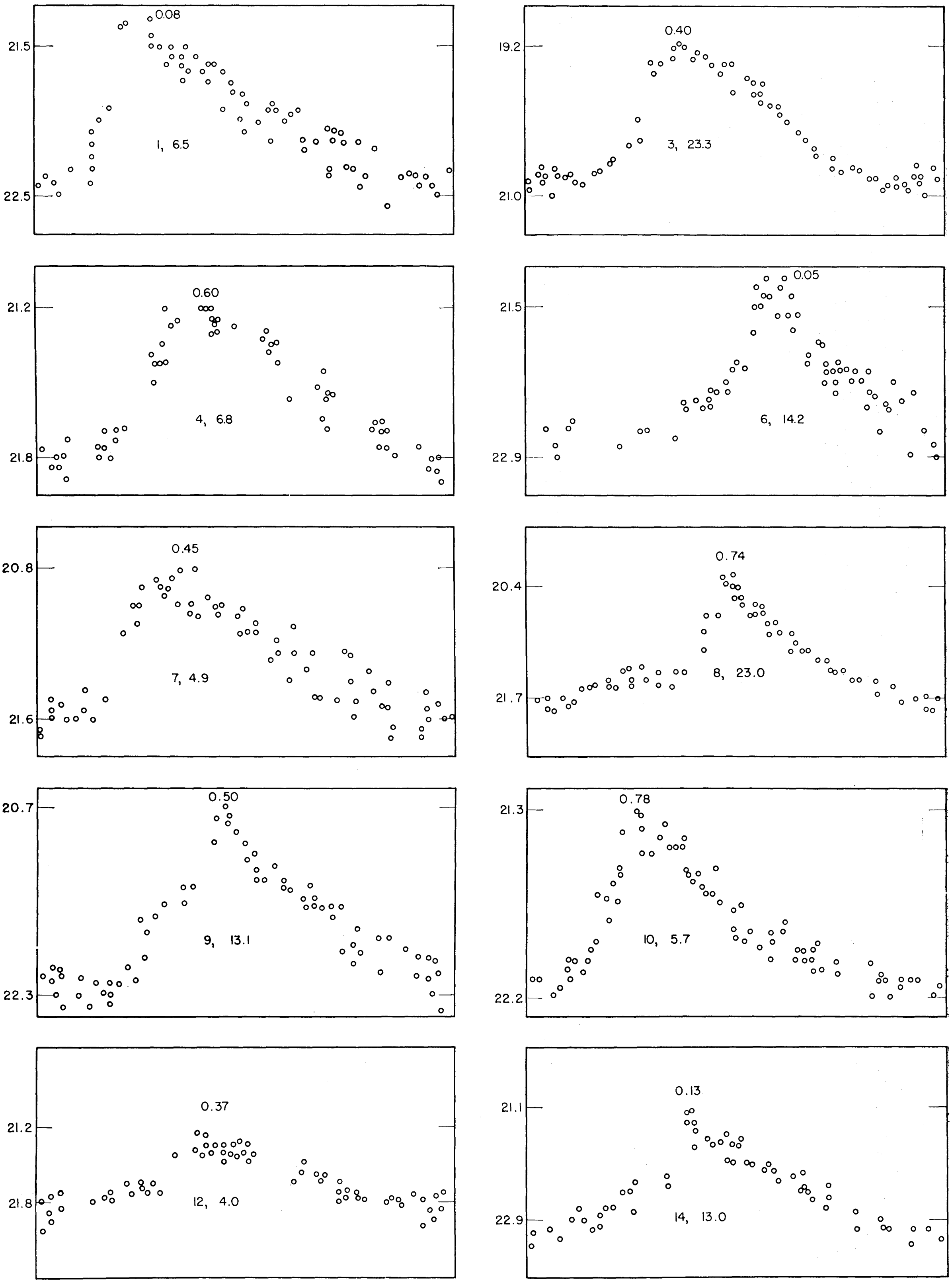

FIG. 4. Light curves of the variables in M31. Abscissa—Phases in terms of the period (each section is equal to 1/10 of the period). Ordinate—Photographic magnitudes on the international scale. The number at maximum for a Cepheid, or at a minimum for an eclipsing variable, gives the corresponding phase. Two other numbers, usually in the middle of the drawing, denote the star and its period, respectively.

FIG. 4 (*continued*)

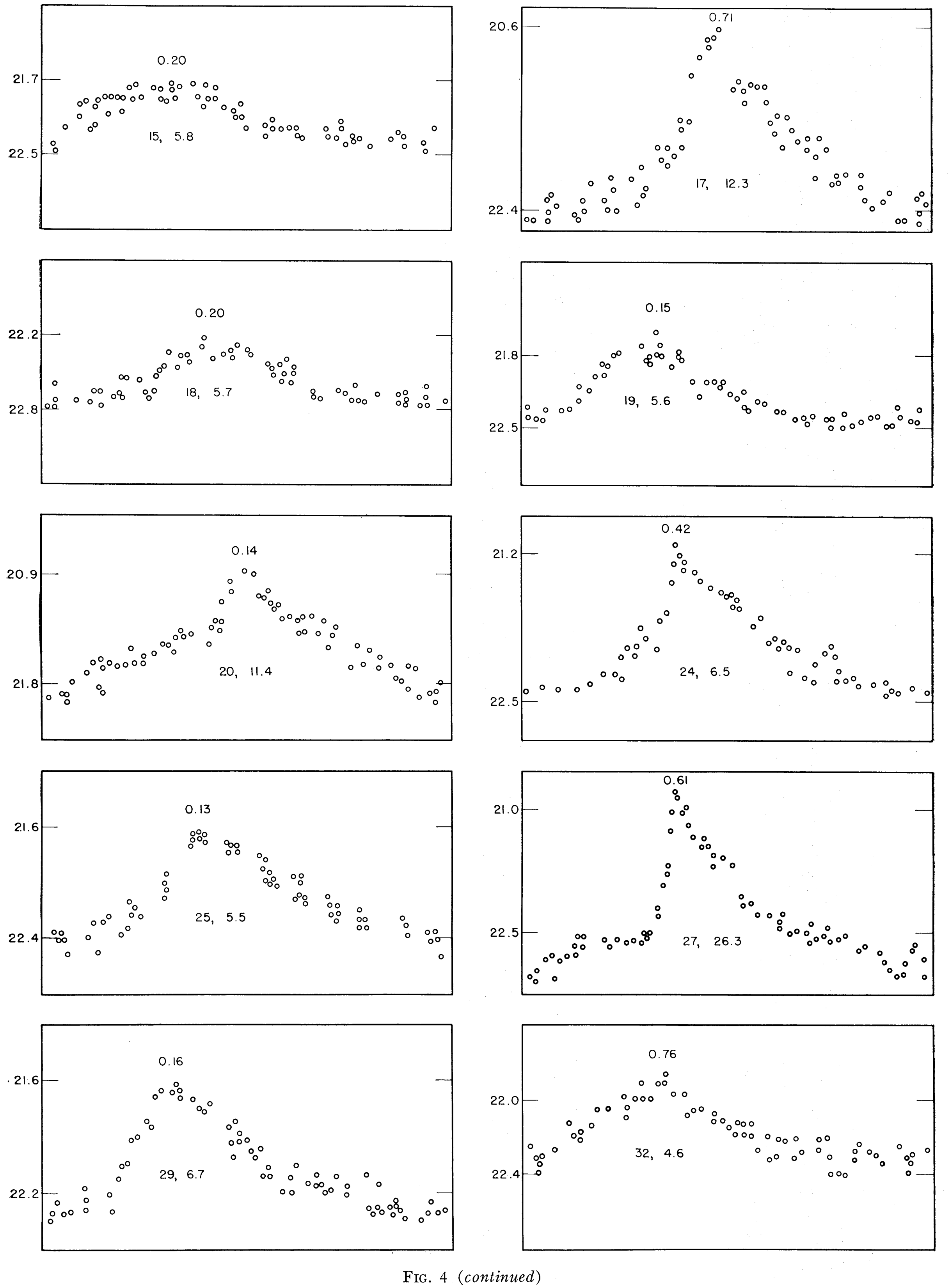

FIG. 4 (*continued*)

