A SPIRAL NEBULA AS A STELLAR SYSTEM, MESSIER 31[1]

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ABSTRACT

Material.—The present discussion of M 31 is *based on the study of about 350 photographs* taken with the 60- and 100-inch reflectors, distributed over an interval of about eighteen years. Two-thirds of the total number were obtained by the writer during the five years 1923–1928. Since the image of the nebula is much larger than the usable fields of the telescopes, *attention was concentrated on four regions centered* on (1) the nucleus, (2) 23′ north following, (3) 17′ south, (4) 48′ south preceding the nucleus. The combined *area*, with allowance for overlapping, *represents about 40 per cent of the entire nebula.*

Resolution.—The *outer regions* of the spiral arms are *partially resolved into swarms of faint stars*, while the *nuclear* region *shows no* indications of *resolution under any conditions* with the 100-inch reflector. Intermediate regions show isolated patches where resolution is pronounced or suggested.

Variables.—Fifty variables have been found, nearly all in the outer regions where resolution is pronounced. The *survey* is believed to be *fairly exhaustive in the four selected regions down to 19.0 photographic magnitude.*

Cepheids.—Forty of the *variables* are *known to be Cepheids* with periods from *48 days to 10 days* and *maxima from 18.1 to 19.3 photographic magnitude;* one exceptional star varies from 17.9 to 19.2 in a period of 175 days. The *period-luminosity relation is conspicuous*, and the slope is *approximately that* found among *Cepheids in other extra-galactic systems.*

Distance of M 31 derived from Cepheid criteria.—Comparisons of period-luminosity diagrams indicate that M 31 is about 0.1 mag. or 5 per cent more distant than M 33, and about 8.5 times more distant than the Small Magellanic Cloud. Using Shapley's value for the Cloud, we find the *distance of M 31* to be *275,000 parsecs.*

Variables other than Cepheids.—Of the 10 remaining variables, 4 are probably very faint Cepheids for which the data are insufficient to establish the characteristics, and 6 are irregular or long-period variables. The latter group includes the brightest variables in the nebula.

Novae.—Sixty-three novae have been found by the writer, which, together with the 22 previously observed, gives a *total of 85 observed photographically* which are now *available* for *statistical investigation.* The novae exhibit a striking similarity in their behavior, and the *mean light-curve is of the same general character as that for galactic novae.* The frequency distribution of magnitudes at maxima can be represented by an error-curve with a maximum at about 16.5 ($M = -5.7$ for the distance indicated by the Cepheids) and a probable error for a single nova of about 0.5 mag. Selective effects appear to be unimportant, and a restricted range of about 4 mag. seems to be established.

Novae are most frequent in the nuclear region, and, in a general way, the distribution follows that of the luminosity in the nebula. Position in the nebula appears to have no effect on the luminosity of novae. It is *estimated* that *novae appear at the rate of about 30 per year.*

Brighter non-variable stars.—Preliminary surveys suggest that few stars in M 31 are brighter than $M = -6$ (distance, that indicated by the Cepheids) and that large numbers are to be found only for M fainter than -5. A study of the open cluster N.G.C. 206, involved in M 31, indicates that the average color-index of the brighter stars is of the order $+0.3$ or $+0.4$ mag.

Mass and luminosity densities in M 31.—The mass density of M 31 appears to be of the order of one sun per 20 cubic parsecs, and the luminosity density, about 9.0 mag. per

[1] *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 376.

cubic parsec. With the sun as unit, $Mass = 5.5L$. These values are of the *same order as those for the galactic system* in the neighborhood of the sun. As the nucleus is approached, the coefficient of the mass-luminosity relation decreases until, for the nucleus itself (diameter about 4 parsecs), it falls below 0.001.

Relative dimensions of M 31 and the galactic system.—A tentative comparison of sizes, masses, luminosities, and densities suggests that the *galactic system is much larger than M 31* but that the ratio is not greater than that between M 31 and other known extra-galactic systems.

Messier 31, the great nebula in Andromeda, is the most conspicuous of all the spirals and the only one which can be seen easily with the naked eye. It appears as a hazy patch about 30′ by 15′, somewhat brighter in the center, with a total luminosity variously estimated as from the fourth to the fifth magnitude. The object is listed as a nebula in the tenth-century star catalogue of Al-Sufi, and appears on some of the pre-telescopic star charts. It was first examined with a telescope in 1612 by Marius, who gave the famous description, "like a candle seen through a horn." Of the many subsequent drawings and descriptions that were based on visual observations, the most notable are those by Bond and by Trouvelot.

In 1885 interest in the nebula was stimulated by the appearance of a nova very close to the nucleus, which reached the eighth magnitude. Two years later the photographs made by Isaac Roberts with his 20-inch reflector showed for the first time the main pattern of the spiral structure. Ranyard reproduced one of Roberts' photographs in *Knowledge* for February, 1889, and the article which accompanied it was the best discussion of a spiral nebula which had appeared up to that date.[1] Among other things he mentioned the numerous stars in the outer regions of the nebula, the significance of which was not fully appreciated until many years later.

Early visual observers of the spectrum reported bright lines on a continuous background. In 1899, however, Scheiner[2] photographed the now familiar solar-type absorption spectrum and announced emphatically that the nebula must be a system of stars. Radial velocities of the order of −300 km/sec. have since been measured by several observers. The inclination of the lines which appears when the slit is oriented along the major axis, first reported by Slipher, was

[1] This first reproduction was from a drawing copied from the negative. The same volume, however, contains two photographic reproductions, the later of which, in the August number, is exceptionally good.

[2] *Astrophysical Journal*, **9**, 149, 1899.

measured by Pease[1] in 1917. The linear velocity of rotation as indicated by the measures is of the order of $0.48x$ km/sec., where x is the distance from the nucleus in seconds of arc. The measures extend to about 150″ from the nucleus, and the rotation is in the sense that the south preceding end of the nebula is approaching us relative to the nucleus.

Ritchey,[2] in 1917, discovered two faint novae on his earlier photographs of M 31, and since then the observers at Mount Wilson, following the nebula for the purpose, have found eighty-three others. In the course of this work the writer, in 1923, found two faint variable stars which further investigation proved to be Cepheids with periods of twenty and thirty-one days, respectively. About the same time, photographs centered along the outer arms of the spiral revealed a high degree of resolution into individual stars (Plate III), which was entirely lacking in the nuclear region where previous plates had been centered. This opened a new field for investigation—the study of individual stars involved in a spiral nebula—which has been developed primarily by means of the 100-inch reflector.

Thus far some fifty variables have been found in M 31, and forty of them are known to be Cepheids. The period-luminosity relation is conspicuous among the Cepheids, hence the distance of the spiral is determined with considerable accuracy in terms of the distance of the Magellanic Clouds. Shapley's value for the zero point of the period-luminosity relation leads to a provisional value for the absolute distance.

The stars in M 31, including the novae and the Cepheids, are so closely comparable with those in the neighboring spiral, M 33, that the two systems may be combined for a general discussion. The considerable numerical data resulting from this combination, together with the consistency of the various independent criteria, confirm the general order of the distances derived from the Cepheids and suggest no revision of Shapley's value for the zero point of the period-luminosity relation. The data for M 33 have already been published,[3] and will be used freely in the present discussion of M 31.

[1] *Proceedings of the National Academy of Sciences*, **4**, 21, 1918.

[2] *Publications of the Astronomical Society of the Pacific*, **29**, 210, 1917.

[3] *Mt. Wilson Contr.*, No. 310; *Astrophysical Journal*, **63**, 236, 1926.

VARIABLE STARS

M 31 is an intermediate-type spiral, Sb in the writer's classification,[1] with its equatorial plane inclined about 15° to the line of sight. The unresolved nuclear region is about $30' \times 10'$, and the maximum extension of the arms, on long exposures, is about $160' \times 40'$. The arms exhibit considerable resolution, and there are patches, especially in the south preceding end, where the stars fairly swarm on the photographic plates.

Fifty variables have been found among the stars scattered over the image of the spiral, and most of these undoubtedly belong to the nebula. The search is believed to be fairly exhaustive, down to 19.0 photographic magnitude, in four regions of the nebula, centered as follows:

Region 1. The nucleus
2. 23′ north following the nucleus
3. 17′ south of the nucleus
4. 48′ south preceding the nucleus

The usable fields around these centers have radii of from 12′ to 15′, and the combined area, with allowance for overlap in Regions 1–3, represents about 40 per cent of the entire nebula.

For the central region and for the brighter stars in the adjacent regions as well, some two hundred and seventy plates covering a period of eighteen years are available. A series of ten photographs by Ritchey in the autumn of 1909 is followed by a gap of eight years during which only three usable plates were obtained, but from 1917 on the material is fairly well distributed. Previous to 1920 the plates were all obtained with the 60-inch reflector; since then the 60- and the 100-inch have been used indiscriminately. The exposures and seeing conditions vary widely since many of the plates were obtained in the search for the relatively bright novae. The better photographs represent average exposures of about sixty minutes with the 60-inch reflector and thirty to forty minutes with the 100-inch, although occasional plates were exposed up to five hours or more. In general, fast plates were used throughout.

The photographs centered on Regions 2, 3, and 4 represent exposures of seventy-five to ninety minutes with the 100-inch reflec-

[1] *Mt. Wilson Contr.*, No. 324; *Astrophysical Journal*, **64**, 321, 1926.

tor and, in general, are of a rather better quality. The variables in Regions 2 and 3 have been followed consistently only since 1924, but some of them are found on the larger and longer-exposed plates of the earlier series. The season 1924–1925 is especially well represented. Two series of fifteen and ten consecutive nights, respectively, during which the observing conditions were uniformly excellent, indicated immediately the general nature of the light-curves of many of the variables, and suggested periods which were confirmed by reference to earlier plates. Variables Nos. 5 and 10, with about sixty-five observations each, are the least well observed.

Some seventy-five plates of Region 4 have been assembled, representing exposures on about sixty different nights. The material appears to be rather scanty, but, in this region as well as in the others, each variable for which a period has been determined has been followed for at least one complete season after the determination, and in no case has this test led to a radical revision. Periods close to an even day, or submultiple of a day, have been definitely eliminated by sets of plates obtained on single nights. In all, about twenty such sets were made, often on successive nights, representing intervals ranging from two to nine hours.

Sequences of comparison stars with steps averaging about 0.2 mag. were selected for each variable and were calibrated by some sixteen comparisons with Selected Areas 20, 21, 44, and 45. The magnitudes are all photographic. The unpublished magnitudes of stars in the Selected Areas, available through the kindness of Mr. Seares, extend to about 18.5. Fainter magnitudes are extrapolations; but to 19.0 they are believed to be of the same accuracy as the fainter stars of the Selected Areas. From 19.0 to 20.0 the extrapolations must be considered as increasingly unreliable, although the results from the various plates are in substantial agreement. In the case of a few variables, notably Nos. 3 and 4, the background of nebulosity is so dense that the measures are very uncertain even for the brighter stars.

The magnitudes of the variables, estimated to the nearest tenth by comparison with the sequences, are believed to be fairly trustworthy (except where the plates were exposed under poor conditions) over the brighter portion of the light-curves. The minima, however,

TABLE I

Variables in M 31, Central Region

J.D.*	Plate†	Qy.	1‖	2	3	4	5§	6	7	8	9
8562.7‡	R18	F	19.0	19.1+	18.6	19.3+	18.8+	......	18.9	19.5	......
8563.5‡	20	G	19.15	19.2	18.85	19.7	18.9+	18.7	18.9	19.6	......
8565.5	26	G	19.15	18.6	18.9	19.7	19.1+	18.9	19.0	19.7	19.3
8566.6	27	F	19.0+	18.6	18.9	19.4+	18.8+	18.7	18.9	19.7	......
8591.5	34	G	19.05	19.3	18.9	19.6	18.9	18.6	18.4	19.5	19.4
8593.4	39	G	19.1	19.2	19.3	19.1	18.7	18.9	18.4	19.2	19.4
8885.6	108	G	19.3	19.0	18.4	19.1	......	19.5	18.95	19.7	......
0720.5	121	E	18.35	19.1	18.4	19.1	......	19.0	18.85	20.0	......
0781.5	122	E	18.25	19.1	19.3	19.0	......	19.6	18.2	19.3	......
1462.6	P300	F	19.2+	18.8	19.2+	19.1	......	......	18.2	19.5	......
1483.5	Sh3991	P	18.7+	19.0+	......	......	......	19.0	18.7	......	......
1489.5	R146	G	19.3	19.1+	19.2+	19.4+	......	19.4+	18.8	19.0	......
1518.5	147	F	19.3	18.6	......	......	......	......	18.7	......	......
1547.5	151	G	19.2	19.1+	19.3+	19.4	......	18.7	18.1	19.5	......
1575.4	154	G	19.1	19.1+	19.2+	19.5+	......	19.5	19.0	19.5	......
1576.4	156	G	19.2	19.15	19.4	19.5+	......	19.5	18.8	19.3	......
1609.3	161	G	19.3	19.4	19.4	19.2	......	18.9	18.7	19.6	......
1634.3	162	P	18.8+	19.1+	19.2+	19.3+	......	18.6	18.5	19.4	......
1635.3	163	P	18.8+	......	19.2+	......	......	18.7	18.4	19.4	......
1781.6	D2	P	18.6+	18.9	19.1	......	......	......	18.3	......	......
1782.6	5	P	18.2	18.8	......	......	......	......	......	......	......
1783.6	9	P	18.2	18.9	......	......	......	......	......	......	......
1811.3‡	11	P	19.0+	19.0+	......	19.0	......	18.65	18.85	19.3	......
2104.7	Sh4934	P	18.6	18.8	......	......	......	......	......	......	......
2161.6	4978	F	18.25	18.7	......	19.1	......	......	18.8	......	......
2163.6	5025	F	18.6	18.5	......	19.3	......	......	18.8	19.0	......
2168.6	D24	P	18.85	19.2+	......	......	......	18.7	......	......	......
2169.6	27	F	19.0	19.1	19.4+	19.5+	......	18.8	18.9	19.5+	......
2195.5	30	F	18.6	19.1+	19.3+	19.5+	......	18.8	18.6	19.3+	......
2223.5	Sh5054	P	18.3	18.7	......	19.0	......	......	......	......	......
2263.4	5117	G	19.0	18.8	19:1	19.3	......	......	18.7	19.6	18.9
2311.3	5149	F	19.0+	19.2	......	......	......	......	18.4	19.4	......
2314.3	5160	G	19.0	19.2+	18.4	......	......	19.5	18.1	19.6	19.2+
2317.3	Hg2	G	18.25	19.3+	......	......	......	......	18.2	......	18.2
2521.6	D37	P	18.8+	19.2+	19.2+	19.4+	......	18.6	19.0	19.2	......
2545.6	Sh5489	F	18.9	19.0	......	......	......	18.6	18.2	......	18.2
2547.6‡	D42	F	19.1	19.2	19.4+	19.7	18.55	18.6	18.3	......	18.4
2548.6	44	E	19.15	19.2	19.7	19.7	18.5	18.7	18.3	19.8	18.4
2580.5	62	F	19.15	19.1+	19.3+	19.4	......	19.6	18.6	19.5	......
2581.6	65	P	......	18.8+	19.2+	......	......	......	18.4	19.4+	......
2584.4	70	F	19.2	18.7	18.4	19.5+	19.0+	19.6	18.1	......	18.8
2585.0‡	71	G	19.4	18.7	18.4	19.6+	19.3+	19.6	18.1	19.7	18.8
2585.3	72	P	19.2	18.8	......	......	19.0+	......	18.1	......	18.9
2608.5	76	F	18.9	19.2	19.2+	19.4+	......	19.3+	18.9	19.0	......
2609.6	80	P	18.8+	18.9+	19.4	......	......	18.7	18.9	19.2	......
2612.3	S68	F	19.1	19.1+	18.3	19.3+	......	18.7	18.8	19.3	......
2641.6	75	F	19.1	19.2+	19.1	......	......	......	18.6	19.2	......
2642.5	77	G	19.1	19.0	18.6	19.6	......	......	......	19.1	......
2669.3‡	D106	F	18.8	18.9+	18.9	19.4+	......	......	18.6	19.5	......
2694.3‡	118	G	18.2	19.2+	18.65	19.5+	......	......	18.6	19.4	......
2695.3	122	F	18.3	19.1+	18.9	19.5	......	......	18.9	19.1	......
2698.4‡	131	F	18.5	19.1+	19.1	19.2	......	19.2+	18.85	19.05	......
2903.4‡	200	P	18.8+	18.8+	......	19.0	......	18.8	18.2	......	......
2935.5	H150	E	......	......	......	......	18.8	......	......	......	......
3029.4	A10	F	19.3	19.1	19.5	19.2	......	......	18.8	19.4+	......
3256.6	29	P	19.1	19.1+	19.4	19.2	......	18.7	18.7	19.6+	......
3258.7	B51	F	18.2	19.0+	......	......	......	18.8	......	......	......
3259.6	56	P	18.2	19.0+	18.6	......	......	18.8	......	......	......
3260.7	S156	P	18.25	18.7+	18.4	......	......	......	18.1	......	......
3264.6	D222	P	18.6	19.0+	......	......	......	......	18.3	19.0	......