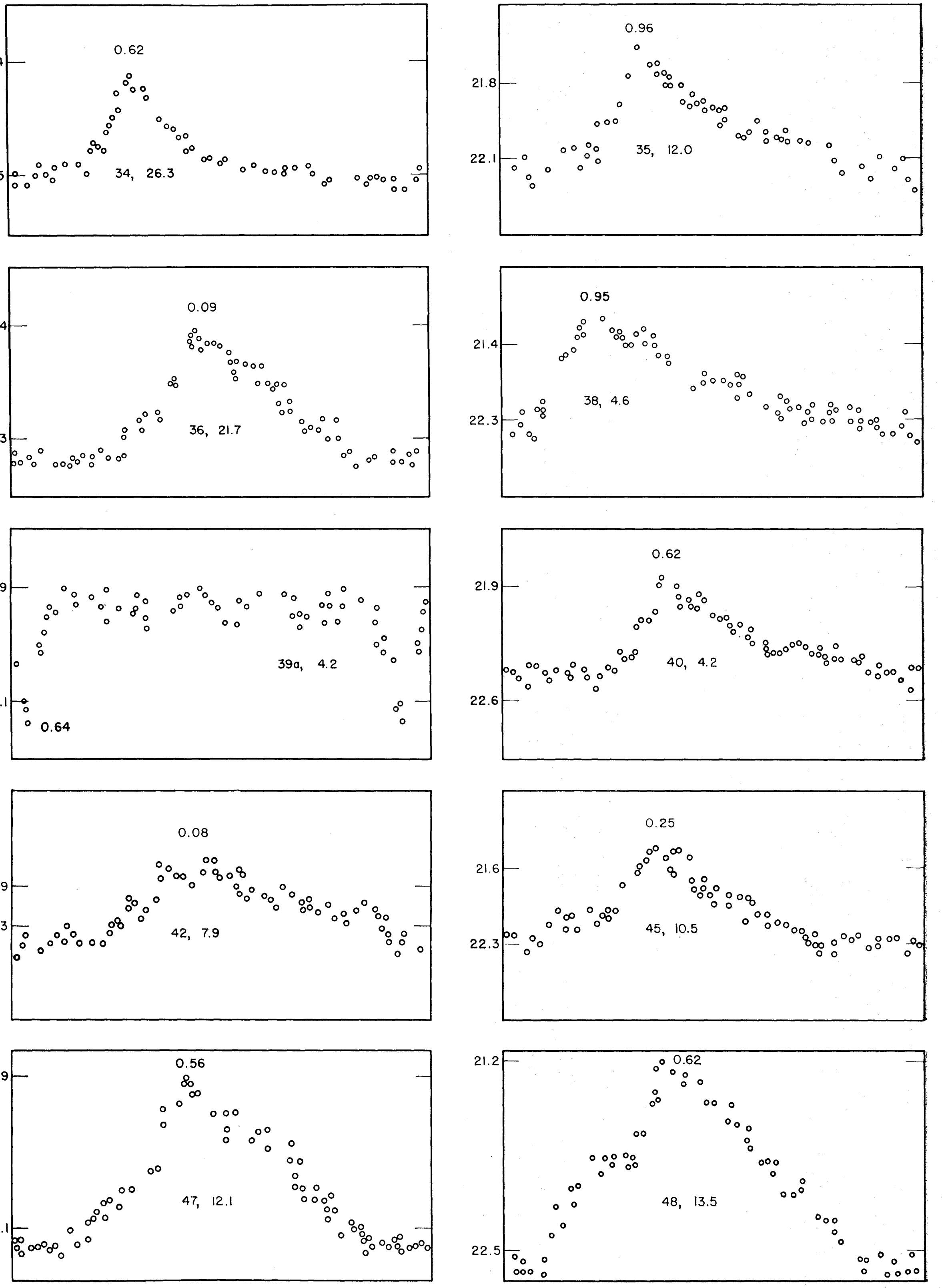

FIG. 4 (*continued*)

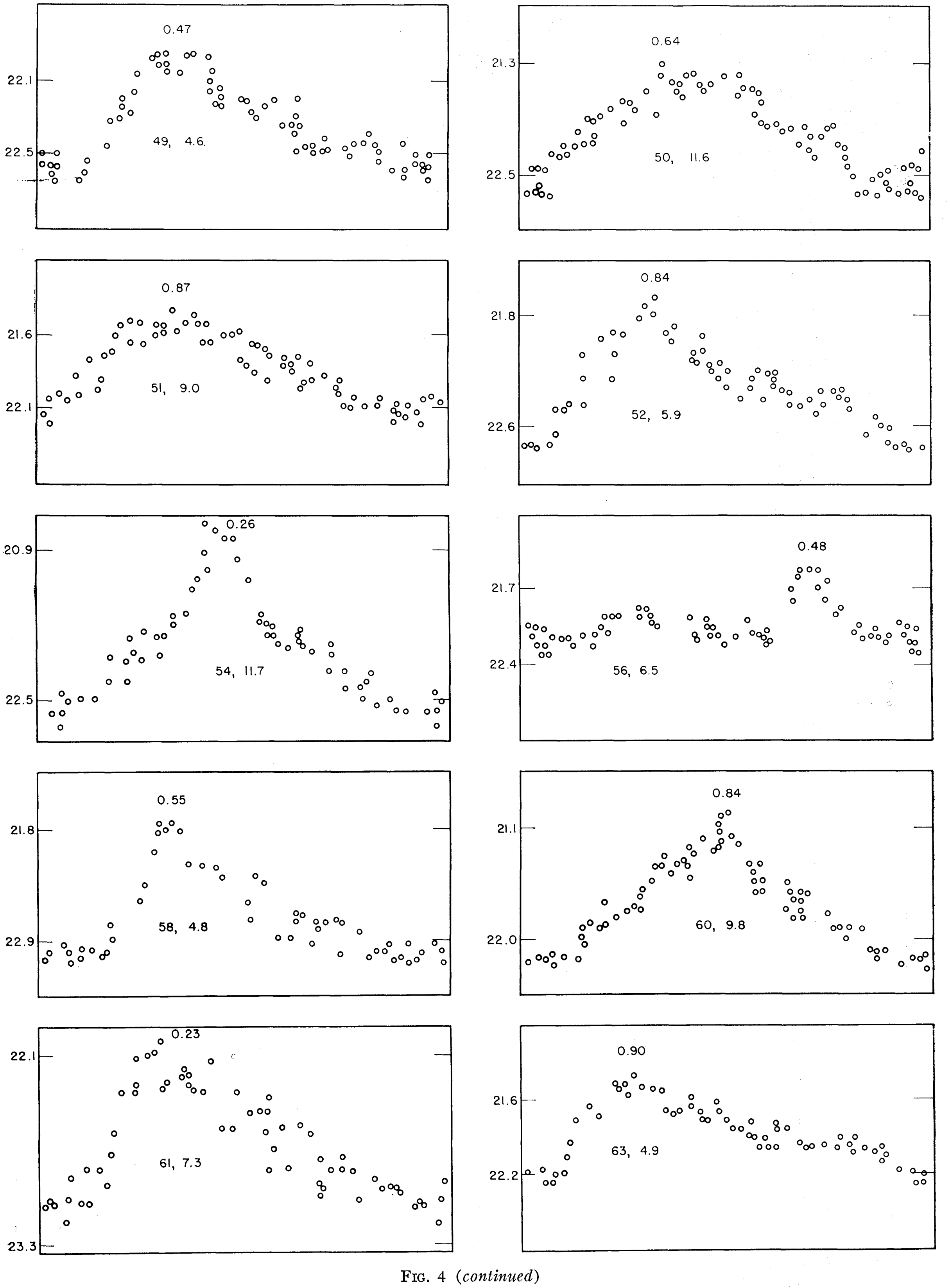

FIG. 4 (*continued*)

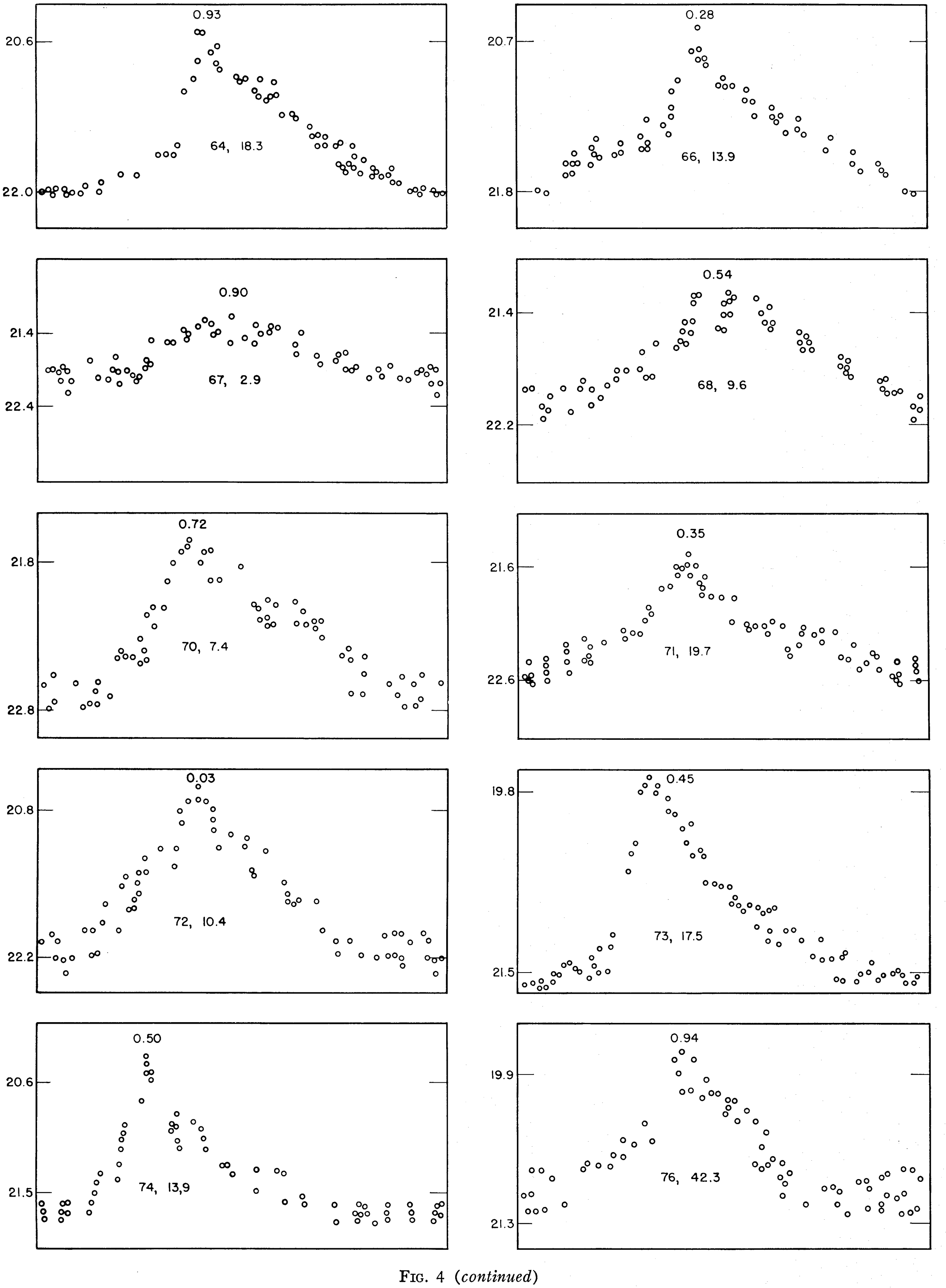

FIG. 4 (*continued*)