TABLE I

VARIABLES IN M 31, CENTRAL REGION

J.D.	10§	11	12	13	14	15	16	17	18	19
8562.7‡	......	......	......	......	......	17.5	......	......	......	16.0
8563.5‡	19 0+	......	......	......	......	17.5	......	19.35	......	16.0
8565.5	19.3	19.5+	19.5+	19.3	......	17.5	......	19.0	......	16.0
8566.6	......	......	19.3+	19.3	......	17.5	19.5+	18.8	19.7+	16.0
8591.5	19.2+	19.5	19.5	19.5	19.8	17.6	19.3	19.9	19.9	16.0
8593.4	19.2+	......	......	19.8	......	17.6	19.3	19.9	19.2	15.9
8885.6	......	19.5+	19.1	19.7+	......	17.5	19.3	19.1	19.7+	15.85
0720.5	......	19.5	19.8+	19.5	19.7	17.4	18.8	19.7	19.9+	15.3
0781.5	......	19.3	......	19.1	18.9	17.3	18.5	18.9	19.2	15.3
1462.6	......	18.9	19.0	......	......	17.0	18.8	......	19.5+	15.8
1483.5	......	18.6	......	......	......	17.1	......	......	......	15.6
1489.5	......	18.5	19.2	......	......	17.0	......	......	......	15.6
1518.5	......	18.7	19.4+	19.4	19.6+	17.0	19.4	19.5	19.6+	15.5
1547.5	......	18.6	19.4+	19.5	......	16.9	......	......	19.6+	15.55
1575.4	......	18.6	19.15	19.6+	19.1	16.9	......	......	19.6+	15.6
1576.4	......	18.7	19.4	19.6+	19.0	16.9	......	19.9	19.6+	15.6
1609.3	......	19.0	......	19.4	19.3	16.9	19.5+	19.1	19.6+	15.7
1634.3	......	19.2	......	......	......	16.8	19.1	......	19.3	15.7
1635.3	......	19.1	......	......	......	17.0	18.9	......	19.2	15.8
1781.6	......	......	......	......	......	......	......	......	......	16.15
1782.6	......	......	......	......	......	17.1	......	......	......	16.2
1783.6	......	......	......	......	......	16.9	......	......	......	16.1
1811.3‡	......	19.2	......	......	......	17.0	......	......	......	16.15
2104.7	......	......	......	......	......	17.1	......	......	......	16.2
2161.6	......	......	......	19.5+	19.5	17.2	18.9	......	......	16.3
2163.6	......	......	......	......	......	17.1	18.8	19.6+	......	16.3
2168.6	......	......	......	......	......	16.8	......	......	......	16.2
2169.6	......	19.3	......	......	......	......	19.4	18.9	19.6	16.2
2195.5	......	19.2	19.1	19.6+	19.3	16.9	19.4+	......	19.5+	16.3
2223.5	......	......	......	......	......	17.1	......	......	......	16.4
2263.4	......	19.4	19.1	19.6+	19.0	17.0	19.4	18.9	19.3	16.2
2311.3	......	19.5	......	19.5+	......	17.1	......	......	......	16.2
2314.3	......	19.3	19.4+	19.5+	19.2	16.8	19.5+	19.6+	19.5+	16.2
2317.3	......	......	19.4+	19.6+	19.3	......	......	......	......	16.1
2521.6	......	19.2	......	19.5	......	16.8	......	......	......	15.6
2545.6	......	......	......	......	18.9	16.8	......	......	19.5	15.7
2547.6‡	18.8	19.3+	19.5+	19.7	19.3	16.9	19.45	19.15	19.7	15.7
2548.6	18.9	19.3	19.5	19.7	19.4	16.9	19.3	19.0	19.7	15.6
2580.5	......	......	......	......	18.9	......	19.3	19.3	19.3	15.5
2581.6	......	......	......	......	......	17.0	......	19.1	......	15.5
2584.4	19.2+	19.4+	19.5+	19.2	19.5	16.9	19.5	19.1	19.5	......
2585.0‡	19.4	19.3	19.8+	19.2	19.5	17.0	19.3	19.1	19.8	......
2585.3	19.2+	......	......	......	......	......	......	......	......	......
2608.5	......	......	......	19.4	......	......	19.3+	......	......	15.5
2609.6	......	......	......	......	......	16.9	......	......	......	15.4
2612.3	......	19.4	......	......	......	17.1	18.9	......	......	15.4
2641.6	......	......	......	......	......	17.0	......	......	......	15.4
2642.5	......	......	......	......	19.4+	17.1	......	......	19.6+	15.3
2669.3‡	......	......	......	......	18.9	17.0	......	......	......	15.4
2694.3‡	......	19.5+	19.3	19.5+	19.4+	16.8	19.1	19.1	19.4	15.4
2695.3	......	......	......	19.5+	19.4+	17.0	18.8	18.75	19.5	15.5
2698.4‡	......	......	19.2+	......	......	16.9	18.8	......	19.6	15.6
2903.4‡	......	......	......	......	......	16.8	......	......	......	15.3
2935.5	18.8	......	......	......	......	......	19.8+	19.8	19.7	15.3
3029.4	......	19.2+	......	......	19.6	......	18.9	......	19.5	15.3
3256.6	......	......	......	......	19.6	......	......	......	......	15.9
3258.7	......	......	......	......	......	......	......	18.7	......	16.0
3259.6	......	......	......	......	......	......	......	18.75	......	15.9
3260.7	......	......	......	......	......	16.8	......	......	......	15.85
3264.6	......	......	......	......	......	16.8	......	......	......	15.9

TABLE I—*Continued*

J.D.*	Plate†	Qy.	1‖	2	3	4	5§	6	7	8	9
3287.6	B58	P	18.6+	18.6	18.6	......	......	......	......	19.2	......
3289.6	62	P	18.25	18.9+	18.6	......	......	......	18.9	......	......
3317.7	S172	F	18.9+	19.1+	18.7	......	......	......	18.4	18.9	......
3350.3	A42	P	18.8+	18.7	......	......	......	......	......	......	......
3433.3	B100	F	19.1	19.1	19.5	......	......	18.7	18.8	19.5+	......
3610.6	126	F	18.5	19.0	18.6	......	......	......	18.9	19.3	......
3612.6	131	P	19.0	19.2	......	......	......	......	19.0	......	......
3615.7	A58	P	19.15	19.1+	......	......	......	......	18.8	......	......
3617.7	S254	P	19.1	18.7+	18.9	......	......	......	18.5	19.4+	......
3639.7	267	F	18.3	18.8+	......	......	......	19.1	18.6	18.9	......
3641.5	S278	P	18.5	18.8+	18.5	......	......	......	......	19.2+	......
3698.6	H335	G	18.3	19.4	19.4	19.7	......	......	......	19.7	......
3737.6	339	G	18.85	19.2	19.5	19.7	......	19.6+	18.9	19.6	......
3765.45	348	F	18.5	19.2+	19.5	19.7	......	19.5	18.3	19.2	......
3768.4	351	P	18.7	18.55	......	......	......	18.7	18.5	19.5	......
3789.3	353	P	18.8+	18.6	......	......	......	18.6	......	19.3+	
3790.4	S285	F	18.8	18.8	19.4+	19.1	......	18.6	......	19.5+	18.8
3791.4	292	F	18.3	18.8	19.3+	19.0	......	18.5	......	19.6	18.9
3818.3	301	F	19.3	19.1+	19.0	19.3+	......	......	18.55	19.2	18.4
3819.3	310	F	19.1+	19.1+	19.1+	19.3+	......	......	18.65	19.3	18.5
3820.3	320	F	19.1+	19.3	......	......	......	......	18.7	......	18.6
3821.3	H355	G	19.1	19.1+	19.5	19.7	......	19.3	18.65	19.5	......
3822.3	357	F	18.6	19.2+	19.6+	19.6	......	19.5	18.7	19.7	......
3823.3	363	F	18.3	19.2+	19.6+	19.6+	......	19.5+	18.7	19.6	......
3843.3	A73	P	......	......	......	......	......	......	......	......	......
3969.6‡	H376	P	......	18.7	18.8	......	18.9	......	......	......	......
3970.6	381	F	......	......	......	19.3+	......	18.9	19.2	19.3+	19.4+
3971.6	S329	P	19.2+	18.5	......	......	......	......	......	......	......
3990.6‡	336	P	......	18.6	18.4	......	......	......	......	......	......
3991.6	338	G	19.3	18.85	18.7	......	19.4+	18.6	......	19.3	......
3993.6	S339	G	19.3	18.95	18.9	......	19.4+	18.6	......	19.1	......
3994.6‡	343,4	F	19.4	19.0	19.1	19.3+	19.6	18.9	18.6	19.0	19.4
3995.6‡	348,9	G	19.4	19.2	18.9	19.2	19.5	18.8	18.6	19.15	19.3
3996.6‡	H384,5	E	19.4	19.4	19.3	19.0	19.3	18.9	18.7	19.3	19.4
3997.6‡	389,0	G	19.4	19.4	19.5	19.0	19.1	19.0	18.5	19.4+	19.4
3998.6‡	394,5	E	19.4	19.4	19.5	19.2	18.9	19.3	18.5	19.3+	19.4
3999.6‡	S350,1	G	19.4	19.4	19.5	......	18.6	19.1	18.7	......	19.4+
4000.6‡	H397	F	19.4	19.3	19.6	......	18.7	......	18.7	19.3+	19.4
4001.6‡	398	F	19.3	19.5	19.5	......	18.6	......	18.8	19.3+	19.4
4002.6‡	403,4	E	19.4	19.3+	19.55	19.4+	18.55	19.5	18.9	19.4+	......
4003.6‡	409,0	E	19.4	19.5	......	......	18.5	19.6	18.8	19.3+	19.4
4004.5‡	414,5	E	19.4	19.5	19.5	......	18.6	......	19.0	19.5+	19.5
4023.4	B182	F	19.3	19.4+	19.4	......	19.3+	......	......	......	......
4024.5‡	D238,1	F	19.2	19.4+	19.25	19.3+	19.3	19.5	18.2	19.7	19.4
4025.5‡	243,6	F	19.4	19.4	19.3	19.7	19.3	19.5	18.1	19.5	19.3
4026.5‡	S353,6	F	19.3	19.5	19.3+	......	19.3	19.5	18.2	19.4+	19.3
4027.6‡	359,0	F	19.4	19.35	19.5	......	19.2+	19.7	18.2	18.9	19.4
4028.5	H418	G	......	19.1	19.5+	19.6+	......	19.8	18.1	19.0	......
4029.4	S361	F	19.1+	18.75	......	......	19.1+	......	......	......	......
4030.5	362	F	......	18.6	......	......	......	19.7	18.25	19.1	19.4
4031.5‡	H420,1	G	19.1+	18.6	19.4	......	19.4	19.5	18.2	19.3	19.4
4032.5‡	424,6	G	19.3	18.9	19.6	19.7	19.2+	18.6	18.35	19.3	19.4+
4033.6‡	427,0	G	19.3+	19.05	19.7+	19.3+	19.3	18.75	18.3	19.5	19.4
4049.5‡	S366,0	F	18.8	18.6	18.7	......	18.6	19.4+	18.8	......	18.75
4050.5‡	372,4	F	18.9	18.55	19.1	......	18.6	19.7	18.8	19.4+	18.8
4054.6‡	H434	F	......	......	......	19.4+	......	......	18.9	19.4+	18.9
4055.6	S376	G	19.2	19.15	19.3+	......	18.6	18.7	......	......	......
4056.6	385	G	......	19.2	......	......	18.75	18.6	19.0	19.5+	19.1
4057.4	388	G	19.3	19.3	19.7	19.0	18.7	18.6	19.1	19.6+	19.3
4059.4‡	H443,4	G	......	......	......	19.0	18.7	18.6	19.0	19.5+	19.3

TABLE I—*Continued*

J.D.	10§	11	12	13	14	15	16	17	18	19
3287.6	......	......	......	......	......	......	......	......	......	16.0
3289.6	......	......	19.3	......	......	16.7	......	......	......	16.0
3317.7	......	19.1	......	......	......	16.8	......	18.75	19.4+	16.2
3350.3	......	......	19.1	......	......	......	......	......	......	16.0
3433.3	......	......	......	......	......	......	19.3	19.4	......	16.2
3610.6	......	......	......	......	......	16.9	19.2	19.4+	......	16.0
3612.6	......	......	19.1	......	......	......	19.3	......	......	16.1
3615.7	......	......	......	......	......	......	......	18.85	......	......
3617.7	......	......	......	......	......	16.8	......	......	......	16.0
3639.7	......	......		......	19.3	16.8	18.9	......	......	16.2
3641.5	......	......	......	......	......	16.9	......	......	......	16.1
3698.6	......	19.4	......	......	19.5+	......	......	......	......	16.2
3737.6	......	19.3	......	19.5	19.5+	16.9	......	......	19.6+	16.3
3765.45	......	19.1	19.3+	19.5	19.6	17.0	18.85	......	19.1	16.3
3768.4	......	......	......	......	......	......	......	......	......	16.2
3789.3	......	......	......	......	......	17.0	19.5	......	19.6	16.1
3790.4	......	19.1	......	19.5	19.5+	17.0	19.5+	19.6	19.6	16.2
3791.4	......	19.1	19.4+	19.6+	19.6+	17.1	......	......	19.8	16.1
3818.3	......	......	19.0	19.3+	19.4+	17.2	19.2	......	19.3	16.2
3819.3	......	19.3+	19.3	19.4+	19.6	17.2	19.3	19.6+	19.4+	16.2
3820.3	......	......	19.1	19.3+	19.3+	17.1	19.4	19.3	19.25	16.3
3821.3	......	19.4+	19.2	19.2	19.6+	17.0	......	......	19.2	16.3
3822.3	......	19.3+	19.2+	19.2	19.5+	17.1	......	......	19.3	16.3
3823.3	......	......	19.3+	19.2+	19.4+	17.0	......	......	19.3	16.3
3843.3	......	......	......	......	......	......	......	18.8	......	16.3
3969.6‡	19.1+	......	......	......	......	......	18.85	19.4	19.0	16.1
3970.6	......	......	19.6+	19.7+	19.7+	16.9	......	......	......	16.2
3971.6	......	......	......	......	......	......	19.1	......	......	......
3990.6‡	......	......	......	......	......	16.7	......	18.7	......	16.3
3991.6	18.9	19.4	......	......	......	16.8	19.5	18.75	19.4	16.3
3993.6	19.0	19.3	......	......	......	......	19.5	19.1	19.6	16.2
3994.6‡	19.2	19.3	19.2	19.7	19.4	17.0	19.7	19.25	19.7	16.3
3995.6‡	19.2	......	19.2	19.2	19.5	16.8	19.8	19.3	19.7	16.3
3996.6‡	19.2	......	19.0	19.2	19.8	16.8	19.8	19.35	19.7+	16.2
3997.6‡	19.3	......	19.2	19.3	19.8	16.8	19.6	19.6	19.9	16.2
3998.6‡	19.4	......	19.2	19.4	19.8+	16.9	19.8	19.6	19.9	16.1
3999.6‡	19.4+	19.3	19.35	19.4	19.8+	17.0	19.7	19.7	19.8+	16.0
4000.6‡	......	......	19.4	19.4	19.8+	17.0	19.9	19.7	19.9	16.2
4001.6‡	19.3	......	19.4	19.4	19.8+	16.8	19.8+	19.7	19.9	16.1
4002.6‡	......	19.1	19.4	19.5	19.8+	16.7	19.7+	19.7	19.8+	16.2
4003.6‡	19.5	19.3	19.6	19.6	19.9	16.7	19.8	19.7	19.9	16.2
4004.5‡	19.4	......	19.6	19.6	......	16.9	19.9	19.7	......	16.2
4023.4	19.4+	......	......	......	19.6+	......	19.15	19.8+	19.7+	......
4024.5‡	19.4+	19.2	19.7	19.7	19.8	16.6	19.2	19.9	19.2	16.0
4025.5‡	19.5+	19.3	19.7	19.8	19.2	16.7	19.35	19.9	19.2	16.1
4026.5‡	19.4+	19.1	19.7	19.8	19.0	16.8	19.4	19.4	19.2	16.2
4027.6‡	19.2	19.1	19.7	19.8	19.05	16.8	19.4	18.75	19.3	16.1
4028.5	......	19.3	19.7+	19.8+	19.2	16.7	......	......	......	15.9
4029.4	18.8	......	......	19.4+	19.2	16.8	19.5	19.1	19.5+	16.0
4030.5	......	19.1	19.8+	19.8+	19.3	16.9	......	......	......	16.1
4031.5‡	18.9	19.1	19.8	19.8+	19.7	16.7	19.4	19.1	19.7+	16.1
4032.5‡	18.95	......	19.7+	19.8+	19.7	16.8	19.5	19.4	19.7+	16.1
4033.6‡	......	19.15	19.7+	19.8+	19.9	16.7	19.6	19.35	19.7	16.2
4049.5‡	19.3+	19.0	19.8+	19.8+	......	16.7	19.2	19.0	19.7+	16.3
4050.5‡	19.1	18.9	19.8+	19.9	19.8	16.7	19.1	18.9	19.7	16.3
4054.6‡	......	......	19.8	19.8	19.8	16.8	......	......	......	16.2
4055.6	18.8	19.0	......	......	19.8	......	18.85	19.4	19.7+	16.2
4056.6	18.95	18.9	19.8	19.9	19.9+	16.9	......	......	......	16.2
4057.4	18.95	19.0	19.8	20.0	20.0	16.7	18.8	19.6	......	16.2
4059.4‡	19.0	18.8	19.7	19.8	19.8+	16.7	18.9	19.7	19.7+	16.2