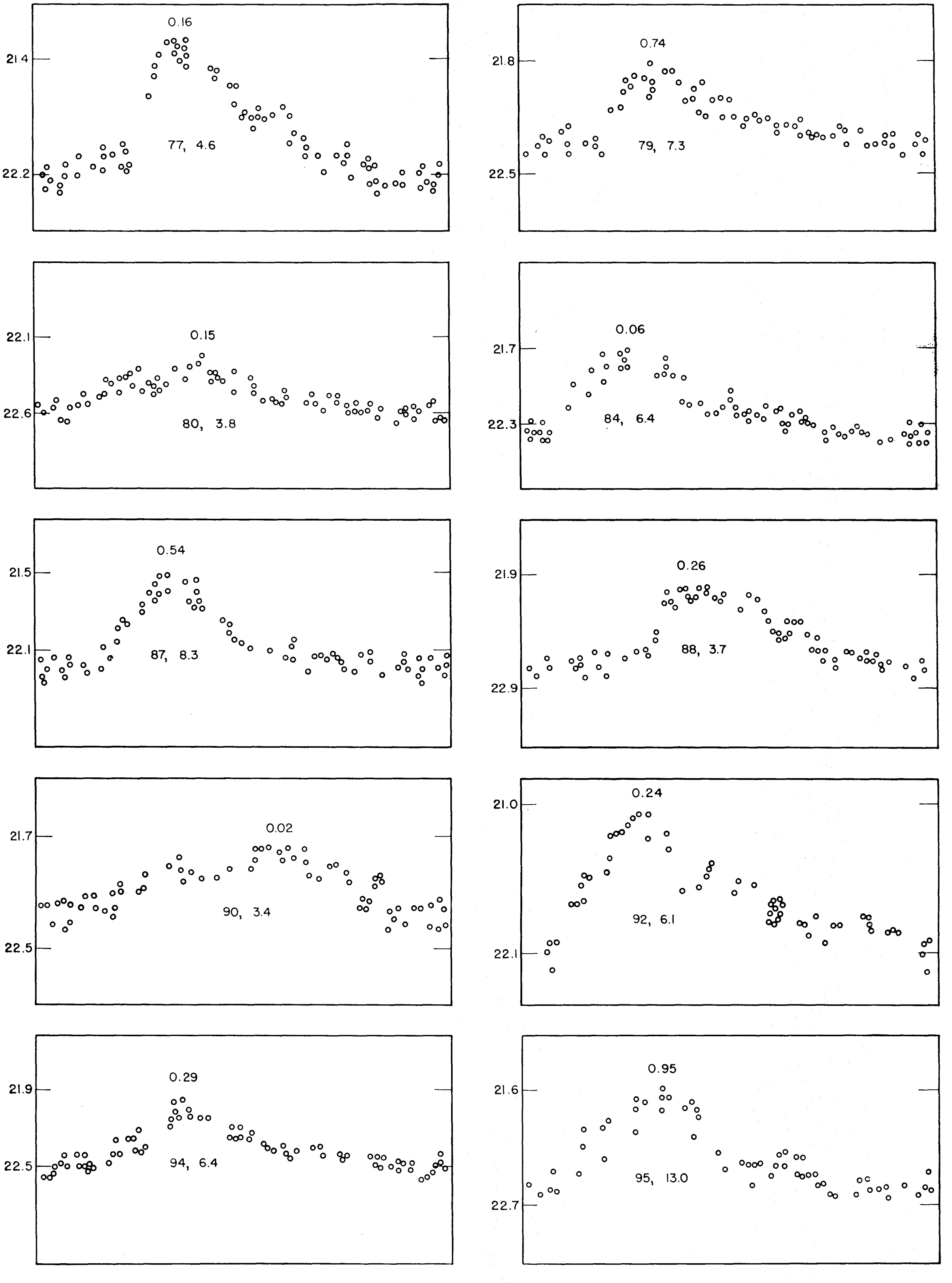

FIG. 4 (*continued*)

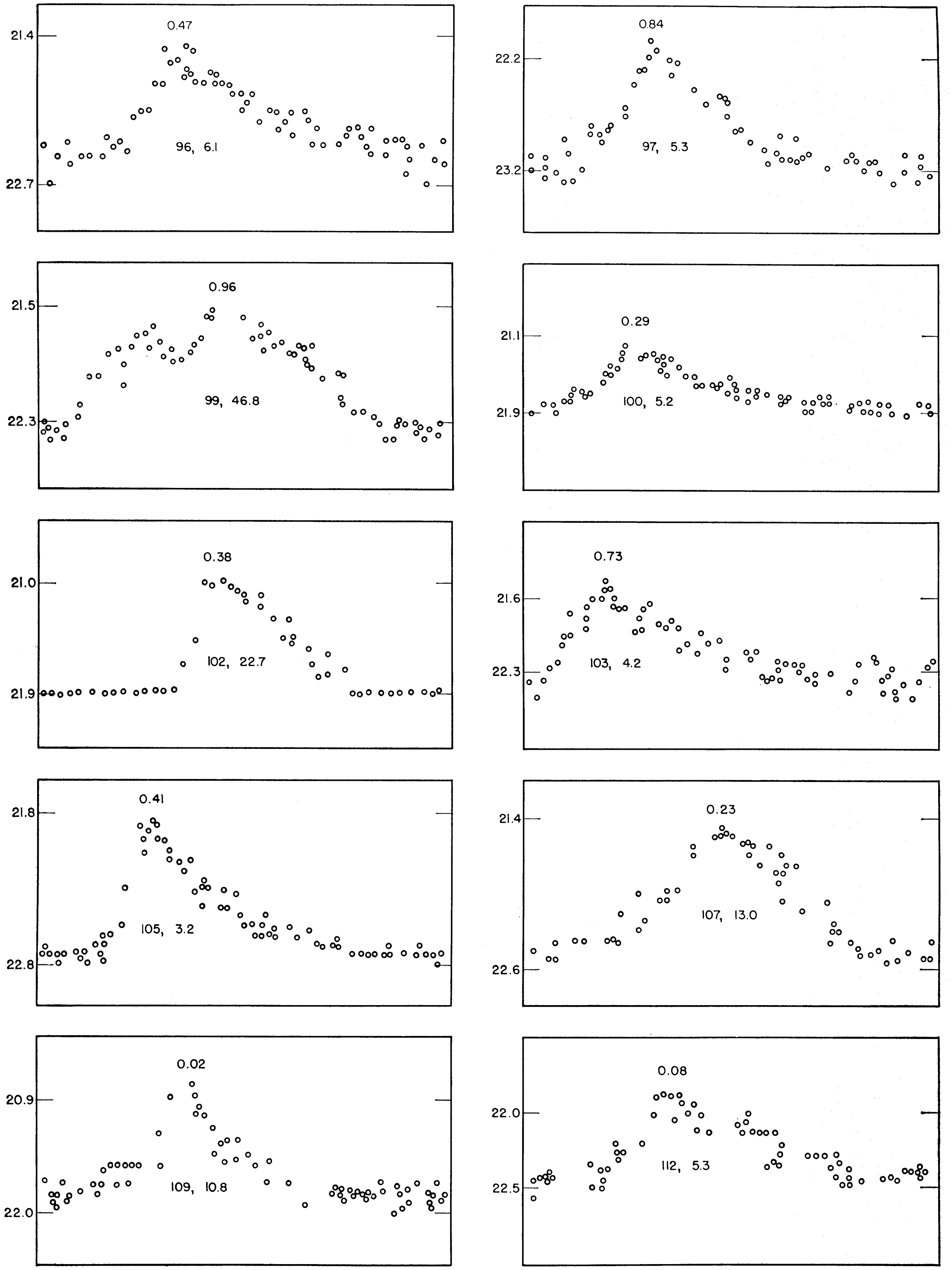

Fig. 4 (*continued*)

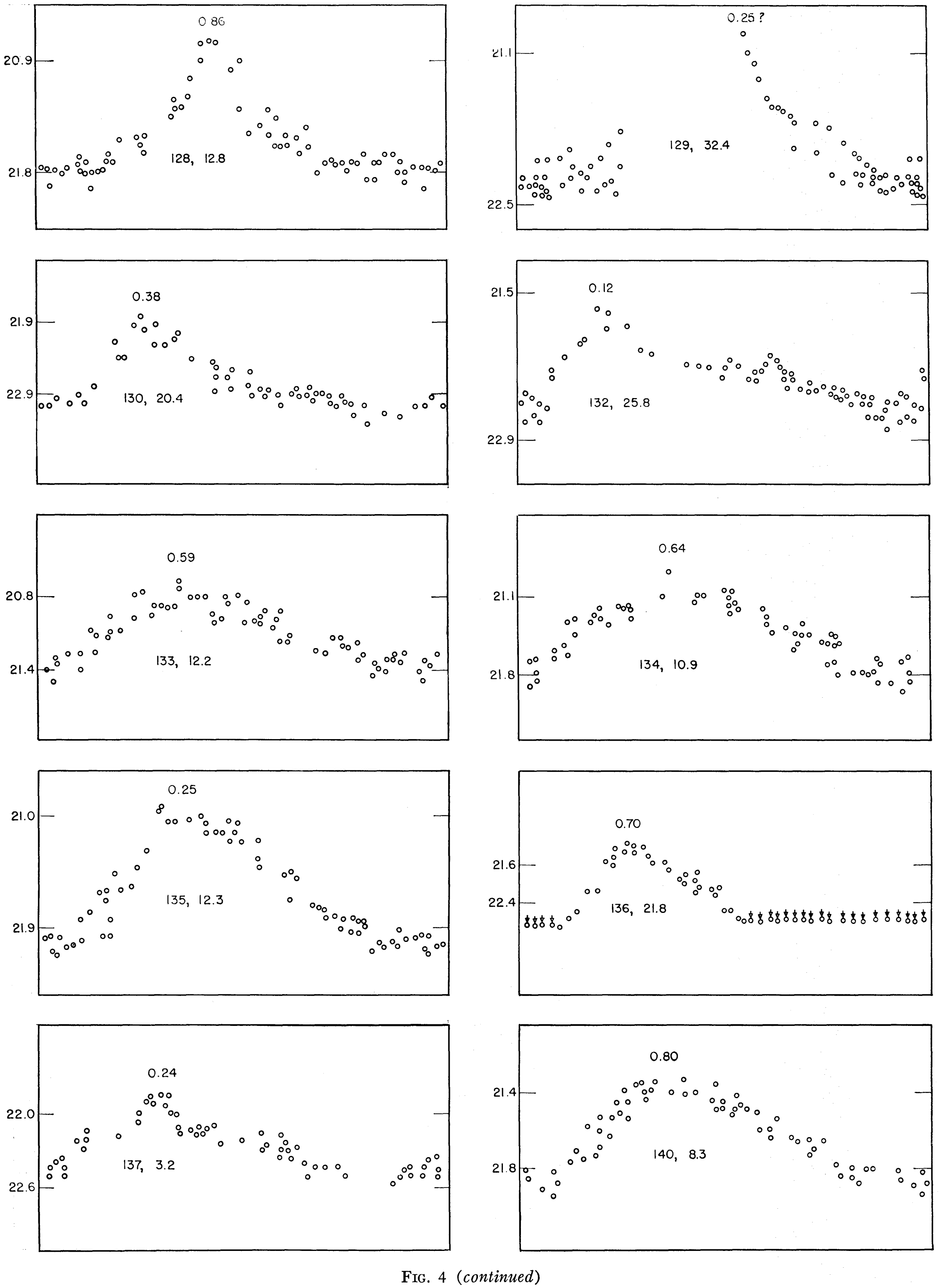

FIG. 4 (*continued*)

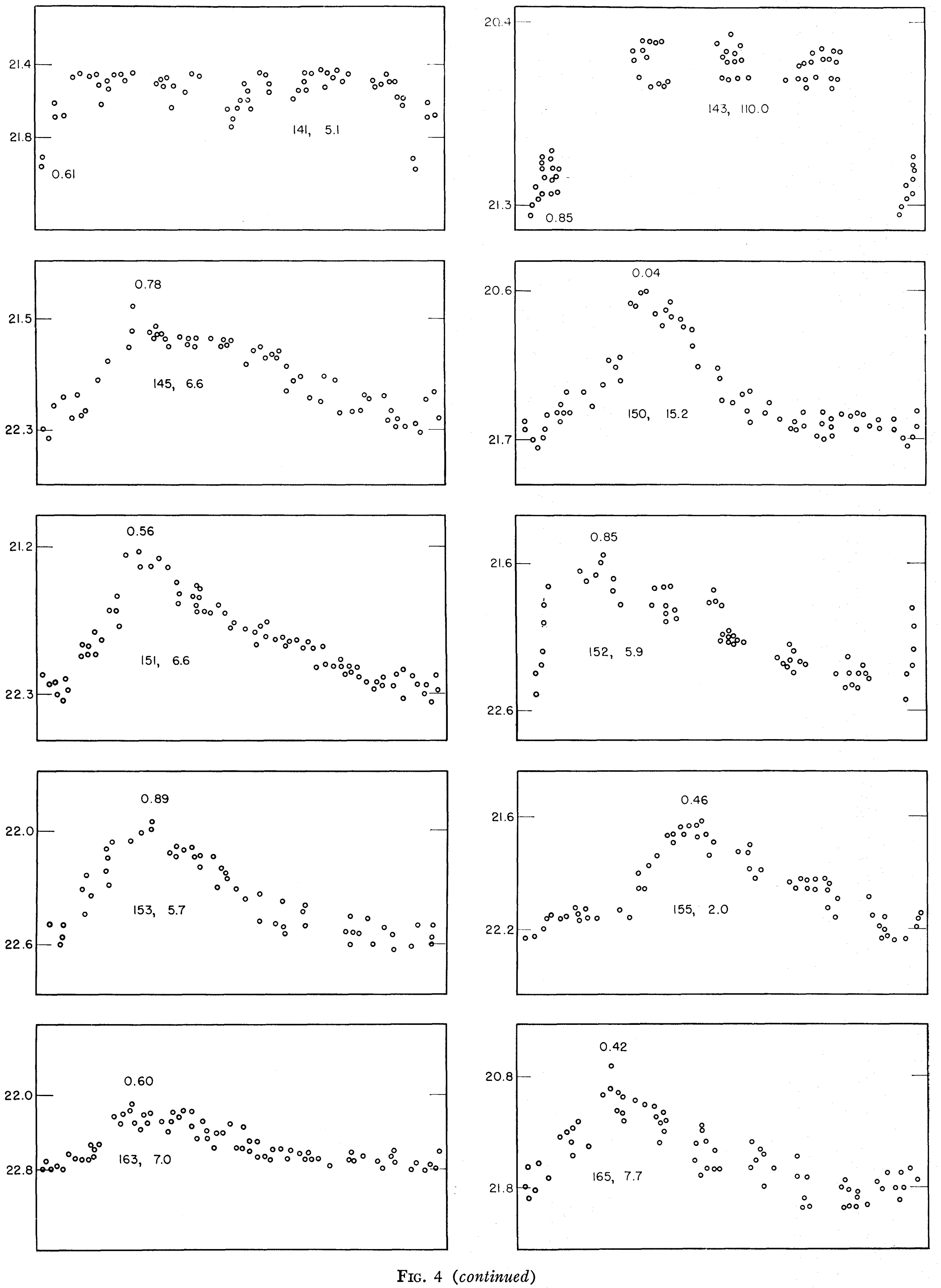

FIG. 4 (*continued*)