TABLE I—*Continued*

J.D.*	Plate†	Qy.	1‖	2	3	4	5§	6	7	8	9
4085.4	451	G	......	......	19.4	......	19.2+	......	......	......	......
4086.4‡	S394,5	F	19.1	19.3+	19.3+	......	19.1+	......	18.5	......	19.05
4089.4‡	400,1	G	19.2	18.8	19.4+	......	19.5+	19.15	18.7	19.6	19.3
4090.4	H457	G	......	......	......	......	......	......	18.7	19.7	19.4
4092.3	464	F	......	18.6	......	......	......	19.5	18.8	......	19.4
4108.4‡	H469,0	F	18.45	19.2	19.5+	......	18.85	......	18.8	19.5+	18.2
4109.3	471	F	......	......	......	19.7	......	19.5	18.8	19.7+	18.3
4114.4	S411	G	19.0	19.0	19.4	19.7	19.05	19.6	18.2	19.4+	18.7
4150.3	H510	P	19.1+	18.55	18.4	......	......	19.3+	18.9+	......	......
4168.3	S417	P	18.2	18.8+	......	......	......	18.6	18.4	......	19.2+
4177.4	424	F	19.0	19.2+	18.7	......	......	19.1	18.6	19.6	......
4178.3	433	F	19.1	19.2+	18.4	19.5+	......	......	18.8	19.6+	18.8
4181.3	H531	P	19.1	19.4	18.7	19.0	......	......	18.9	......	......
4197.3	S434	P	19.1	19.4	......	......	......	......	19.2	......	19.2+
4207.3	446	P	......	......	......	......	......	......	18.15	......	......
4319.6	H571	F	19.4	19.3	19.3	19.7	......	19.6	18.7	19.6+	......
4321.6	S483	G	19.4	19.3+	19.1	......	19.2+	18.8	......	......	......
4349.5	H580	F	......	19.1	19.3+	19.0	......	19.0	18.4	19.1	......
4351.6	D251	F	19.4	18.5	19.5	19.2	......	19.3	18.6	19.2	19.1
4356.6	268	G	18.2	19.2	19.5	19.5	......	19.5	18.7	19.6+	18.9+
4358.5	S496	G	18.2	19.3	19.4+	19.6	......	19.7	18.7	19.5+	19.3+
4377.4	H586	F	19.3+	19.3	19.3	19.6+	......	19.3	18.9	19.7+	......
4379.7	598	P	19.2+	19.2	19.3+	......	......	19.3	18.9	19.7	......
4406.6	607	P	......	......	......	......	......	......	18.9	19.3+	18.8
4414.7	609	F	......	18.9	19.5+	19.2	......	18.6	19.0	19.8	18.9
4433.3	615	P	......	18.6	19.4	......	......	......	18.0	19.3+	......
4441.5	S505	F	19.3+	19.2	......	......	......	19.0	18.3	19.5	18.9
4444.4	H617	F	......	......	......	19.6	......	19.6	18.5	19.7	18.9
4475.3	621	P	......	......	18.6	......	......	19.3+	18.1	19.5	......
4476.5	Sr6276	P	19.2+	19.1	18.4	......	......	......	18.2	......	......
4493.4	H624	F	19.1	18.85	19.5	19.1	......	19.6	18.7	19.2	......
4495.3	626	P	19.3	19.0	......	......	18.95	......	......	......	......
4522.3	627	P	......	......	......	......	......	18.6	18.2	......	......
4530.3	SS45	P	19.2+	19.3	18.4	19.3+	......	19.1	18.4	19.5	......
4531.3	H629	P	19.2+	18.65	18.6	19.3	......	19.3	18.4	......	......
4671.6	S533	P	18.4	19.0	......	......	......	......	18.65	......	......
4680.6	D304	P	19.0	19.2+	......	......	......	18.6	18.9	......	......
4700.6	315	G	18.7	19.4	19.5	19.2	......	18.6	18.0	19.7	......
4709.6	H668	F	18.9	19.4	19.5	19.6	......	19.5	18.4	19.5	......
4711.6	S539	F	19.1	19.3	......	......	......	......	18.3	......	......
4739.5	540	P	18.6	19.15	......	19.0	......	19.6	19.0	19.0	......
4762.4	H675	G	19.3	19.4	19.6	19.2	......	19.6	18.55	19.5	......
4764.4‡	686	E	18.25	19.5	19.4	19.3	......	19.6	18.6	19.6	......
4770.4	690	E	18.9	19.4	19.1	19.6	......	18.6	18.8	19.6	......
4772.4‡	703	E	18.8	18.75	18.4	19.6	......	18.9	18.9	19.5+	......
4793.3	S545	F	19.2	18.45	19.5	19.5+	......	18.6	18.1	19.2	18.6
4800.3	H708	E	18.5	19.2	18.4	19.0	......	19.6	18.3	19.6	......
4801.3	S547	P	18.6	19.3	18.7	19.1	......	......	18.5	......	......
4822.5	BB104	F	19.3+	19.5	......	19.2	......	19.6	18.8	......	......
4823.5	117	F	19.4	19.3+	19.3+	19.3	......	......	18.9	19.5	......
4882.3	166	F	19.4+	19.4+	18.5	18.9	......	18.7	18.2	19.0	......
4883.3	180	P	19.1+	19.1+	18.7	19.1	......	18.8	18.0	......	......
4908.3	H715	G	19.4	19.6	18.4	19.4	......	19.3	19.0	19.6+	......
4918.3	720	F	19.2+	19.05	19.3+	19.4+	......	......	19.0	19.2	......
4938.3	732	P	19.2	19.0	18.6	......	......	......	18.5	19.2	......
5035.6	780	P	19.3	18.5	......	......	......	18.7	18.8	19.6	......
5036.6	785	F	19.3	18.7	19.6	19.6+	......	18.8	18.8	19.7	......
5063.6	798	F	19.1	19.5	19.6+	19.5	......	19.4	18.2	19.5	......
5083.5	812	F	18.6	19.5	19.8	19.8	......	19.2	18.7	19.6	......
5091.5	815	P	......	......	19.3+	19.2	......	......	19.0	......	......

TABLE I—*Continued*

J.D.	10§	11	12	13	14	15	16	17	18	19
4085.4	19.1+	......	......	......	......	......	19.8	18.85	19.4	......
4086.4‡	19.1+	19.0	19.35	19.4	19.6+	16.7	......	19.1	19.5	16.2
4089.4‡	19.3+	19.2	19.6	19.7	19.8	16.7	19.4	19.4	19.8	16.1
4090.4	......	18.9	19.7	19.8	19.6+	......	......	......	......	16.15
4092.3	......	19.1	19.6+	19.6+	19.7	16.7	......	......	......	......
4108.4‡	19.1	19.0	19.1	......	......	16.8	19.3	19.2	19.5	16.2
4109.3	......	19.1	19.2	19.5	19.8	16.9	......	......	......	16.3
4114.4	19.4+	19.0	19.4	19.5	19.1	16.9	19.5	19.4	19.7+	16.1
4150.3	......	19.2	18.9	......	19.0	16.9	......	......	......	16.2
4168.3	......	......	......	......	19.2	......	......	......	......	16.0
4177.4	......	......	19.5	......	19.6+	16.8	18.85	19.0	19.7+	16.2
4178.3	......	19.3	......	......	19.6+	16.8	18.9	18.75	......	16.2
4181.3	......	......	19.6	......	......	16.8	......	......	......	16.3
4197.3	......	19.2	19.3	......	......	......	19.3	18.8	19.7+	16.2
4207.3	......	......	......	......	......	......	......	......	......	16.1
4319.6	......	19.0	19.3+	19.6+	19.6+	16.9	......	......	19.5	15.9
4321.6	19.3+	19.2	......	......	......	16.8	19.4	19.6	19.0	16.0
4349.5	......	......	19.2+	......	......	16.7	......	......	......	16.0
4351.6	......	19.2	18.8	......	19.7	......	19.3	19.35	19.8+	16.0
4356.6	......	19.3	19.2+	......	......	16.7	19.5	19.7	19.7	15.9
4358.5	......	19.4	19.4	19.6+	19.7+	16.8	19.4	19.7+	19.1	15.8
4377.4	......	19.3+	19.0	19.6+	19.4	16.7	......	......	......	15.9
4379.7	......	......	......	......	18.9	16.8	......	......	......	15.8
4406.6	......	......	......	......	......	16.8	......	......	......	15.7
4414.7	......	19.5+	19.6+	19.6	19.0	16.7	......	......	......	15.7
4433.3	......	......	......	......	19.2	16.7	......	......	......	15.7
4441.5	......	19.4+	18.9	19.5+	19.4+	16.7	19.6	18.7	19.7+	15.6
4444.4	......	19.4+	19.3	......	......	16.8	......	......	......	15.6
4475.3	......	19.4+	......	19.0	......	16.8	......	......	......	15.3
4476.5	......	......	......	19.1	......	16.8	......	......	......	15.4
4493.4	......	19.6	......	......	......	16.9	......	......	......	15.3
4495.3	19.2	......	......	......	......	......	19.7	19.7	19.7+	15.4
4522.3	......	......	......	......	......	......	......	......	......	15.3
4530.3	......	......	......	......	......	17.0	......	......	......	15.4
4531.3	......	......	......	......	......	16.9	......	......	......	15.4
4671.6	......	......	......	......	......	17.3	......	......	......	15.55
4680.6	......	......	......	......	19.3	17.3	19.3	19.4+	19.5+	15.55
4700.6	......	......	......	......	......	17.2	......	......	19.7	15.4
4709.6	......	......	......	......	......	17.3	......	......	19.3	15.5
4711.6	......	......	......	......	......	17.3	18.7	18.9	19.1	15.4
4739.5	......	......	......	19.2	......	17.2	19.5+	19.2	19.6+	15.5
4762.4	......	19.6	19.6+	19.6+	19.7	17.2	18.9	......	19.8+	15.55
4764.4‡	......	......	......	......	19.7	17.1	......	......	19.8+	15.6
4770.4	......	19.6	19.4	......	19.4	17.2	......	......	......	15.7
4772.4‡	......	19.6	......	......	19.7	17.1	19.4	19.7	19.7	15.6
4793.3	......	......	......	......	......	17.2	18.9	19.7	19.7+	15.6
4800.3	......	19.6+	19.3	19.0	19.7+	17.3	19.05	......	......	15.6
4801.3	......	......	19.3+	19.1	19.0	17.3	19.2	18.9	......	15.7
4822.5	......	......	19.4+	18.9	19.1	17.2	19.5+	19.2	19.1	15.6
4823.5	......	19.4	19.3+	19.2	19.4	17.2	19.5+	19.2	19.2	15.6
4882.3	......	......	......	......	......	17.2	19.1	19.4	......	15.4
4883.3	......	......	......	......	......	17.2	18.85	19.3+	......	15.5
4908.3	......	19.5+	18.9	19.1	19.2	17.2	......	......	......	15.4
4918.3	......	......	19.2+	19.3+	19.4+	17.1	18.75	19.5	19.25	15.4
4938.3	......	......	......	......	......	17.2	......	......	......	15.45
5035.6	......	......	19.2+	......	......	17.2	......	......	......	15.8
5036.6	......	19.6+	......	19.8	19.8+	17.1	......	......	19.4+	15.9
5063.6	......	......	19.1	19.5	19.8+	17.2	19.5	......	19.15	16.0
5083.5	......	......	......	19.1	19.5	......	18.8	......	19.35	16.0
5091.5	......	......	......	......	19.7	17.1	19.1	......	19.7	16.0

TABLE I—*Continued*

J.D.*	Plate†	Qy.	1‖	2	3	4	5§	6	7	8	9
5115.4........	H824	F	18.7	18.6	19.6	19.3	......	19.6	18.2	19.4	......
5116.4........	828	F	18.8	18.8	19.6	19.4	......	19.7	18.3	19.4	......
5124.4........	H832	P	19.2	19.6	18.7	19.7	......	18.9	18.5	19.7	......
5145.4........	S577	F	18.3	19.5+	19.4+	19.5+	......	18.8	18.9	19.5	......
5147.6........	H848	P	18.6	......	19.2	......	......	19.0	18.8	19.1	......
5149.6........	H855	F	18.9	19.6+	18.7	19.5	......	19.1	18.4	19.1	......

are often below the limits of the plates, and generally below the limits of accuracy. For this reason statistical discussions must be confined largely to the magnitudes at maxima.

Magnitudes for the variables in Regions 1, 2, and 3 are listed in Table I, and for those in Region 4, in Table II. Values for different plates exposed during a single night are generally combined, as they seldom differ by more than the errors of observation.

TABLE I—*Continued*

J.D.	10§	11	12	13	14	15	16	17	18	19
5115.4	....	19.6	19.3+	19.7	19.8	17.0	....	....	....	16.0
5116.4	....	19.6	19.4+	19.5+	19.8	17.0	....	....	19.4+	16.0
5124.4	....	19.8	....	19.4	19.6	17.0	....	....	19.4+	16.0
5145.4	....	....	....	....	....	17.2	....	....	....	16.0
5147.6	....	....	....	19.0	....	17.1	....	....	....	16.0
5149.6	....	19.6	19.1	19.3	....	17.0	....	....	19.7	16.0

* Add 2,410,000 to the first seven dates and 2,420,000 to the remainder.

† Letters preceding the plate numbers refer to the following observers: R = Ritchey, P = Pease, Sh = Shapley, D = Duncan, Hg = Hoge, S and H = Hubble, A and B = Humason, Sr = Seares, SS = Schilt, BB = Brown.

‡ Nights on which more than one plate were obtained.

|| A plus sign following magnitude indicates that the variable was invisible, but certainly fainter than the tabulated value.

§ See Table I*a* for additional observations.

TABLE I*a*

ADDITIONAL OBSERVATIONS, VARIABLES IN M 31, CENTRAL REGION; VARIABLES NOS. 5 AND 10

J.D.	Plate	Qy.	5	10
4054.4	H432	P	....	18.8
4056.4	S379	G	18.65	....
4113.4	408	P	18.9	19.2+
4168.3	416	P	19.1+	18.85
4323.6	494	F	19.2+	19.2+
4384.5	D276	E	18.65	19.2+
4387.5	287	E	18.5	19.2+
4731.5	323	F	....	19.4+
4739.5	S541	F	19.0	18.9

TABLE II

VARIABLES IN M 31, REGION 4

J.D.*	Plate†	Qy.	21‖	22	23	24	25	26	27	28
4032.4	H424	F	19.9	20.1	19.5	19.4	19.7	19.05	19.0	19.1
4054.4	432	P	19.2	19.5+	19.6	19.6	19.8+	19.7	19.4	19.3
4056.4	S379	G	19.0	19.3	18.7	19.8	19.8	19.1	19.3	19.25
4058.55	H438	F	19.2	18.95	19.0	19.8	20.0	19.1	18.7	19.2
4085.6	454	E	19.9	19.7	19.8	19.2	19.2	19.2	19.0	19.4
4090.55	461	P	19.1	19.5	18.7	19.7	19.8	19.6	19.5	19.2
4108.35	468	F	19.1	19.5	18.8	19.7	18.95	19.45	18.8	19.2
4113.4	S408	P	19.35	....	19.2	....	....	19.2	....	19.3
4115.5	H478	F	19.8	19.4	19.4	19.9	19.9	19.5	19.4	19.4
4117.5	497	F	19.8	19.7	....	19.8+	19.7	19.45	19.5	19.3
4147.4	504	P	19.5	19.1	19.3	19.7+	19.55	19.7+	19.5	18.3
4151.4	512	F	19.9	19.5	19.7	19.9	19.7+	19.8	19.5	18.8
4168.3	S416	P	....	....	....	....	....	....	....	....
4171.3	H516	G	20.0	19.7	19.6	20.0	19.7	19.6	19.5	19.3
4180.3	525	F	19.35	18.9	18.8	19.7	19.4	19.9	18.9	18.7
4198.3	S439	P	....	....	....	....	....	....	....	....
4320.6	H573	F	19.8	19.1	18.8	19.8	19.6	19.0	19.5	19.15
4323.6	S494	F	....	....	19.2	19.7+	19.5	19.2	18.7	19.1
4349.6	H581	G	19.3	19.7	19.8	19.25	19.9	19.35	18.95	19.2
4353.6	D257	P	19.6	....	18.8	19.55	19.8+	19.6	18.9	19.2
4357.5	H583	G	20.1	19.0	19.1	19.8	19.05	19.6	19.4	19.3
4377.5	587	E	20.1	19.1	19.4	20.0+	19.7	19.4	19.2	19.3
4379.5	599	P	....	....	....	....	....	19.4+	19.3	....
4384.5	D276	E	19.3	19.8	19.6	19.2	19.7	20.0	19.5	19.35
4387.45	287	E	19.5	19.8	19.6	19.55	20.1	19.9	19.4	18.8
4405.4	H605	G	19.6	19.7	19.45	19.5	19.4	19.5	19.4	19.3
4414.4	610	F	19.6	19.5	19.5	20.0	19.5	19.9	19.5	18.5
4444.3	616	F	19.9	18.9	19.1	19.9	19.9+	19.8	18.8	18.5
4493.4	625	F	19.7	19.7	19.4	19.55	20.0	20.0	18.7	19.35
4709.6	669	F	19.0	19.15	19.1	19.8	19.7	19.8	18.75	18.2
4731.5	D323	F	19.7	19.7	19.7+	19.9	19.9	19.8	19.3	19.3
4739.5	S541	F	19.8	19.6+	18.9	19.5	19.7	19.0	19.15	18.25
4762.5	H676	G	19.3	19.0	19.2	19.7	19.8	19.7	19.15	18.5
4770.5‡	691	F	19.8	19.6	19.6	19.8	19.2	19.5	19.5	18.8
4771.5‡	697	F	19.9	19.7	19.6	19.45	19.4	19.6	19.5	18.9
4772.5	707	P	....	....	....	....	....	19.5	....	19.1
4800.4	709	G	19.6	19.4	19.55	19.8	19.8	19.8	19.5	19.2
4907.3	714	F	19.8	19.3	19.6	19.8+	20.0	19.9	19.15	19.2
4947.3	S556	P	....	....	....	....	....	18.9	....	....
5035.63	H781	VP	....	....	....	....	....	....	....	....
5053.60	794	P	....	....	19.5	19.4	19.2	19.0	....	19.3
5063.61	799	G	20.0	19.3	19.5	19.9	19.7	19.6	19.4	18.6
5065.68	810	G	19.8	19.4	19.6	20.0	19.2	19.8	19.5	18.7
5083.55	813	P	19.3	19.4	19.5+	19.6+	....	19.45	19.4	18.9
5091.6	816	F	19.7	19.6	18.7	19.55	19.5	19.9	19.5	18.8
5115.5	825	F	20.0	19.3	19.5	20.0	19.5	19.6	19.4	18.4
5116.48‡	829	E	19.75	19.4	19.6	20.0	19.7	19.8	19.4	18.5
5124.45	H833	F	19.7	19.7	19.6	19.4	19.4	20.0	19.2	19.2
5145.52	S578	P	....	....	19.1	....	....	....	19.0	18.9
5147.5‡	H843	F	20.0	18.8	19.1	19.7	19.6	19.8	19.1	18.9
5148.3	850	P	....	18.8	19.2	....	....	....	....	18.9
5149.5‡	851	F	20.0	19.05	19.3	19.8	19.15	19.8	19.3	19.1
5150.5‡	858	F	19.8	19.15	19.45	19.9	19.3	20.0	19.4	19.2
5266.3	899	P	19.8	....	18.7	19.5	....	19.2	18.8	19.4
5475.5	920	G	19.9	19.6	19.45	19.9	20.1	19.4	19.4	19.2

TABLE II

VARIABLES IN M 31, REGION 4

J.D.	29	30	31	32	33	34	35	36	37	38
4032.4	19.7	19.9+	19.2	19.4+	18.7	18.8	19.6	19.6	19.9	19.6
4054.4	19.2	19.5	19.2	19.6	18.9	19.8+	19.6	19.3	19.35	19.5
4056.4	19.8	18.9	19.5	19.5	18.95	19.8+	19.6	19.1	19.65	19.8
4058.55	19.6+	18.8	19.7	19.4	19.1	19.6+	19.4+	19.3	19.8+	19.9
4085.6	19.9+	19.8	19.8	19.5	19.0	19.9	19.6	19.7	20.0	19.7
4090.55	19.6+	19.4+	19.9	18.7	18.9	19.5+	19.6	19.1	19.8	19.7+
4108.35	19.7+	19.4	20.0	19.5	18.75	19.55	19.5+	19.1	19.5	19.8
4113.4	19.5	19.05	19.4+	19.3	19.1	19.6+	19.0	19.4	19.6+	....
4115.5	19.5	19.2	20.0	18.7	19.3	19.6	19.3	19.5	19.9	19.6
4117.5	19.6+	19.6+	19.8+	19.0	19.4	....	....	19.6	19.8+	19.8+
4147.4	19.6+	18.75	19.4	19.2	18.9	19.6+	18.9	19.2	19.4	....
4151.4	19.5	19.3	19.8	19.4	19.1	19.6+	19.4	19.6	19.9	19.9
4168.3	....	18.8	....	19.0	19.0	19.4+	19.3	....	....	....
4171.3	19.4	19.3	19.65	19.1	19.2	19.5	19.5	19.6	19.8	20.0+
4180.3	19.8+	19.4	19.8+	19.4	19.0	19.7+	19.5+	19.1	19.9	19.9
4198.3	....	....	....	....	19.2	....	....	....	....	....
4320.6	19.8+	19.8	19.9	18.9	19.1	19.6	....	19.6	19.4	19.9
4323.6	....	19.8	19.8	19.2	19.2	18.7	19.0	19.0	19.6	19.7+
4349.6	19.7	18.75	19.1	19.3	18.95	19.8	19.6+	19.5	19.8	19.8
4353.6	....	19.1	19.5	19.4	18.75	19.3	19.4+	19.7	19.8+	19.7+
4357.5	19.9+	19.6	19.8	19.6	18.9	18.9	18.95	19.6	19.9	19.3
4377.5	19.9+	19.9	19.6	19.3	19.1	19.9	19.2	19.2	19.9	19.3
4379.5	....	....	....	....	19.2	....	....	....	....	....
4384.5	19.4	18.7	20.0	....	19.4	19.6	19.6	19.6	19.8	19.9
4387.45	19.8	18.8	20.0	19.6	19.0	18.7	19.7	19.7	19.4	19.4
4405.4	19.3	18.9	19.8	19.5	19.2	19.8+	19.6	19.6	19.8	19.8
4414.4	19.9+	19.8	19.9	19.4	19.0	19.8	19.4	19.2	19.4	20.1
4444.3	19.2	19.2	19.5	18.9	19.1	19.8	19.2	19.7	19.9	19.9+
4493.4	19.9	19.4	19.9	19.4	19.3	19.4	19.6	19.6	19.35	19.8
4709.6	19.9+	19.9	20.0	19.4	18.6	18.9	19.15	19.6	19.55	19.8
4731.5	19.9+	19.1	20.0	19.1	18.9	19.9	19.5	19.6	19.7	19.5
4739.5	19.6+	19.2	19.3	19.4	19.3	19.6+	19.6	19.4	19.9	19.8
4762.5	20.0+	19.9+	19.3	19.5	19.3	19.9	19.2	19.6	19.55	19.35
4770.5‡	20.0+	18.8	20.0	19.6	19.1	19.8	19.6	19.5	19.7	19.8
4771.5‡	19.8+	19.0	19.9	19.5	19.0	19.55	19.6	19.0	19.7	19.6
4772.5	....	19.15	19.5+	19.4	19.1	....	....	19.0	19.3	19.5
4800.4	19.9+	19.8	19.9	18.8	19.3	19.8	19.4	19.7	19.5	19.9
4907.3	19.9+	19.7+	19.9	19.2	19.3	19.2	19.5	19.6	19.4	19.8
4947.3	....	....	....	....	....	....	....	....	....	....
5035.63	....	....	....	....	19.1	....	....	....	....	....
5053.60	....	19.3+	19.2	18.75	19.1	....	....	....	....	....
5063.61	20.0+	18.95	19.9	19.4	19.3	19.05	19.4	19.65	19.9	19.7
5065.58	20.0+	19.1	19.9	19.4	19.2	19.05	19.6	19.65	19.6	19.4
5083.55	19.4+	19.1	19.6	19.0	19.3	19.4+	....	19.6+	19.7	19.8
5091.6	19.5	19.6	19.9	19.5	18.95	19.7	19.6	19.6	19.9	19.9+
5115.5	19.8+	19.2	20.0	19.5	19.4	19.7	19.5	19.5	20.0	19.6
5116.48‡	19.9+	18.65	19.9	19.6	19.4	19.8	19.6	19.6	20.0	19.4
5124.45	19.6	19.7	19.3	19.5	18.6	19.8	19.6	19.8	19.9	19.7
5145.52	19.5	19.6+	....	....	18.9	....	18.9	19.5	19.6	....
5147.5‡	19.4	19.7	19.3	19.5	18.95	19.7	19.3	19.1	19.4	19.3
5148.3	....	....	....	....	18.9	....	....	19.2	....	....
5149.5‡	19.6	19.65	19.5	19.5	19.15	19.8	19.4	19.4	19.6	19.75
5150.5‡	19.7	19.55	19.6	19.5	19.2	19.8	19.5	19.5	19.7	19.9
5266.3	....	18.8	....	19.2	19.4	....	....	19.5+	19.4	....
5475.5	19.8	19.7	19.8	19.7	19.4	19.8	19.6	19.5	19.8	19.8

TABLE II—*Continued*

J.D.*	Plate†	Qy.	39	40	41	42§	43	44	45	46
4032.4	H424	F	19.7	19.0	19.6	19.0	19.8	19.2	19.6	19.7
4054.4	432	P	19.8+	19.0	19.3	18.5	19.7	19.1	20.0	19.6
4056.4	S379	G	19.9+	19.1	19.6	18.4	19.8+	18.7	19.7	19.7
4068.55	H438	F	....	18.9	19.6	18.2	19.7	19.1	19.3	19.8
4085.6	454	E	19.3	19.0	19.7	17.9	19.7	19.3	19.35	19.7
4090.55	461	P	....	18.8+	19.6+	17.9	19.7	19.2	19.7+	19.4
4108.35	468	F	19.1	18.6	19.4	18.4	19.7+	19.1	19.9	19.8
4113.4	S408	P	....	....	19.4+	18.4	....	19.0	19.7	19.6
4115.5	H478	F	19.7	19.0	19.7	18.5	19.8+	19.2	19.9	19.4
4117.5	497	F	19.5+	19.0	19.5+	18.4	19.7	19.2	19.7+	19.5
4147.4	504	P	19.5+	18.9	19.4	19.0	19.6	18.7	19.7	19.7
4151.4	512	F	19.8	19.15	18.9	19.1	19.7	18.7	19.7	19.7
4168.3	S416	P	....	....	....	19.0	....	....	....	....
4171.3	H516	G	19.8	18.4	19.6	19.0	19.9	18.7	19.9	19.7
4180.3	525	F	19.2	18.75	19.0	19.0	19.7+	19.0	19.9	19.2
4198.3	S439	P	....	....	....	19.1	....	....	....	....
4320.6	H573	F	19.6	19.1	19.6	18.8	19.5	18.7	19.7	19.45
4323.6	S494	F	19.2	19.1	19.5	18.9	....	18.7	19.9+	19.35
4349.6	H581	G	19.45	18.9	19.7	19.0	19.4	18.7	20.0	19.4
4353.6	D257	P	....	18.8+	18.9	19.0	19.3	18.8	19.9	19.7
4357.5	H583	G	19.9	19.2	18.95	18.9	19.3	18.8	19.7	19.6
4377.5	587	E	19.7	18.7	19.2	18.9	19.35	18.8	19.95	19.6
4379.5	599	P	....	18.75	18.7	19.0	....	....	....	....
4384.5	D276	E	20.1	18.9	19.1	18.9	19.4	18.8	19.8	19.6
4387.45	287	E	20.0	19.2	19.4	18.85	19.4	18.9	20.0	19.3
4405.4	H605	G	20.0	18.4	18.8	18.3	19.5	18.7	19.8	19.8
4414.4	610	F	20.0	18.8	19.4	17.9	19.45	18.8	20.0	19.3
4444.3	616	F	19.3	18.75	19.7	18.1	19.6	18.7	19.8	19.7
4493.4	625	F	19.45	19.1	19.5	19.0	19.7	18.8	19.9	19.5
4709.6	669	F	19.5	18.6	19.2	19.1	19.3	19.3	20.0	19.3
4731.5	D323	F	19.15	19.2	19.7	19.0	19.1	19.4	19.5	19.8
4739.5	S541	F	19.8	18.5	19.0	19.2	19.2	19.3	19.8+	19.5
4762.5	H676	G	19.9	19.15	18.95	18.3	18.9	19.3	20.0	19.2
4770.5‡	691	F	19.8+	18.8	19.6	18.1	19.1	19.1	19.45	19.7
4771.5‡	697	F	20.0	18.5	19.6	18.0	18.9	19.1	19.6	19.6
4772.5	707	P	....	18.3	19.6	18.0	....	19.1	....	....
4800.4	709	G	19.5	19.2	19.7	18.3	19.0	19.1	19.9	19.25
4907.3	714	F	19.7	18.4	19.6	19.0	19.7	19.2	20.0	19.5
4947.3	S556	P	....	....	....	18.2	....	....	....	....
5035.63	H781	VP	....	....	....	19.0	....	....	....	....
5053.60	794	P	....	18.9	....	19.1	....	....	....	....
5063.61	799	G	19.6	19.1	19.6	19.2	19.75	19.25	19.7	19.6
5065.58	810	G	19.0	19.1	19.5	19.2	19.75	19.2	19.3	19.8
5083.55	813	P	19.5+	18.75	19.5+	19.1	....	....	19.9	19.5
5091.6	816	F	19.35	19.1	19.3	18.8	19.5	19.3	19.5	19.8
5115.5	825	F	19.4	18.7	19.7	18.2	19.4	19.2	19.7	19.7
5116.48‡	829	E	19.5	18.75	19.5	18.2	19.3	19.1	19.2	19.9
5124.45	H833	F	19.8	19.2	19.15	17.8	19.25	19.2	20.0	19.35
5145.52	S578	P	....	18.6	18.8	17.9	19.2	19.2	....	....
5147.5‡	H843	F	19.8+	18.7	19.0	18.1	19.0	19.2	19.9	19.55
5148.3	850	P	....	18.8	19.1	18.1	....	....	....	....
5149.5‡	851	F	19.9	18.8	19.25	18.2	18.9	19.1	19.9	19.25
5150.5‡	858	F	19.9	18.85	19.4	18.25	18.9	19.1	20.0	19.25
5266.3	899	P	....	19.1	19.5	18.8	19.5	19.2	19.5+	19.2
5475.5	920	G	19.7	18.4	18.8	18.0	19.8	19.4	19.9	19.5

* Add 2,420,000.

† D plates were obtained by Duncan; S and H plates, by Hubble.

‡ Two or more plates in one night.

|| The plus sign following a magnitude indicates that the variable was invisible, but certainly fainter than the tabulated magnitude.

§ Additional observation of Variable No. 42, H916, J.D. 5291.3, 17.9.