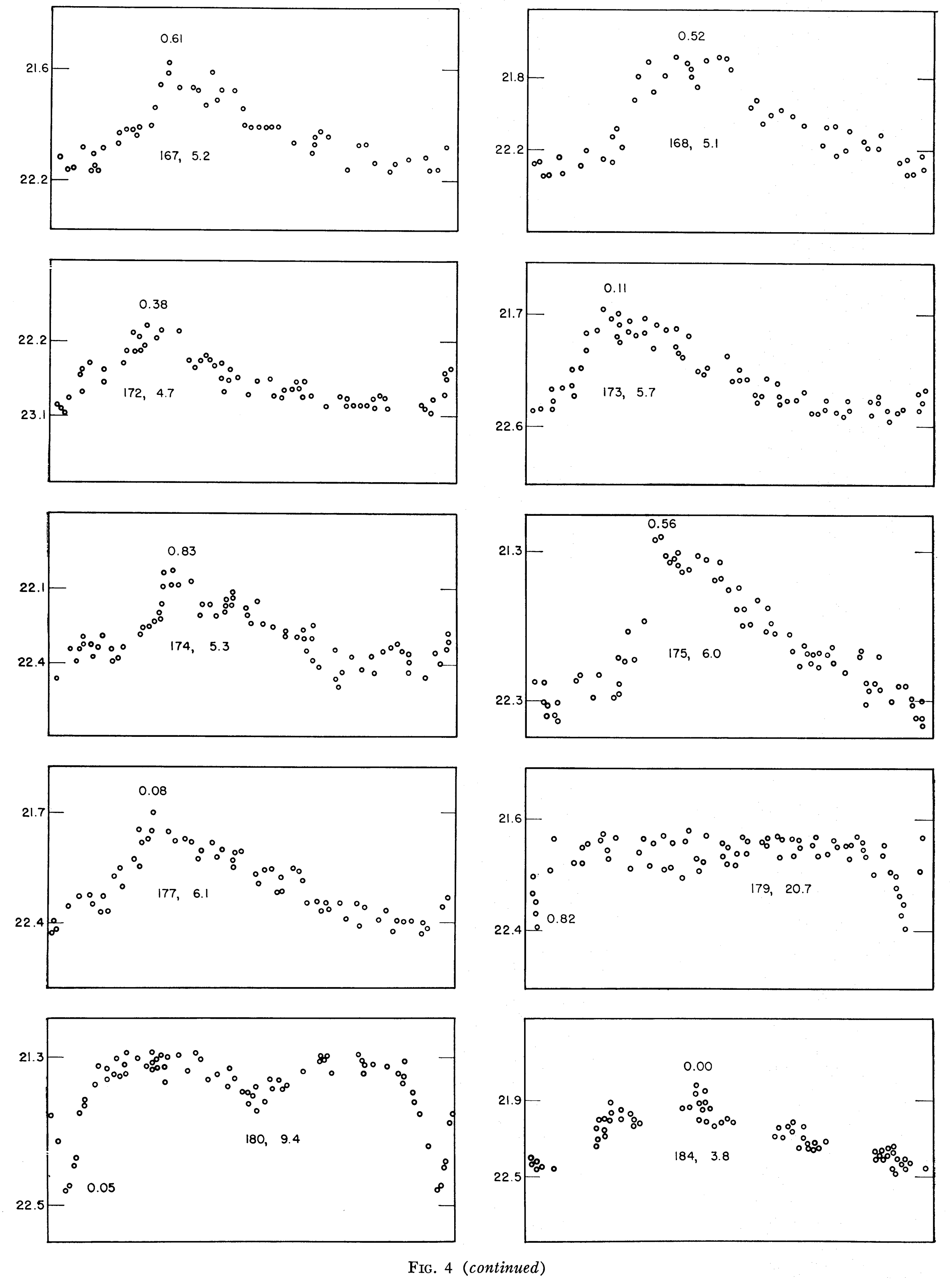

FIG. 4 (*continued*)

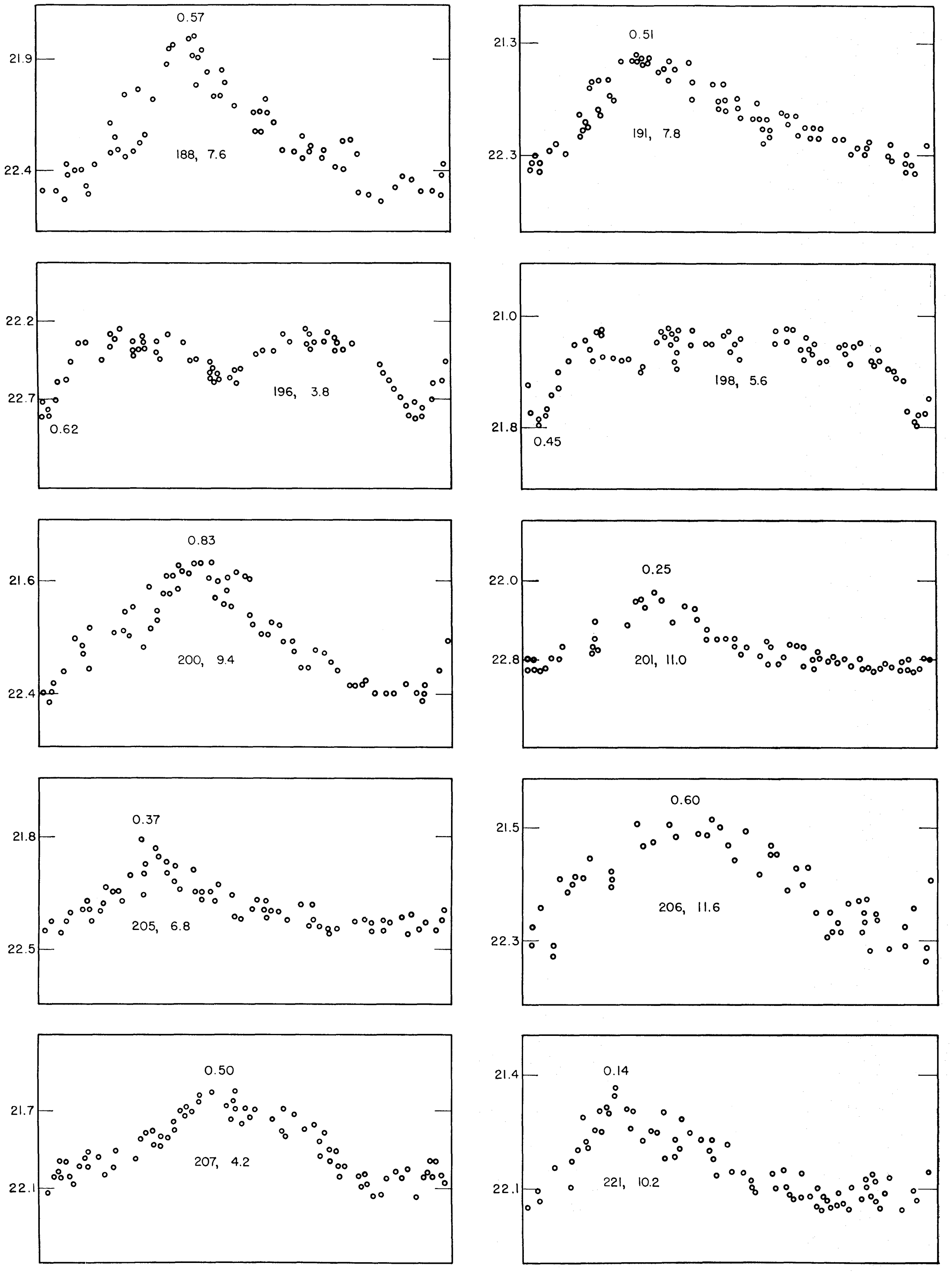

Fig. 4 (*continued*)

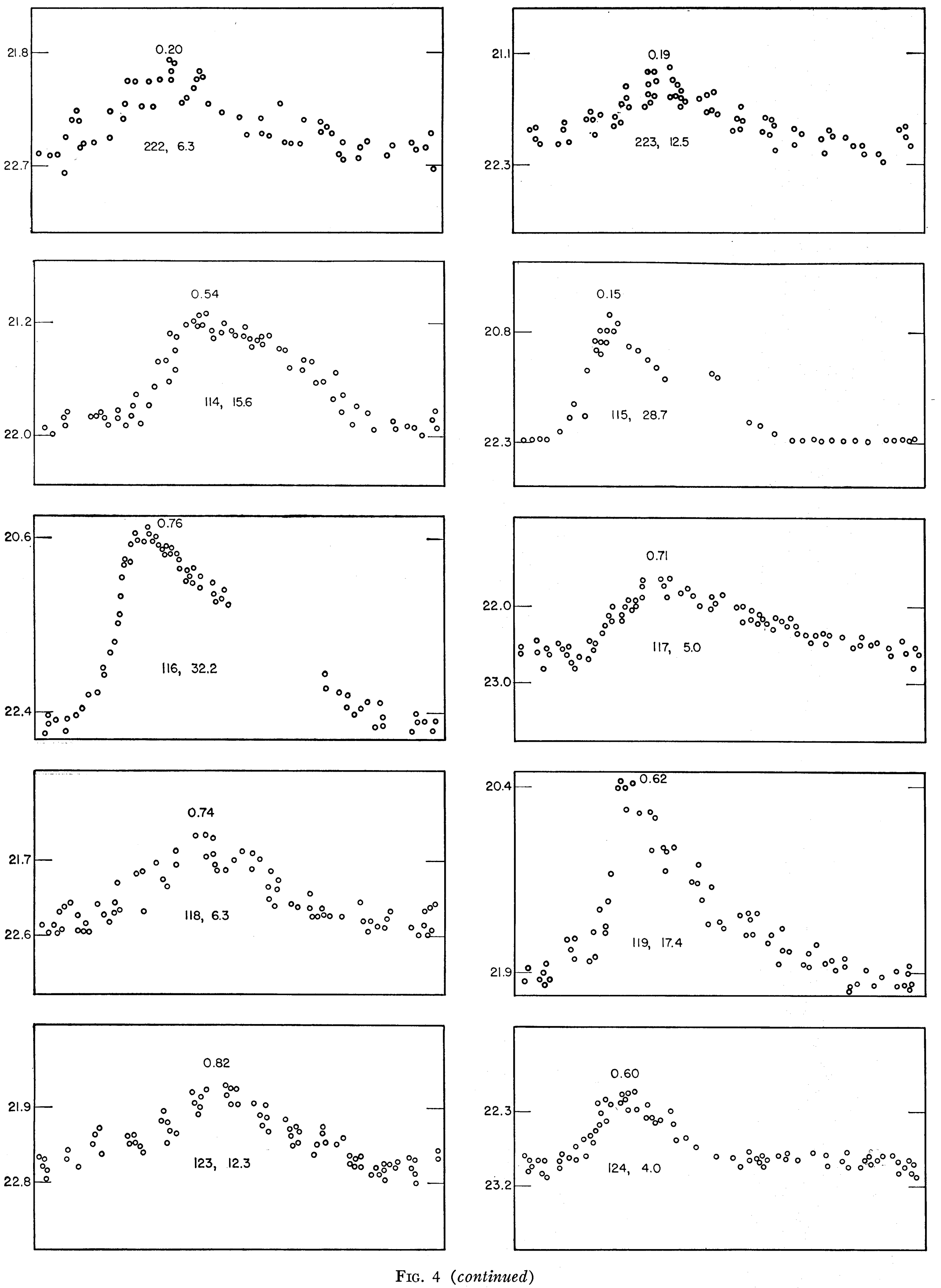

FIG. 4 (*continued*)

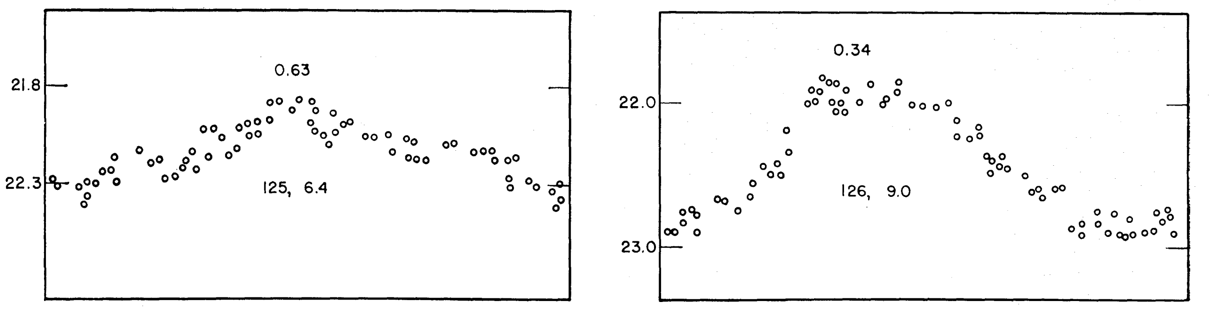

FIG. 4. (*continued*)

range of their intrinsic brightness, but, even more, by their number. As far as I am aware, no such percentage of these stars is found in our Galaxy as a whole.

There are eight eclipsing variables with definite periods and nine with uncertain periods, totaling about 8% of the group. None of these has a period less than $3^{\mathrm{d}}.8$ and each system is a β Lyrae type; both these facts are only to be expected, if we neglect for the moment the Algol type of the ζ Aurigae class. The probability of discovering such an Algol star is very remote because of the distribution of the plates.

There is one possible nova and one long-period variable; both facts are also only to be expected. A few variables are questionable.

Even a cursory glance at the location of the variables convinces us that the majority are imbedded in gas and dust. The inevitable conclusion follows that the brightness of each variable suffers from absorption. Even if there were a method (as far as I know there is not) of determining the amount of obscuration of stars in the Andromeda Nebula, my material consisting mainly of the photographic plates would not be sufficient to investigate problems connected with absolute magnitudes.

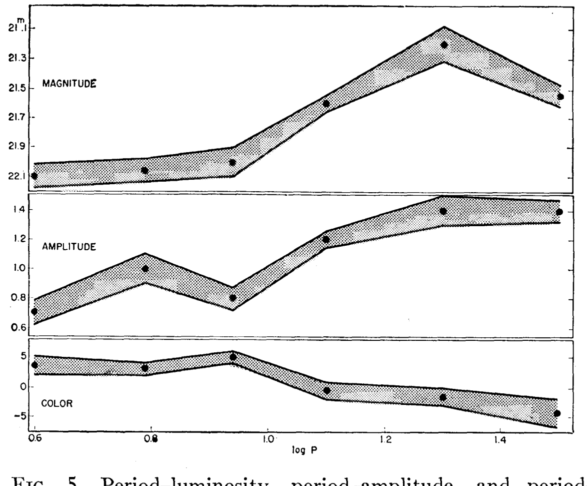

FIG. 5. Period–luminosity, period–amplitude, and period–color relations for the Cepheids in M31. Abscissa—Logarithms of the period. Ordinate—(top) Photographic magnitudes on the international scale. (middle) Amplitude of brightness variation. (bottom) Red color on an arbitrary scale.