Cepheids.—Data for the normal light-curves of the forty variables recognized as Cepheids are given in Table III. Magnitudes at minima and ranges are included, but in most cases they are very uncer-

TABLE III

CEPHEIDS IN M 31

Var. No.	Period in Days	log P	Photographic Magnitudes				Epoch J.D.*	Position†	
			Max.	Min.	Range	Med.		X	Y
1	31.390	1.497	18.2	19.4	1.2	18.8	3823.0	+13.7	+ 8.1
2	20.090	.303	18.6	(19.6)‡	(1.0)	(19.1)	4029.5	− 1.6	−13.9
3	27.00	.431	18.4	19.7	1.3	19.05	4771.0	+ 8.0	− 4.3
4	20.60	.314	19.0	(19.8)	(0.8)	(19.4)	3995.5	− 1.4	+ 5.0
5	48.36	.684	18.5	(19.7)	(1.2)	(19.1)	3990.0	+21.6	−10.6
6	22.23	.347	18.6	19.7	1.1	19.15	3788.0	−10.7	− 9.7
7	45.05	.654	18.1	19.1	1.0	18.6	2583.0	−16.9	− 3.2
8	17.764	.249	19.0	(19.8)	(0.8)	(19.4)	3992.5	− 4.2	+ 2.0
9	32.56	.513	18.2	19.4	1.2	18.8	4108.0	−23.1	+ 1.4
10	22.823	.358	18.8	(19.6)	(0.8)	(19.2)	4029.0	+24.2	−15.3
12	22.225	.347	18.9	(20.0)	(1.1)	(19.45)	3994.5	−18.3	− 3.2
13	21.726	.337	19.05	(19.95)	(0.9)	(19.5)	3822.0	−16.7	− 6.8
14	17.632	.246	18.9	(20.0)	(1.1)	(19.45)	4026.0	− 9.8	− 7.3
16	41.157	.614	18.8	19.8	1.0	19.3	4011.0	+11.9	−10.5
17	18.773	.274	18.75	19.9	1.15	19.3	3990.0	+14.3	− 8.0
18	18.538	.268	19.1	(19.9)	(0.8)	(19.5)	4025.0	+11.5	− 7.3
21	17.15	.234	19.0	20.0	1.0	19.5	4055.0	+51.0	− 0.9
22	17.60	.246	18.95	(19.85)	(0.9)	(19.4)	4181.0	46.7	+ 0.5
23	17.54	.244	18.7	19.7	1.0	19.2	4319.0	54.5	− 4.1
24	17.61	.246	19.25	(20.0)	(0.75)	(19.6)	4349.0	49.7	− 3.2
25	11.82	.073	19.1	19.9	0.8	19.5	4511.0	49.2	3.6
26	26.18	.418	19.0	19.9	0.9	19.45	4319.0	46.6	3.6
27	24.07	.381	18.75	19.45	0.7	19.1	4324.0	49.4	5.8
28	26.78	.428	18.25	19.35	1.1	18.8	4147.0	51.7	6.9
29	19.524	.290	19.1	(20.0)	(0.9)	(19.55)	4444.0	49.4	6.7
30	18.28	.262	18.75	19.85	1.1	19.3	4383.0	44.5	4.9
31	22.73	.357	19.1	20.0	0.9	19.55	4349.0	48.0	2.1
32	25.32	.403	18.7	19.6	0.9	19.15	4318.0	61.9	6.0
33	18.82	.275	18.7	19.3	0.6	19.0	4031.0	54.0	1.9
34	32.25	.508	18.8	19.9	1.1	19.35	4708.0	42.0	9.4
35	17.49	.243	18.95	(19.6)	(0.65)	(19.3)	4356.0	34.3	4.2
36	17.90	.253	19.05	(19.75)	(0.7)	(19.4)	4325.0	53.0	8.4
37	13.328	.125	19.3	(19.9)	(0.6)	(19.6)	4319.5	52.6	2.6
38	10.128	.005	19.3	(20.0)	(0.7)	(19.65)	4357.0	51.2	5.1
39	23.92	.379	19.1	(20.1)	(1.0)	(19.6)	4730.0	46.5	7.4
40	33.455	.524	18.4	19.2	0.8	18.8	4373.0	48.0	3.5
41	25.458	1.406	18.8	19.7	0.9	19.25	4379.0	56.7	5.1
42	175.	2.243	17.9	19.2	1.3	18.55	4425.0	58.1	2.4
45	12.90	1.111	19.3	(20.0)	(0.7)	(19.65)	4084.0	51.9	8.0
46	12.93	1.112	19.2	(19.8)	(0.6)	(19.6)	4321.5	+52.4	−1.4
Mean	....	1.350	18.81	....	....	....	....	....	....
Mean, omitting No. 42	....	1.327	18.83	....	....	....	....	....	....

* Add 2,420,000 to tabular values.

† Positions are referred to the nucleus, X along the major axis, + to the south preceding; Y along the minor axis, + to the north preceding.

‡ Magnitudes in parentheses are uncertain.

tain and are bracketed in order to indicate this fact. Positions are given to the nearest 0.'1 with respect to a system of co-ordinates determined by the major and minor axes of the nebula, and the stars themselves are marked on the various plates used as illustrations. The same system is used for the novae and will be described more fully in connection with the distribution of those objects. For the present it is sufficient to mention that Cepheids are rare in the un-

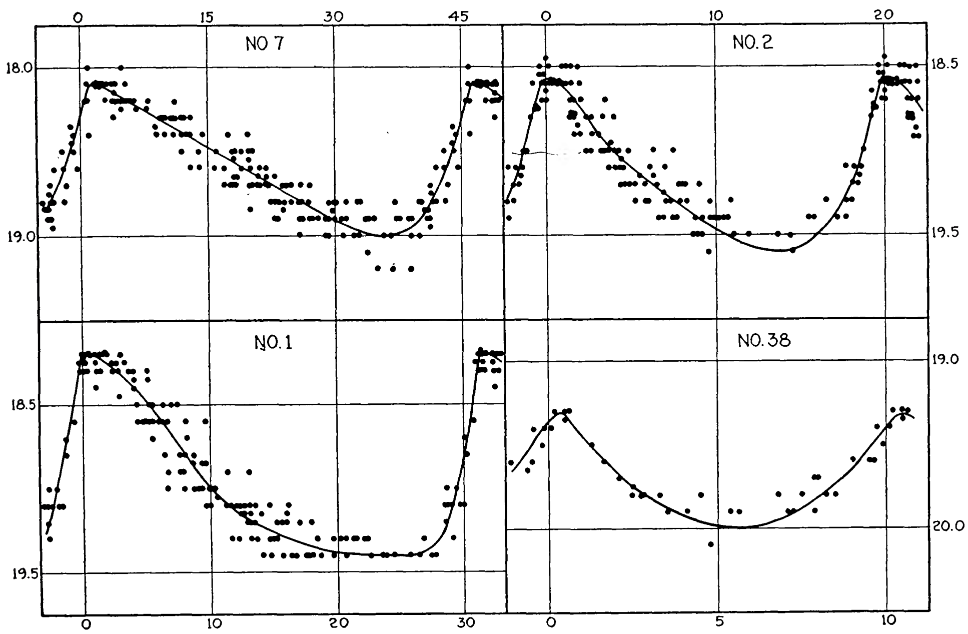

FIG. 1.—Light-curves of four Cepheids in M 31; ordinates, photographic magnitudes; abscissae, days.

resolved nuclear region and that position in the nebula appears to have no effect on the period-luminosity relation.

The periods of the Cepheids range from forty-eight to ten days, and the magnitudes at maxima, from 18.1 to 19.3, with the exception of No. 42, which varies from 17.9 to 19.2 in a period of one hundred and seventy-five days. The Cepheid characteristics are obvious in the normal curves illustrated in Figure 1, and the forms of the curves tend to harmonize with Hertzsprung's relation between shape and period.[1]

The numbers of Cepheids increase steadily as the periods shorten,

[1] *Bulletin of the Astronomical Institute of the Netherlands*, **3**, 115 (No. 96), 1926.

with a limit at about seventeen days. This appears to represent the general limit of the data, and the five variables with shorter periods may be regarded as chance catches. Other very faint variables have been found, but the very exacting conditions required for determining periods have not as yet been realized. There are indications, however, that the periods of some at least are less than ten days.

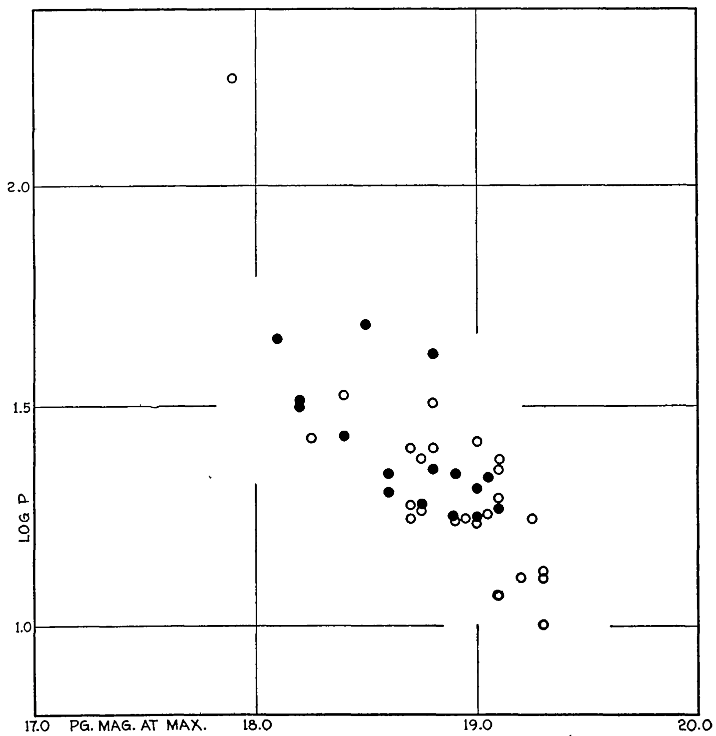

FIG. 2.—Period-luminosity relation among Cepheids in M 31. Photographic magnitude at maximum plotted against logarithm of period expressed in days. Cepheids in Region 4 are designated by circles in order to emphasize the absence of any selective effect due to position in the nebula.

In Figure 2, the logarithms of the periods have been plotted against magnitudes at maxima. The variables in Region 4 have been distinguished by circles in order to emphasize the absence of any effect that can be attributed to location in the nebula. The relatively larger number of very faint variables in the outer region is probably due to the longer exposures used in studying that field.

The period-luminosity relation is clearly shown, although the range is limited and the data for the fainter magnitudes are incomplete. The slope is approximately that of the curve published by Shapley for Cepheids in the Small Magellanic Cloud.[1] The residuals, which average about 0.2 mag., are slightly smaller than those found by Shapley, but the difference can be attributed largely to the incompleteness of the data for the fainter variables. Number 42, the outstanding exception, deviates from the curve by 0.75 mag., but the next largest residual, that for No. 16, is less than 0.5 mag.

The distance of M 31 has been derived by comparing Figure 2 with corresponding diagrams for Cepheids in M 33 and in the Small Magellanic Cloud. The latter diagrams, drawn on transparent paper, were superposed on Figure 2 and shifted along the axis of magnitudes until the best fit was obtained. Some personal judgment was involved in allowing for the effects of selection in favor of brighter stars among the shorter periods, but the limits of the probable errors are small.

In the case of the two spirals, where the scales of magnitudes are strictly comparable, since they are based largely upon the same Selected Areas, the shift in m, the apparent magnitude, was determined as 0.1 mag., in the sense that the stars in M 31 are the fainter. A shift of 0.1 mag. in either direction from this adopted value appreciably unbalanced the fit, hence the probable error of the determination was estimated to be of the order of 0.05 mag.

M 33 had already been compared with the Small Magellanic Cloud in order to determine the relative distance, hence the comparison of M 31 with the cloud was largely a check on the previous comparison. The result for the new comparison, $\Delta m = 4.7 \pm 0.1$, agrees, within the probable errors, with the value for M 33 when corrected for the difference between the two spirals.

The data for the two spirals are so nearly comparable—thirty-five Cepheids being known in M 33 and forty in M 31—that they may be combined into a single diagram for a final comparison with the diagram for the Small Magellanic Cloud. The result is shown in Figure 3. The magnitudes for the Cepheids in M 33 have been increased by 0.1 mag. in order to reduce them to the distance of M 31. These seventy-five variables form a period-luminosity diagram of

[1] *Harvard Circular*, No. 280, 1925.

considerable weight, in which the internal relations are reasonably consistent.

To obtain the best fit, the superposed diagram for the Small Cloud was shifted 4.65 mag., with an estimated probable error of 0.1 mag. The magnitudes at maximum of the Cepheids in the Small Cloud, increased by 4.65 mag., are included in Figure 3 in order to show the appearance of the diagram for what was judged to be the best agreement. For the sake of completeness, nine Cepheids in N.G.C. 6822 have also been included, their magnitudes increased by 0.55 mag.[1] Figure 3, therefore, includes all extra-galactic Cepheids for which data have been published.

No corrections to the distances of N.G.C. 6822 and M 33 as previously determined are indicated. The distance of M 31 is about 0.1 mag., or 5 per cent, greater than that of M 33, and 8.5 times the distance of the Small Magellanic Cloud. Using Shapley's value for the cloud ($m-M=17.55$), we find for M 31

$$m-M=22.2$$
$$\pi=0\overset{''}{.}00000363$$
$$\text{Distance}=275{,}000 \text{ parsecs}$$
$$=900{,}000 \text{ light-years}$$

[1] The periods of the Cepheids in N.G.C. 6822, as published in *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, **62**, 409, 1925, were derived from rather limited material. Additional data collected in the last two years have led to some revision. The revised periods, which are believed to be reliable, are as follows:

No. 7	65.05 days	No. 4	17.36 days
2	37.50	9	16.84
1	30.47	5	13.864
3	29.24	13	122.
6	20.00		

The possibility of periods close to an even day or submultiple thereof has definitely been eliminated in the case of variables Nos. 2, 4, 5, and 6 by series of morning and evening plates on successive nights. Numbers 10 and 12 appear bright and faint in alternate seasons and probably have periods of the order of six hundred days. Their color-indices are estimated as moderately large, but the stars are not red. No revisions have been found necessary for Nos. 8 and 11, but the data in these cases are very uncertain. Two new variables have been found, both of which appear to be irregular. One of these stars is very red.

Continued observation of M 33 has led to the discovery of two additional novae, making four in all, and of two new variables, but to no revision in the periods of the Cepheids. Dr. W. Baade, of the Hamburg Observatory, has communicated by letter his discovery of an additional variable in the extreme northern region of M 33. This star appears near the edge of several of the Mount Wilson plates, where the variation, although small, is quite definite. It is one of the brightest variables in the region, being surpassed only by Nos. 1 and 2.

The accuracy of the relative distances is very satisfactory. In the case of the two spirals, the probable error is of the order of 2.5 per cent; for the spirals and the Cloud, it is of the order of 5 per cent. The accuracy of the distances in parsecs or light-years, however, depends largely upon the accuracy of the zero point of the period-

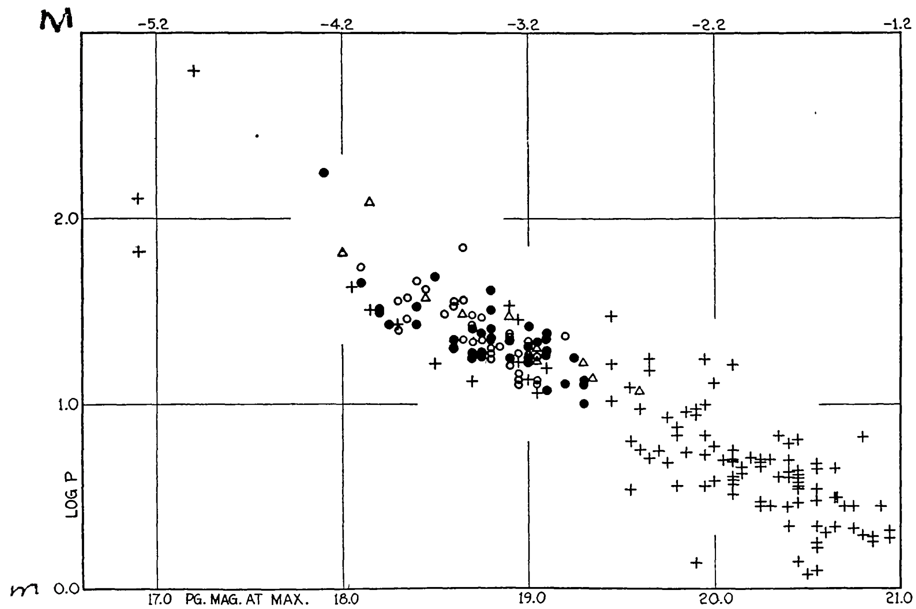

FIG. 3.—Period-luminosity relation among the extra-galactic Cepheids. The crosses refer to 106 Cepheids observed by Shapley in the Small Magellanic Cloud; the black discs, to 40 Cepheids in M 31; the open circles, to 35 in M 33; the triangles, to 9 in N.G.C. 6822. The apparent magnitudes at maxima have been reduced to the distance of M 31 by adding 4.65 to those in the Small Magellanic Cloud, 0.1 to those in M 33, and 0.55 to those in N.G.C. 6822. The absolute photographic magnitudes at the top of the diagram are based upon Shapley's zero point ($m-M=17.55$ for the Small Magellanic Cloud).

luminosity curve. Accumulating evidence indicates that Shapley's value is certainly of the right general order of magnitude, but there still remains the possibility of a considerable correction when more data on galactic Cepheids become available.

Variables other than Cepheids.—Of the ten variables other than recognized Cepheids, four are probably Cepheids for which the data are insufficient to establish the characteristics, while six are irregular or have long periods. To the first class belong the following stars:

Variable No.	Max.	Min.	X	Y
47.......	19.7	20.3	+55.5	−3.9
48.......	19.6	20.3	48.8	4.0
49.......	19.6	20.3	49.7	4.4
50.......	19.2	(19.5)	+50.0	−6.2

Number 50 is involved in a group or cluster, and is especially difficult to observe. These stars can be followed, in general, only on plates exposed under exceptionally good conditions. Short periods, however, may be inferred from the short duration of maxima. In the case of No. 47, two maxima have been observed with an interval of five days.

The irregular or long-period variables are Nos. 11, 15, 19, 20, 43, and 44.

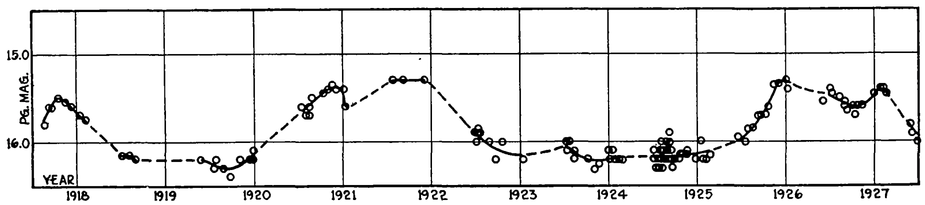

FIG. 4.—Light-curve of variable No. 19

Number 11 ($X = -7'.5$; $Y = -8'.3$) has varied from 18.6 to about 19.6. The brightest maximum occurred in the autumn of 1917, and seven years later it again rose above 19.0.

Number 15 ($X = -16'.1$; $Y = -10'.4$), the second brightest variable in the nebula, rose gradually from 17.5 in 1909 to 16.8 in 1924. In 1926 it faded to 17.3, but rose again to 17.0 in 1927 and in 1928, to about 16.7. The absolute magnitude at maximum, calculated with the distance indicated by the Cepheids, is about −5.5. The color-index appears to be less than 0.2 mag.

Number 19 ($X = -2'.3$; $Y = -9'.8$) is the brightest of all the variables that have been observed. Its color-index is uncertainly estimated as of the same order as that of No. 15—less than 0.2 mag. The variation is from about 15.3 to 16.3, and there are some indications of a period of the order of five years. The light-curve, however, which is shown in Figure 4, does not repeat itself very faithfully, and further observations will be required to settle the question. If the star actually belongs to the nebula, the absolute magnitude varies from -6.9 to -5.9. Numbers 15 and 19 show some analogies with variables Nos. 1 and 2 in M 33. Number 19 was found independently by W. J. Luyten on plates made with the 24-inch Bruce camera.[1]

Number 20 ($X = +4'.6$; $Y = +11'.5$) was recorded on several plates from 1909 to 1910 as about 18.6. By 1915, however, it had risen to about 18.0, where it has remained up to the present. For this reason the individual observations are not listed in Table I. The star may be similar to those listed as novae Nos. 36 and 39, which appeared suddenly but have remained constant since their appearance. It may be significant that these are among the faintest novae that have been observed.

Numbers 43 ($X = +51'.3$; $Y = -4'.8$) and 44 ($X = +43'.5$; $Y = -8'.1$) are in Region 4 and hence have been observed only since 1924. The former appears to be red, while the latter has a color-index considerably less than the color-indices of the Cepheids. Number 43 averaged about 19.8 in 1924–1925 and about 19.4 in 1925–1926. From 19.2 in August, 1926, it rose to 18.9 in September, only to fade again until by January, 1927, it was 19.6. In July it was still faint, about 19.7, but rose rapidly to 18.9 in October. By January, 1928, however, it had faded to 19.5, and by August had reached 19.8.

Number 44 has varied from 18.7 to about 19.4. It was active during the first season, 1924–1925, rising, fading, and rising again to the maximum observed luminosity. During 1925–1926 it averaged about 18.8, and since then, about 19.2.

The significant feature of these stars appears to be their restricted ranges in luminosities. They are giant stars and might well be classed as "super-giants." One, No. 43, is clearly red, but three at least appear to be early-type stars. The red star may be analogous to Betelgeuse, but stars similar to the other three variables are not known in our own system. It is not improbable, however, that the variables found in M 81 and N.G.C. 2403, and some at least of those in M 101, are similar to the bright irregular variables in M 31 and 33, and may eventually be used as rough criteria of distances.

[1] *Harvard College Observatory Bulletin*, No. 851, 1927, in which Luyten announces another variable, about 13.5 at maximum, on the extreme edge of M 31, north following the nucleus. Color and type of variation are uncertain, but in view of the relative luminosity, further data will be required to determine a connection with the spiral.

NOVAE

S Andromedae, the first nova found in the spiral, was discovered visually in August, 1885. It was announced by Hartwig, although, as subsequently disclosed, it had been seen previously by several other observers. The position of this nova, about 16″ preceding and 4″ south of the nucleus, is unique. No other has been found within 1ʹ.5 of the nucleus, although it should be remembered that only exceptionally bright novae could be detected on the dense background of unresolved nebulosity in this region. The photometric measures of the first nova are rather discordant, but a general review of the published results indicates that the visual magnitude at maximum was about 8.0. This places it at once in that mysterious class of exceptional novae which attain luminosities that are respectable fractions of the total luminosities of the systems in which they appear.

Photographic observations of novae in M 31 began in 1917. Ritchey had found a nova in N.G.C. 6946 and, following up the suggestion, examined all the negatives of spirals in his collection. Indications of changes, novae or variables, were reported in M 81, M 101, and N.G.C. 2403, but no further investigations were made of these objects.[1] In M 31, however, two novae were found on the first plates of the nebula obtained with the 60-inch reflector in the autumn of 1909, and sufficient data were available to establish the character

[1] *Publications of the Astronomical Society of the Pacific*, **29**, 210, 1917. Ritchey's remarks refer to the following objects: (*a*) The star in M 81 is 4ʹ.5 from the nucleus in a direction S 27° W. On two plates taken in February, 1910, it was about 19.0; on three plates in March, 1916, and March and December, 1917, it was about 18.6; in April, 1921, and from 1924 to 1927 it was normal again at 19.0. Six additional variables have since been found, and all appear to be analogous to the brighter irregular variables in M 31. (*b*) The object in N.G.C. 2403 appears to be a defect. Under a microscope the edges are sharper and the color more brownish than the ordinary star-images. Five variables are now known in this nebula, but the nature of the variations is uncertain. (*c*) In M 101, two stars were marked. One, 2ʹ.85 due south of the nucleus, was about 18.8 in March, 1910, and about 19.5 in May, 1915. On a few subsequent long exposures it appears about the latter luminosity. The other star, 4ʹ.13 from the nucleus in the direction S 4° E, was about 19.2 in 1910 and 19.6 in 1915. From 1922 onward it has remained constant at about 18.5. Eight other variables have since been found.

The 1910 plate of M 101 shows a star of 16.8 mag., some 12ʹ.3 from the nucleus in the direction W 35° N, which does not appear on any of the later plates. It was not mentioned by Ritchey, although the image shares the distortion, due to coma, of the other images and there seems to be no reason for doubting that it represents an actual star. It might well be an unusually bright nova.

of the variation. Other plates of the spiral were immediately obtained, and these led to the discovery of six additional novae during the season 1917–1918, by Ritchey, Shapley, and Duncan. During the next five years the spiral was photographed more or less sporadically, and thirteen novae were discovered by Sanford, Humason, Duncan, Shapley, and Miss Ritchie.

In the autumn of 1923 the writer began to photograph the nebula more systematically in order to accumulate data for the statistical study of novae. Since that time sixty-three additional novae have been found, and the material is now sufficient for a preliminary general discussion.[1] The nova of 1885 is clearly an exceptional case, and the eighty-five photographic novae must be considered as normal.

Although more than three hundred plates are now available, the material is not strictly homogeneous with respect either to effective exposure or to spacing in time. The 60- and 100-inch reflectors have been used indiscriminately under all conditions of seeing and with exposures ranging from twenty minutes to upward of two hours. The limiting magnitudes on the various plates are usually 19.0 or fainter, although occasionally they may be brighter than this by 0.5 mag. or more. A hundred plates, however, show stars fainter than 20.0. The observing seasons ran from June to February. The exposures were all made during the dark of the moon. From first quarter to third quarter both reflectors are always used in the Cassegrain form with the spectrographs attached, and hence are not available for direct photography. As a result, at least half of each lunation was unobserved, and generally the remaining half was not fully covered. For the years before 1923, the gaps are considerably greater. Following Ritchey's excellent series in the autumn of 1909, only four plates were exposed during an interval of eight years.

In general, the plates were centered on the nucleus and, as regards limiting magnitudes, the distortion of the images in the outer regions is roughly balanced by the background of unresolved nebulosity near the nucleus. Since the plane of the spiral is but little in-

[1] The four novae, Nos. 87–90, discovered by Duncan in August, 1928, are not included in the present discussion. The announcement is in *Publications of the Astronomical Society of the Pacific*, 40, 347, 1928.

clined to the line of sight, a strip nearly 30′ wide, extending entirely across the nebula at right angles to the major axis, has been observed in a fairly homogeneous manner. In addition, Region 4, with its center some 48′ south preceding the nucleus along the major axis, has been under observation since 1924; Regions 2 and 3 were well observed during the season 1924–1925; about thirty plates were centered on other regions or covered large areas with long exposures. These furnish information concerning the outer regions of the spiral supplementary to that contained in the main series centered on the nucleus.

Following the procedure established in 1917, the novae have been numbered serially according to the date of discovery. Number 1 is therefore the great nova of 1885, S Andromedae; Nos. 2–22, inclusive, are the photographic novae found at Mount Wilson from 1917 to 1922; Nos. 23 and upward are the novae found by the writer from 1923 to 1927. Data on Nos. 2–21 have been published from time to time in *Publications of the Astronomical Society of the Pacific*.[1] The magnitudes were generally estimated by comparison with a sequence of stars measured by Shapley with the 60-inch telescope. These measures have not been published, but are on file at Mount Wilson.

New measures by the writer with the 100-inch are in fair agreement down to about 17.0, but beyond this point they diverge somewhat, probably because of the greater efficiency of the larger telescope in registering star-images free from the nebulous background. For the sake of homogeneity, the plates of the older novae have been re-examined and the magnitudes have been re-estimated by comparison with the new sequence. These data, together with those for the more recent novae, are given in full in Table IV. The date of the plate immediately preceding that on which a nova first appeared and the date of the plate next following that on which it was last

[1] The references are as follows:

Novae 2, 3 ...... **29**, 210, 1917	Novae 12, 13 ...... **31**, 109, 1919
4 ...... **29**, 213, 1917	14, 15, 16 ...... **31**, 280, 1919
5 ...... **29**, 257, 1917	17 ...... **32**, 63, 1920
6, 7, 8 ...... **30**, 162, 1918	18, 19, 20 ...... **33**, 56, 1921
9 ...... **30**, 255, 1918	21 ...... **34**, 222, 1922
10, 11 ...... **30**, 341, 1918	

TABLE IV

Magnitudes of Novae in M 31

1909	J.D.	Plate	Qy.	2‡	3	38				
Sept. 12	8562.5*	R17	G	18.3+	18.2+					
12	8562.7	18	F	17.6	17.5	18.7				
13	8563.45	19	G	16.9	17.7	18.7				
13	8563.65	20	G	17.4	17.7	18.7				
15	8565.45	26	E	16.7	17.4	18.9				
16	8566.65	27	F	16.8	17.1	18.8				
Oct. 11	8591.45	34	E	17.4	17.6	18.8				
13	8593.35	39	G	17.5	17.7	19.4				
Nov. 7	8618.3	47	P	17.9	17.5	19.4+				
7	8618.5	48	P	18.0	17.6	18.3+				
1917–18	J.D.	Plate	Qy.	4	5	6	7	8	9	85
Aug. 12	1462.65†	P300	G	18.6+						
Sept. 11	1483.45	Sh3991	P	17.5						
17	1489.5	R146	G	17.7	18.5+					
Oct. 13	1515.5	Sh4091	VP	18.2+	17.3					
16	1518.5	R147	F	18.6	17.4	18.3+				
Nov. 14	1547.5	151	G	18.5+	18.2	16.5	....	....	....	19.0+
Dec. 12	1575.4	154	G	....	18.5+	17.5	....	....	....	17.4
13	1576.4	156	G	....	....	17.6	18.6+	....	....	17.4
Jan. 15	1609.3	161	G	....	....	18.3	17.1	18.5+	18.5+	19.0+
17	1611.3	Sh4333	VP	....	....	17.6+	17.1	17.6+	17.6+	
Feb. 9	1634.3	R162	F	....	....	18.5+	18.5+	17.5	17.5	
10	1635.3	163	F	....	....	....	....	17.4	17.5	
1918–19	J.D.	Plate	Qy.	10	11	12	13			
Aug. 30	1836.6	Sh4663	P	18.0+	18.0+					
Oct. 7	1874.4	Sa10	F	17.4	17.6					
8	1875.36	Sa12	F	17.5	17.6					
8	1875.38	13	F	17.5	17.7					
Nov. 2	1900.4	17	G	17.8	18.8+					
2	1900.4	18	F	17.8	....	18.5+	18.5+			
Jan. 4	1963.23	21	P	18.0+	....	17.0	17.2			
4	1963.24	22	P	....	....	17.1	17.2			
5	1964.3	23	P	....	....	17.0	17.3			
Feb. 3	1993.25	27	G	....	....	17.5	18.5			
3	1993.3	28	G	....	....	17.5	18.5			
1919	J.D.	Plate	Qy.	14	15	16	17	86		
June 28	2138.7	Sa36	P	....	17.7					
29	2139.7	37	G	....	17.8					
30	2140.6	38	G	....	17.9					
30	2140.7	39	F	18.8+	18.0					
July 21	2161.6	Sh4978	F	16.1	17.4					
23	2163.6	5025	F	16.1	17.5					
28	2168.6	D24	P	16.2	17.4					
29	2169.6	27	G	16.3	17.6	17.8+				
Aug. 24	2195.5	30	F	18.8+	17.9	17.1				
28	2199.5	Sa41	G	....	18.2	17.1				
29	2200.5	42	G	....	18.0	17.1				
Sept. 1	2203.5	46	P	....	18.0	17.2				
21	2223.5	Sh5054	P	....	17.9	17.4	....	16.7		
Oct. 16	2248.4	Sa49	P	....	18.0	17.8+	18.5+			
30	2262.4	Sh5105	VP	....	....	....	15.8			
31	2263.4	5107	G	....	18.0	....	16.6			
Nov. 30	2293.4	Sa50	F	....	18.2	....	18.5+			
Dec. 21	2314.3	Sh5160	G	....	18.2					
1920	J.D.	Plate	Qy.	18	19	20	80	81		
July 22	2528.6	Sh5479	P	....	....	....	17.8+			
Aug. 8	2545.6	5489	G	....	....	....	18.0			
10	2547.63	D42	F	....	....	....	17.9			
11	2548.56	44	E	....	....	....	18.0			
Sept. 12	2580.5	62	F	....	....	....	17.5			
13	2581.6	65	P	....	....	....	17.5			

1929ApJ....69..103H

TABLE IV—*Continued*

1920–21	J.D.	Plate	Qy.	18	19	20	80	81		
Sept. 16, 17.	2585.0	71	G	18.5+	....	....	17.8			
17....	2585.3	72	P	....	....	....	17.8			
Oct. 10....	2608.5	76	F	17.2	....	....	18.1			
11....	2609.6	80	P	17.3	....	....	18.2			
14....	2612.3	S68	F	17.4	....	....	18.1			
Nov. 12....	2641.6	75	F	18.3+	....	....	18.5			
13....	2642.5	77	G	18.5+	18.5+	18.5+	18.5	19.0+		
Dec. 10....	2669.3	D106	F	....	16.0	17.7	18.6	16.7		
10....	2669.35	107	F	....	15.9	17.7	18.6	16.7		
12....	2671.3	112	P	....	16.6	17.6	18.2+	17.1		
12....	2671.33	113	P	....	16.7	17.6	....	17.2		
17....	2676.4	B2	P	....	17.2	17.8	....	18.0		
Jan. 4....	2694.3	D118	G	....	18.2	18.0	....	19.0+		
5....	2695.3	122	F	....	18.3	18.0				
8....	2698.4	132	F	....	18.5	17.8				
Feb. 6....	2727.3	136	P	....	18.0+	18.0+				
1921	J.D.	Plate	Qy.	26§	83	20				
July 3....	2874.6	B5	P	....	18.0+	18.0				
Aug. 1....	2903.4	D200	P	....	17.6	18.0				
1....	2903.45	201	P	....	17.6	18.0				
Oct. 4....	2967.5	A6	P	19.0	18.5					
Dec. 5....	3029.4	10	F	18.6	18.5+	18.3+				
1922–23	J.D.	Plate	Qy.	26	21	22	84	82		
May 29....	3204.6	B40	P	18.6	18.0					
June 23....	3229.6	A22	P	....	17.5					
28....	3234.6	S150	F	....	17.8	....	19.0+			
July 20....	3256.6	A29	P	18.6	18.5+	....	17.5			
22....	3258.7	B51	F	....	....	....	17.5			
23....	3259.6	56	F	....	....	....	17.6			
24....	3260.7	S156	P	....	....	....	17.6			
25....	3261.6	163	F	18.6	....	....	17.6			
27....	3263.6	D220	P	....	....	....	17.6			
28....	3264.65	222	P	18.6	....	....	17.6			
Aug. 20....	3287.6	B58	P	....	....	....	17.7			
22....	3289.6	62	P	....	....	....	17.8			
28....	3295.6	S171	F	18.5	....	....	18.0			
Sept. 19....	3317.7	172	F	18.5	....	....	19.0+			
24....	3322.6	B67	F	....	....	....	....	18.5+		
Oct. 16....	3344.4	70	G	....	....	....	....	17.9		
22....	3350.3	A42	P	....	....	....	....	18.4		
Jan. 13....	3433.3	B100	F	....	....	18.0+	....	18.5+		
Feb. 15....	3466.3	A47	P	18.5	....	16.9				
1923–24	J.D.	Plate	Qy.	23	24	25	27	28	29	30
July 16....	3617.8	S254	F	18.0+						
Aug. 7....	3639.8	267	F	17.0						
9....	3641.5	278	P	17.1	18.0+	18.3+				
Oct. 4....	3697.55	H331	VP	17.5+	17.2	17.3				
5....	3698.55	335	G	18.5+	17.3	17.4				
6....	3699.4	S282	VP	....	17.3	17.4				
8....	3701.35	B142	F	....	17.4	17.3				
9....	3702.5	A61	G	....	17.2	17.3				
Nov. 13....	3737.55	H339	G	....	18.5	18.4	18.5+	19.0+	19.0+	
Dec. 11....	3765.45	348	G	....	18.5+	19.0	17.2	16.2	17.5	
14....	3768.4	351	P	....	....	18.5+	17.5	16.2	18.0	
30....	3784.3	B158	P	....	....	....	18.2	18.2+	18.0	
Jan. 4....	3789.35	H353	P		....	....	18.0			
5....	3790.4	S285	G	31	....	....	18.2			
6....	3791.4	292	G		....	....	18.8	19.0+	19.0	
9....	3794.3	H354	P	18.2+	....	....	18.5+	....	....	18.5+
31....	3816.3	A69	P	16.8	....	....	....	....	....	17.3
Feb. 2....	3818.3	S301	F	17.1	....	....	19.0+	....	19.0+	17.2
3....	3819.3	310	F	17.1	....	....	....	....	....	17.2
4....	3820.3	320	F	17.2	....	....	....	....	....	17.3
5....	3821.3	H355	G	17.2	....	....	....	....	....	17.2
6....	3822.3	357	F	17.2	....	....	....	....	....	17.3
7....	3823.3	363	F	17.3	....	....	....	....	....	17.2
27....	3843.3	A73	P	18.2+	....	....	....	....	....	18.5+