V. CONCLUSIONS

Figure 5 was constructed in the following manner: for successive intervals of the period $<4^{\mathrm{d}}.7$, $<7^{\mathrm{d}}.0$, $<10^{\mathrm{d}}.4$, $<15^{\mathrm{d}}.5$, $<25^{\mathrm{d}}.0$ and $<100^{\mathrm{d}}.0$, average values of period, amplitude, color, and magnitude were plotted. It shows that the median brightness of the Cepheids remains about the same ($22^{\mathrm{m}}.0$) in the period interval of two to about six days, then the brightness increases and reaches its highest point at about 20 days. In other words, the period–luminosity relation, relatively well established in the Magellanic Clouds, appears to be real in the Andromeda Nebula.

The amplitude of the variables increases with period up to about six days, then decreases until about nine days, and finally ascends again to the highest value. These two great regions, before and after the wedge at about nine days, are surprisingly similar to those known in the analogous relation among the Cepheids in the Milky Way.

The colors of the Cepheids in the Andromeda Nebula remain practically unchanged until about the same wedge of nine days, after which they become redder. For my discussion, I reduced the color to the median magnitude; because of the unknown relation to the international red magnitude the color scale and zero point are arbitrary. The color has, however, a definite physical meaning which with reversed sign is

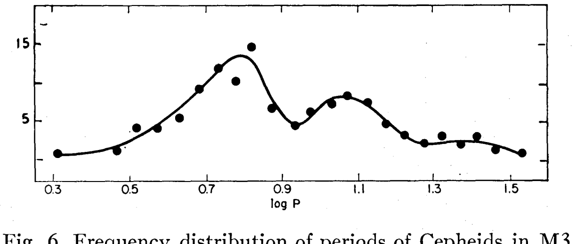

Fig. 6. Frequency distribution of periods of Cepheids in M31. Abscissa—(top) Logarithm of the period. Ordinate—Number of stars.

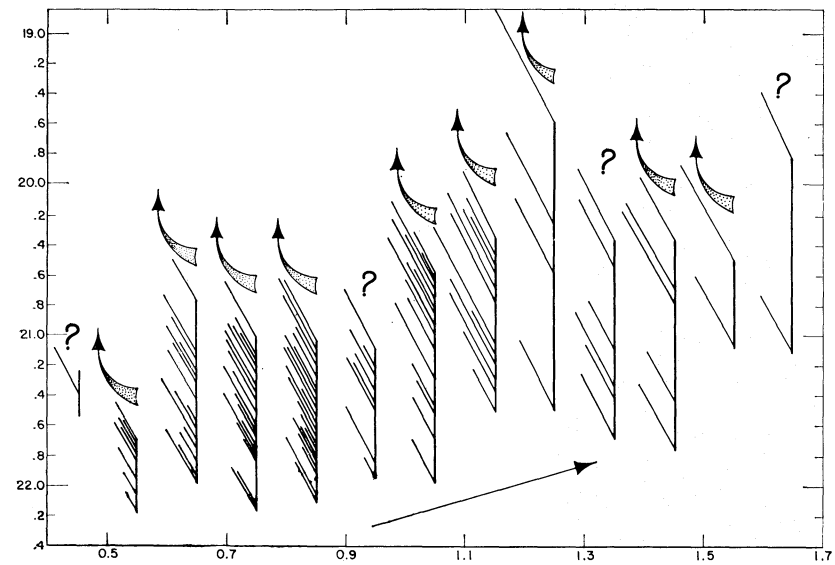

FIG. 7. Diagram of amplitude as a function of period and maximum magnitude for the Cepheids in M31. Abscissa—Logarithm of the period. Ordinate—Magnitude at maximum brightness. Slanted strokes—Size represents the value of the corresponding amplitude. Arrows—Indicate a tendency of the amplitude to increase with an increase of maximum brightness.

similar to the conventional expression of color; zero on this arbitrary scale corresponds approximately to spectral class F.

The distribution of the periods of the Cepheids was plotted in Fig. 6, which shows two maxima: one at about $6^{d}.3$, and the other around $12^{d}.7$.

The lane and coil formations which I have mentioned are the result of my division of the Nebula as photographed on our plates (see Fig. 1). From a general inspection of the field, I delineated seven distinct regions: the central bright coil, the first dark lane, the second bright coil, the second dark lane, the giant bright association, the third bright coil, and the third dark lane. A consideration of the superficial yet natural division of the field into coils and lanes, roughly corresponding to the usual division into arm and interarm regions, allows one to perceive the following possibilities: in the first coil the mean value of the period is $8^{d}.3$ (3 Cepheids) with an amplitude of $0^{m}.6$ and mean magnitude of $22^{m}.0$; in the first dark lane the period is surprisingly large, $16^{d}.6$ (6 Cepheids) with the corresponding values of amplitude $1^{m}.0$ and brightness $21^{m}.0$. This conspicuous difference between the stars in the coil and those in the lane tends to be repeated in the second pair of coils and lanes, i.e., $10^{d}.0$, $1^{m}.0$, $21^{m}.8$ (51 Cepheids), and $13^{d}.3$, $1^{m}.1$, and $21^{m}.8$ (18 Cepheids). In the giant association (11 Cepheids) the period is definitely shorter, $8^{d}.8$, but the brightness seems to be greater, $21^{m}.6$. In the third pair the relation seems to reverse, $12^{d}.6$ (19 Cepheids), and $7^{d}.8$ (12 Cepheids). Ignoring any difference between coil and lane, and regarding the variables as a function of distance from the center of the nebula, I find a definite decrease of the period: first pair, $P=13^{d}.8$ (9 stars); second pair, $P=10.9$ (68 stars); giant association, on the border of the third pair, $P=8.8$ (12 stars); third pair, $P=9.9$ (31 stars). Approximate distances of these regions are six, eight, and ten thousand parsecs from the center. In other words, the Cepheids in the Andromeda Nebula with the highest luminosity appear to be nearer to the center. This result may have only a superficial meaning or it may be a significant characteristic. We must remember that the numbers of participants in these regions, excluding the giant association, are not congruent for direct comparison; the volumes are very different and an assignment of a star to a region is not always easy. However, these very considerations demand a more complete investigation of the problem in the future.

The number of Cepheids discussed here is considerable; they should represent a good sample of standard characteristics. I believe that the most important features of Cepheids are luminosity, period, and amplitude. Therefore, a three-dimensional diagram may be revealing. I have constructed such a diagram (Fig. 6) in the following manner: as abscissa I used the logarithm of the period and as ordinate the apparent magnitudes at maximum; then, on each ordinate for the middle of the interval of logarithm I drew for each Cepheid a straight line so that its lower end corresponded to the maximal brightness and the upper end was placed at an angle of about 30° to the ordinate and at a distance proportional to the amplitude or the range of brightness. As a result, I obtain a diagram which represents not only a period–luminosity but also a period–amplitude and an amplitude–luminosity relation. In the diagram the well-known relation of period–luminosity is indicated by the straight arrow despite the fact that the apparent magnitudes are affected by absorption. The frequency pattern of period–amplitude also stands out. Furthermore, the diagram illustrates a new possible relation; for any given period, the brighter the Cepheid at maximum, the larger its amplitude (arrows indicate this trend). Apparently, the amplitude increases upwards for each particular interval of the period and at the same time increases throughout the period. In some intervals this relation is uncertain, especially at the wedge of nine days where every relation among Cepheids, so to speak, breaks down. This graphic, three-dimensional presentation of fundamental properties of the Cepheids underlines again the importance of accurate photometry in such a study. Although I feel that the faint magnitudes given here are not as accurate as they should or could be, any possible inaccuracy should not nullify the results presented.