TABLE IV—*Continued*

1924–25	J.D.	Plate	Qy.	32	33	34	35¶	37	40	41	42
July 2....	3969.55	H375	P	17.4							
2....	3969.65	376	F	17.2							
4....	3971.6	S329	P	16.4							
23....	3990.5	336	P	17.5							
24....	3991.6	338	G	18.0							
26....	3993.6	339	G	18.0							
27....	3994.6	344	G	18.0							
28....	3995.5	348	G	17.5							
29....	3996.55	H384	G	17.6							
30....	3997.6	390	G	17.7							
31....	3998.6	395	G	18.0							
Aug. 1....	3999.6	S351	G	18.0							
2....	4000.5	H397	F	18.0							
3....	4001.6	398	P	18.3							
4....	4002.6	404	E	18.0							
5....	4003.5	405	E	18.2							
6....	4004.45	414	E	18.2	18.5+	......	18.5+				
25....	4023.4	B182	F	18.2	17.6	......	17.0				
26....	4024.65	D241	F	18.4	17.4	......	16.8				
27....	4025.63	246	G	18.8+	17.3	18.8+	16.9				
28....	4026.5	S356	G	......	17.4	......	16.9				
29....	4027.65	360	F	......	17.1	18.5+	17.1				
30....	4028.5	H418	G	......	17.2	17.0	17.0				
31....	4029.45	S361	F	......	17.3	16.2	17.1				
Sept. 1....	4030.45	362	F	......	17.3	16.2	17.0				
2....	4031.5	H421	G	......	17.4	16.8	17.0				
3....	4032.5	426	G	......	17.3	17.1	17.2				
4....	4033.5	430	G	......	17.4	16.4	17.0				
20....	4049.4	S360	F	......	17.5	17.2	17.6				
21....	4050.5	374	F	......	17.7	17.3	17.7	18.6+			
25....	4054.5	H434	P	......	18.0	17.3	17.8	16.6			
26....	4055.5	S376	G	......	......	17.5	17.8				
27....	4056.5	385	G	......	18.0	17.6	......	16.6			
28....	4057.5	388	G	......	18.0	17.8	18.0	17.2	19.5+		
30....	4059.4	H444	G	......	18.0	18.0	18.2	17.5	19.0		
Oct. 26....	4085.35	451	G	......	18.5+	18.6	18.5	......	19.0		
27....	4086.4	S394	F	......	......	18.5	......	18.5	18.7		
30....	4089.4	401	G	......	......	18.6+	18.7+	18.6	18.5		
31....	4090.4	H457	G	......	......	......	......	18.6			
Nov. 2....	4092.3	464	F	......	......	......	......	......	18.5		
18....	4108.4	469	F	......	......	......	......	......	18.1		
19....	4109.4	471	G	......	......	18.8	......	18.6			
22....	4112.4	S406	P	......	......	......	......	......	18.0		
24....	4114.4	411	G			18.8+		18.8	17.5		
				43	44		45				
Dec. 28....	4148.35	H507	P			......		......	18.4		
30....	4150.35	510	P			......		......	18.4	18.5+	18.3+
Jan. 17....	4168.35	S417	P	......	18.2+	......	18.3+	......	18.1	17.1	16.4
19....	4170.3	H514	P	18.2+	16.5	......	18.2+	......	18.2	17.4	16.7
26....	4177.35	S424	F	16.8	17.8	......	17.7	......	18.3	17.5	17.1
27....	4178.3	433	G	17.0	18.0	......	17.5	......	18.4	17.8	17.2
30....	4181.35	H531	P	17.4	18.0	......	18.0	......	18.2	18.0	17.4
Feb. 15....	4197.3	S434	P	18.2	18.5+	......	18.0	......	18.2	18.2+	18.2+

1925	J.D.	Plate	Qy.	47	48	49	50	51	52	53	54
June 17....	4319.6	H571	F	17.7	17.0	19.0+	19.0+	19.0+	......	18.6	
19....	4321.6	S483	G	17.5	17.0	......	......	......	......		
July 16....	4348.55	H576	P	18.5+	18.2+	17.3	17.6	18.2	......	18.4	
17....	4349.5	580	F	......	......	17.2	18.0	18.1	......	18.4	
19....	4351.6	D251	F	19.0	19.0+	17.2	18.0	18.0	......		
24....	4356.6	268	G	19.2	19.0+	17.8	17.6	18.3	......	18.8	
26....	4358.5	S496	G	19.0+	......	18.0	18.0	18.7+	18.6+		
Aug. 14....	4377.45	H586	F	18.3	......	19.0	19.0	......	17.3	18.6	
16....	4379.7	598	P	18.0	......	19.2	19.0+	......	17.1	18.6	18.8+
Sept. 11....	4405.7	604	VP	18.2	......	19.0	......	......	18.0	......	17.3
12....	4406.6	607	VP	18.6	......	18.8+	......	......	18.5	18.5	15.3
19....	4413.6	S499	P	......	......	......	......	......	18.5	18.5	15.7
20....	4414.7	H609	F	19.0	......	19.2	......	......	18.5	18.8	15.7
Oct. 9....	4433.3	615	P	......	......	......	......	......	18.8+	18.8	18.8+
17....	4441.45	S505	F	19.0+	......	19.0+	......	......	......	......	19.0
20....	4444.35	H617	F	......	......	......	......	......	19.0	18.2	19.0+
Nov. 10....	4465.35	620	P	......	......	......	......	......	......	18.2	
20....	4475.3	621	P	......	......	......	......	......	......	18.2	
Dec. 8....	4493.35	H624	G	......	......	......	......	......	......	18.8	

TABLE IV—*Continued*

1925–26	J.D.	Plate	Qy.	55	56	57	58	59	60	61	
June 17....	4319.6	H571	F								
19....	4321.6	S483	G	19.0+							
July 16....	4348.55	H576	P	17.3							
17....	4349.5	580	F	17.3							
19....	4351.6	D251	F	17.6							
24....	4356.6	268	G	18.0							
26....	4358.5	S496	G	18.1							
Aug. 14....	4377.45	H586	F	18.8							
16....	4379.7	598	P	18.8	19.0+	......	19.0+				
Sept. 11....	4405.7	604	VP	18.5+	......	......	18.5				
12....	4406.6	607	VP	......	18.5+	......	18.5				
19....	4413.6	S499	P	......	17.8						
20....	4414.7	H609	F	......	17.7	18.5+	18.4				
Oct. 9....	4433.3	615	P	......	18.8	17.4	18.6				
17....	4441.45	S505	F	......	19.0	17.8	18.6	19.0+			
20....	4444.35	H617	F	......	19.0+	17.7	17.5				
Nov. 10....	4465.35	620	P	......	......	18.5	18.5	16.5	18.8+		
20....	4475.3	621	P	......	......	18.5+	18.6	17.5	16.6		
21....	4476.5	Se6276	F	......	......	......	......	17.5	16.5		
Dec. 8....	4493.35	H624	G	......	......	......	18.6	18.3	17.8	18.6+	
10....	4495.35	626	P	......	......	......	......	18.4			
Jan. 6....	4522.3	627	P	......	......	......	......	18.8+	18.8+	16.8	
14....	4530.3	SS 45	F	......	......	......	......	......	......	17.3	
15....	4531.3	H629	P	......	......	......	......	......	......	17.5	
Feb. 16....	4563.3	634	P	......	......	......	......	......	......	18.0+	

1926–27	J.D.	Plate	Qy.	62	63	64	65	66	67	68	69
June 4....	4671.65	S533	P	17.7							
13....	4680.6	D304	VP	17.4	......	......	......	......	18.3+		
14....	4681.6	309	VP	17.4	18.0+	18.0+	......	......	18.0+		
July 3....	4700.6	315	G	17.8	17.3	17.5	18.8+	......	18.2		
12....	4709.55	H668	F	18.2	17.4	18.0	18.2	19.0+	18.2		
14....	4711.6	S539	G	18.4	17.4	18.0	18.3	......	18.3		
Aug. 11....	4739.5	540	F	19.0+	17.7	18.0	18.2+	18.2	18.3		
Sept. 3....	4762.4	H675	E	......	18.8	18.5	......	19.0	17.5		
5....	4764.35	686	E	......	18.8	18.8	......	19.2	17.4		
11....	4770.4	690	E	......	18.8	18.8	......	19.2	17.4		
13....	4772.4	703	E	......	19.0+	19.0+	......	19.2	18.2	19.2+	
Oct. 4....	4793.3	S545	G	......	......	......	......	19.2	18.2	17.7	
11....	4800.3	H708	E	......	......	......	......	19.3+	18.5	18.0	
12....	4801.3	S547	F	......	......	......	......	......	18.4	18.1	19.0+
Nov. 2....	4822.5	BB104	G	......	......	......	......	......	18.5	18.4	17.4
3....	4823.5	117	G				......	......	18.5	18.6	17.4
Dec. 1....	4851.5	150	P	70	71	72	......	......	18.2	18.5	18.2
Jan. 1....	4882.3	166	F				......	......	18.3	19.0+	18.6
2....	4883.3	180	F	19.0+	......	......	......	......	18.4+	......	18.7
6....	4887.3	197	P	18.5	......	......	......	......	17.7+		
27....	4908.35	H715	G	18.1	19.0+	......	......	......	17.7	......	19.0
Feb. 6....	4918.35	720	F	18.6	16.6	19.0+	......	......	17.5	......	19.3
25....	4937.3	730	P	18.6	18.1	17.0	......	......	18.3	......	19.2+
26....	4938.3	732	P	18.6+	18.4	17.3	......	......	18.3		

TABLE IV—*Continued*

1927	J.D.	Plate	Qy.	73	74	75	76	77	78	79	
May 23....	5024.65	H770	P	17.4	17.6+						
June 3....	5035.6	780	F	17.6	18.0						
4....	5036.6	785	G	17.7	17.7	18.5+					
20....	5052.6	789	P	17.7	17.8	18.0+					
July 1....	5063.6	798	G	18.0	17.8	18.4					
21....	5083.5	812	F	18.8	18.4	18.2					
29....	5091.5	815	P	18.2+	18.5+	18.0	18.0+				
Aug. 22....	5115.45	824	G	18.6+	......	18.5	17.1				
23....	5116.45	828	G	......	......	18.3	17.2				
31....	5124.4	832	F	......	......	18.3	17.5	19.0+	19.0+		
Sept. 11....	5145.35	S577	F	......	......	18.8	18.0	17.7	18.2		
23....	5147.6	H848	F	......	......	19.0	18.5	17.8	18.2		
25....	5149.6	855	F	......	......	19.0	18.5	17.8	18.3		
Oct. 22....	5176.35	S591	F	......	......	18.8+	18.5+	19.0	19.0+		
Nov. 1....	5186.3	H866	P	......	......	......	......	18.8	......	18.5+	
23....	5208.5	S603	G	......	......	......	......	19.0+	......	16.7	
26....	5211.3	H867	G	......	......	......	......	......	......	16.8	
28....	5213.45	885	F	......	......	......	......	......	......	16.6	
Dec. 19....	5234.4	888	F	......	......	......	......	......	......	17.5	

* Add 2,410,000.

† Add 2,420,000.

‡ A plus sign following the magnitude indicates limiting magnitudes of plates on which the novae did not appear. Novae are tabulated according to observing seasons, but numbered serially according to dates of discovery. High serial numbers in the earlier seasons represent novae found on re-examining the older plates.

§ Number 26 appeared in October, 1921, and by December had risen to 18.6. During the season 1922–1923 it remained about constant at 18.6, and from July, 1923, to December, 1925, at about 18.0. In January, 1925, it began to fade, but declined so slowly that it did not reach 19.5 until January, 1927. In 1928 it did not appear even on the best plates.

¶ Numbers 36, 39, and 46 are not listed. Number 36 first appeared in August, 1917, after an unobserved interval of two years, and has since remained constant at about 18.2. Number 39 first appeared in February, 1924, and is still visible, varying in an apparently irregular manner between 19.0 and 19.5. Number 46 appeared in Region 4, about 42′ from the nucleus, on the first plate of the season 1926–1927. The data are as follows:

J.D. 2,424,709.6	18.7
2,424,731.5	18.8
2,424,739.5	19.2
2,424,762.5	19.4
2,424,800.4	19.7+

On three plates between the last two dates, with limiting magnitudes about 19.4, the nova was invisible.

seen are included in the table. Magnitudes of stars in the immediate region of the nucleus fainter than about 18.0 are uncertain because of the nebulous background, but outside that region they should be fairly reliable down to about 19.0.

The significant data are collected in Table V. These include the observed duration of a nova; the unobserved intervals immediately preceding and following the observations; the magnitudes at the first observation, at maximum, and at the last observation; the intervals between the first observation and maximum, and between maximum and the next following observation; the number of observations; the approximate co-ordinates measured from the nucleus along the major axis (plus to the south preceding) and the minor axis (plus to the north preceding); and, finally, the latter co-ordinates multiplied

TABLE V

NOVAE IN M 31

Nova	Duration*			Magnitude				Interval between Observations		No. Obs.	Position†		
	Prec.	Obs.	Fol.	First Obs.	Last Obs.	Max. Obs.	Max. Cal.	1st – Max.	Max. – N'xt		X	Y	4Y
2	4hr	56d	....	17.6	18.0	16.7	16.7	2.8d	1d	9	+ 4'.0	+ 1'.0	+ 4'.0
3	4hr	56	....	17.6	17.6	17.1	17.1	3.8	25	9	+ 2.5	+ 2.2	+ 8.8
4	21d	35	29	17.5	18.6	17.5	16.7	0	6	3	−10.1	− 0.0	− 0.1
5	26	32	28	17.3	18.2	17.3	16.4	0	3	3	+ 3.9	− 2.2	− 8.8
6	29	62	25	16.5	18.3	16.5	15.5	0	28	4	− 5.2	+ 0.6	+ 2.4
7	33	2	23	17.1	17.1	17.1	15.9	0	2	2	+ 1.5	+ 1.95	+ 7.8
8	25	1	....	17.5	17.4	17.4	16.6	1	....	2	+ 1.8	+ 1.1	+ 4.4
9	25	1	....	17.5	17.5	17.5	16.7	0	1	2	− 8.8	− 2.7	−10.8
10	38	26	63	17.4	17.8	17.4	16.1	0	1	5	− 7.0	+ 2.9	+11.6
11	38	1	25	17.6	17.7	17.6	16.3	0	1	3	+ 4.9	− 3.5	−14.0
12	63	30	....	17.0	17.5	17.0	......	0	1	5	− 2.2	+ 3.3	+13.2
13	63	30	....	17.2	18.5	17.2	......	0	1	5	+ 5.7	+ 0.1	+ 0.4
14	21	8	26	16.1	16.3	16.1	15.3	0	2	4	− 0.1	− 5.3	−21.2
15	......	176	....	17.7	18.2	17.4	......	23	2	17	− 0.8	+ 3.7	+14.8
16	26	28	25	17.1	17.4	17.1	16.2	0	4	5	+ 4.15	+ 0.6	+ 2.4
17	14	1	30	15.8	16.6	15.8	15.2	0	1	2	− 2.2	+ 1.4	+ 5.6
18	25	4	29	17.2	17.4	17.2	16.3	0	1	3	− 0.2	+ 1.3	+ 5.2
19	27	29	29	16.0	18.5	15.9	15.0	1hr	2	8	+ 2.3	− 1.9	− 7.6
20	27	29	....	17.7	17.8	17.6	16.7	2	5	9	− 2.6	− 0.8	− 3.2
21	......	29	22	18.0	17.8	17.5	16.7	24	5	3	− 4.65	− 1.5	− 6.0
22	33	....	....	16.9	16.9	16.9	15.8	....	....	1	− 1.6	− 0.1	− 0.4
23	22	2	56	17.0	17.1	17.0	16.2	0	2	2	+ 1.8	+ 2.65	+10.6
24	56	40	28	17.2	18.5	17.2	......	0	1	6	+ 9.6	+ 1.25	+ 5.0
25	56	68	3	17.3	19.0	17.3	......	0	1	7	+12.35	+ 0.5	+ 2.0
26	64	5.5yr	....	19.0	19.5	18.0	......	3yr	....	....	+ 3.2	− 5.4	−21.6
27	28	26	27	17.2	18.8	17.2	16.3	0	3	6	− 0.5	+11.7	+46.8
28	28	3	16	16.2	16.2	16.2	15.3	0	3	2	− 5.45	− 4.05	−16.2
29	28	26	27	17.5	19.0	17.5	16.6	0	3	4	+ 6.8	− 3.5	−14.0
30	22	7	20	17.3	17.2	17.2	16.4	2	1	7	+11.0	− 6.25	−25.0
31	22	7	20	16.8	17.3	16.8	16.0	0	2	7	0.0	− 2.7	−10.8
32	......	55	1	17.4	18.4	16.4	16.4	2	19	19	+ 6.8	− 0.6	− 2.4
33	19	36	26	17.6	18.0	17.1	16.4	4	1	17	+ 0.75	−2.95	−11.8
34	1	58	3	17.0	18.5	16.2	16.2	1	1	15	− 0.45	− 3.6	−14.4
35	19	62	4	17.0	18.5	16.8	16.3	1	1	18	+ 2.1	+ 1.5	+ 6.0
36‡	......	11yr	....	18.2	18.2	......	......	....	....	....	−10.25	+ 2.6	+10.4
37	4	60	34	16.6	18.8	16.6	16.4	0	2	9	−32.4	−14.3	−57.2
38	......	31	25	18.7	19.4	18.7	......	0	1	8	+16.3	− 9.9	−39.6
39§	25	4.5yr	....	19.0	19.5	......	......	....	....	....	+ 0.7	+ 6.65	+26.0
40	2	138	....	19.0	18.2	17.5	17.5	55	34	16	+ 4.35	−10.3	−41.2
41	18	13	16	17.1	18.0	17.1	16.4	0	2	5	− 5.0	+ 1.3	+ 5.2
42	18	13	16	16.4	17.4	16.4	15.7	0	2	5	+ 3.8	+ 1.3	+ 5.2
43	7	20	....	16.8	18.2	16.8	16.5	0	1	4	+ 4.4	− 0.15	− 0.6
44	2	11	16	16.5	18.0	16.5	16.4	0	7	4	+ 7.9	−11.9	−47.6
45	7	20	....	17.7	18.0	17.5	17.3	1	3	4	+ 3.05	−12.25	−49.0
46	......	53	8	18.7	19.4	18.7	......	0	22	4	+41.5	+ 3.7	+14.8
47	......	95	27	17.7	19.0	17.5	......	2	27	11	− 8.2	− 0.1	− 0.4
48	......	2	27	17.0	17.0	17.0	......	0	2	2	+18.4	+ 2.7	+10.8
49	29	66	27	17.3	19.2	17.2	16.2	1	2	9	− 9.6	− 7.5	−30.0
50	29	29	2	17.6	19.0	17.6	16.6	0	1	6	−13.65	+ 1.1	+ 4.4
51	29	8	2	18.2	18.3	18.0	17.1	3	5	4	+10.2	− 0.5	− 2.0

TABLE V—*Continued*

Nova	Duration*			Magnitude				Interval Between Observations		No. Obs.	Position†		
	Prec.	Obs.	Fol.	First Obs.	Last Obs.	Max. Obs.	Max. Cal.	1st—Max.	Max.—N'xt		*X*	*Y*	4*Y*
52.....	19d	67d	19d	17.3	19.0	17.1	16.4	2	26	8	+ 3.15	− 0.9	− 3.6
53.....	......	174	....	18.6	18.8	18.2	......	126	21	15	− 2.8	+ 0.2	+ 0.8
54.....	26	36	3	17.3	19.0	15.3	15.3	0.8	7	6	−18.6	+ 1.65	+ 6.6
55.....	27	31	26	17.3	18.8	17.3	16.4	0	1	7	+ 5.2	− 0.65	− 2.6
56.....	7	28	3	17.8	19.0	17.0	16.4	1	19	4	− 1.1	+14.5	+58.0
57.....	19	32	10	17.4	18.5	17.4	16.7	0	8	4	+ 4.6	+ 0.7	+ 2.8
58.....	26	88	....	18.5	18.6	17.5	17.5	39	21	9	− 1.6	− 1.8	− 7.2
59.....	24	30	27	16.5	18.4	16.5	15.7	0	10	5	+11.4	− 1.6	− 6.4
60.....	10	18	29	16.6	17.8	16.5	16.1	1	17	3	−24.3	− 7.5	−30.0
61.....	29	9	32	16.8	17.5	16.8	15.8	0	8	3	+ 1.9	− 0.3	− 1.2
62.....	......	40	28	17.7	18.4	17.4	16.7	9	1	6	+17.5	+ 2.2	+ 8.8
63.....	19	70	2	17.3	18.8	17.3	16.6	0	9	7	+ 1.75	− 1.1	− 4.4
64.....	19	70	2	17.5	18.8	17.5	16.8	0	9	7	+ 0.8	+ 1.75	+ 7.0
65.....	9	2	28	18.2	18.3	18.2	17.8	0	2	2	− 0.9	− 1.2	− 4.8
66.....	30	54	7	18.2	19.2	18.2	17.2	0	23	6	+ 2.9	− 6.0	−24.0
67.....	19	238	....	18.2	18.3	17.4	16.6	64	6	21	+ 4.1	+ 1.5	+ 6.0
68.....	21	58	31	17.7	18.5	17.7	16.9	0	7	6	−10.9	+ 2.4	+ 9.6
69.....	21	96	19	17.4	19.3	17.4	16.6	0	1	7	+ 7.8	− 3.5	−14.0
70.....	4	50	1	18.5	18.6	18.1	16.8	21	10	4	−18.1	+ 0.1	+ 0.4
71.....	10	20	....	16.6	18.4	16.6	16.1	0	19	3	−16.9	− 0.5	− 2.0
72.....	19	1	....	17.0	17.3	17.0	16.2	0	1	2	+ 2.5	− 1.3	− 5.2
73.....	......	59	8	17.4	18.8	17.4	......	0	11	6	+ 4.3	− 0.35	− 1.4
74.....	11	48	8	18.0	18.4	17.7	17.7	1	16	5	+16.1	− 2.6	−10.4
75.....	11	86	27	18.4	19.0	18.0	16.9	28	24	9	− 5.95	− 2.6	−10.4
76.....	24	34	27	17.1	18.5	17.1	16.3	0	1	6	+ 3.45	− 0.6	− 2.4
77.....	21	41	22	17.7	18.2	17.7	16.9	0	2	5	+ 6.05	+ 7.55	+30.2
78.....	21	4	27	18.8	18.3	18.2	17.4	0	2	3	+14.5	+ 0.5	+ 2.0
79.....	22	26	....	16.7	17.5	16.7	15.9	0	3	4	+ 1.5	+ 2.0	+ 8.0
80.....	17	124	2	18.0	18.6	17.5	17.3	35	1	14	+ 3.0	+ 2.8	+11.2
81.....	27	7	18	16.7	18.0	16.7	15.8	0	2	5	− 7.4	−11.7	−46.8
82.....	22	6	....	17.9	18.4	17.9	17.1	0	6	2	− 7.1	+ 1.8	+ 7.2
83.....	27	64	62	17.6	18.5	17.6	16.7	0	64	3	+ 3.0	− 2.35	− 9.4
84.....	22	39	22	17.5	18.0	17.5	16.7	0	2	10	+12.2	− 1.15	− 4.6
85.....	28	1	33	17.4	17.4	17.4	16.5	0	1	2	−11.5	− 8.3	−25.2
86.....	20	0	25	16.7	......	16.7	16.0	....	....	1	− 9.4	− 3.3	−13.2
Mean ¶	......	....	....	......	......	17.20	16.43	....	....	....	....	....	......

* Under "Duration" are listed the length of the unobserved interval preceding the first observation, the interval between the first and the last plates on which the nova appeared, and the unobserved interval following the last observation. When no preceding interval is given, the nova appeared on the first plate of an observing season. The intervals are expressed in days unless otherwise designated.

† Positions are given with respect to the nucleus, *X* along the major axis (plus to the south preceding), *Y* along the minor axis (plus to the north preceding). The last column gives the *Y* co-ordinate corrected for foreshortening due to the inclination of the nebula to the line of sight.

‡ Number 36 first appeared in August, 1917, following an unobserved interval of two years, and has maintained a constant luminosity, 18.2, up to the present time.

§ Number 39 first appeared in February, 1924, and has remained visible up to the present, varying between 19.0 and 19.5.

¶ The mean observed maximum represents 82 novae; Nos. 26, 36, and 39 are rejected. The mean calculated maximum represents 71 novae. In addition to Nos. 26, 36, and 39, the following are omitted on the grounds that the preceding unobserved intervals are excessive—Nos. 12, 13, 15, 24, 25, 38, 46, 47, 48, 53, and 73.

by 4 in order to correct for the inclination of the plane of the spiral to the line of sight. The position of the major axis was estimated on several plates of long exposures on different scales. The line selected was then drawn on a print of the nebula and the orientation was measured with reference to stars whose positions were accurately known. The position angle of the major axis as thus determined is N $36\overset{\circ}{.}7$ E. The ratio of the axes was estimated on long exposures as about 4 to 1, hence the inclination of the spiral to the line of sight is of the order of 15°. The nuclear region, by analogy with other spirals of the same type which are seen edge on, is probably much less flattened than the nebula as a whole—a circumstance to be considered in reconstructing the image as it would appear were the plane perpendicular to the line of sight.

An inspection of Table V indicates the necessity of some culling before entering upon a general discussion. The most conspicuous abnormalities occur in Nos. 26, 36, and 39. Number 26 was first observed in October, 1921, at about 19.0. It brightened slowly until by July, 1924, it was about 18.0. By December of the same year it had begun to fade and now, four years later, it has vanished. The description appears to be that of a long-period or an irregular variable rather than of a nova, and analogies may possibly be found in variables Nos. 15 and 19 in M 31 and Nos. 1 and 2 in M 33. Numbers 36 and 39 appeared, the former between 1915 and 1917, the latter in February, 1924, at about 18.6 and 19.0, respectively, and have maintained constant luminosities up to the present date. These stars may be of the same general type as No. 26, or possibly they may be ordinary stars which have drifted out from behind clouds of dark nebulosity. Variable No. 20 in M 31 may be a similar object. At any rate, the three stars clearly are not normal novae and can be discarded in statistical discussions. It is significant also that they are among the faintest which were originally observed as novae.

Number 22, discovered by Humason in February, 1923, appeared on only one plate. The image, however, shares the distortion, due to astigmatism in the mirror, which the other stars exhibit, hence there is no doubt as to the reality of the nova. Number 86 is a similar case, but no other object is included which has not appeared on more than one plate. For the following sixteen, however, the observations are very meager: Nos. 7, 8, 9, 11, 17, 18, 23, 28, 48, 51, 61, 65, 71, 72, 82, and 85. In these cases there are either but two observations or three or four covering a short interval of time.

Numbers 15, 38, 46, 47, 48, 53, 62, and 73 appeared on the first plates obtained after unobserved intervals of more than a hundred days. The maximum observed magnitudes of some of these are probably much fainter than the real maxima, which may have occurred some weeks earlier. This offers a ready explanation of the faintest two maxima listed in Table V, 18.7 for Nos. 38 and 46. In eight other cases, the first observations follow unobserved intervals of more than thirty days.

In five cases, Nos. 40, 58, 67, 75, and 80, observed maxima occurred several weeks after the first observations, although it is uncertain whether these represent primary or secondary maxima. In the discussions which follow, all novae are included excepting Nos. 1, 26, 36, and 39. The twenty-three novae listed in the two preceding paragraphs, however, and, to a lesser degree, the six mentioned at the beginning of the present paragraph are entitled to smaller weight than the remaining novae.

These stars have been called novae because they flare up very suddenly, fade slowly, and vanish completely. In the eighty-five cases listed, none has reappeared during the eighteen years covered by the observations at Mount Wilson. Occasional plates at other observatories extend the period less certainly over an additional ten years. Novae are the only galactic objects which exhibit such characteristics.

These stars at maxima, moreover, are about the brightest objects in the spiral, and average more than 2 mag. brighter than the Cepheids. In the case of No. 54, a small-scale slitless spectrogram was obtained by Humason, at the Newtonian focus of the 100-inch reflector, some six days after maximum. The continuous spectrum extended well into the violet, and faint patches of emission could be seen in the region of the Balmer lines of hydrogen. The color-index was less than the errors of the determination, which were estimated as about 0.2 mag. These indications, while by no means conclusive, strengthen the analogy with galactic novae.

LIGHT-CURVES OF NOVAE

The data on individual stars are usually fragmentary, but in a few cases they are sufficient to indicate the general form of the light-curves. The sharp initial rise, familiar in galactic novae, appears to be certainly present. The most conspicuous examples are novae Nos. 2 and 3, which Ritchey found on a plate exposed on the morning of September 13, 1909, although they were not visible on a plate exposed four hours earlier. Both novae had brightened at least 0.7 mag. within that interval. By the next exposure, on the late evening

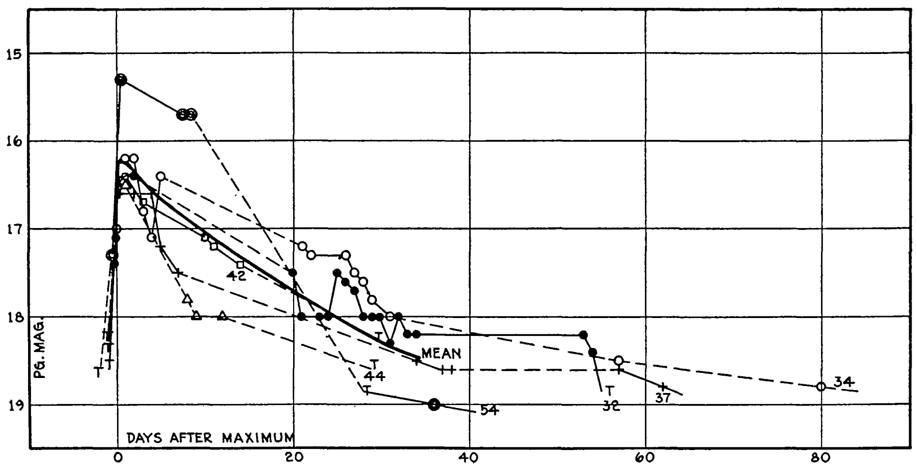

FIG. 5.—Light-curves of six novae in M 31 observed near maximum

of the same day, No. 2 had brightened another 0.7 mag. Nova No. 34 rose 1.5 mag. above the limits of the plates during an unobserved interval of about twenty hours, and on the next plate, a day later, was 0.8 mag. brighter yet. Other instances are Nos. 37 and 44, which appeared about 2 mag. above the limits of the plates after unobserved intervals of four and two days, respectively. Number 54 first appeared at 17.3 after a long unobserved interval, but on the next plate, twenty-two hours later, it was 15.3. Since these data set lower limits only, the actual rates of brightening may be considered comparable with those of galactic novae.

Data for six novae well observed near maximum, Nos. 32, 34, 37, 42, 44, and 54, furnish a mean light-curve, shown in Figure 5, in which the rapid rise, the minor fluctuations, and the slow decline are conspicuous. A composite light-curve, incorporating most of the data in Table IV, has also been constructed on the assumption that the actual maxima of the various novae occurred in the middle of the unobserved interval preceding the first observation. Novae for which this unobserved interval exceeds thirty days were excluded, and, in addition, those for which the observed maxima occurred long after the first observations, and Nos. 21 and 70, for which the data were so poorly distributed that the curves could not be reconstructed with any certainty. This selection reduced the number of available novae to fifty-seven.

Mean magnitudes were computed for various dates after maximum, and the mean curve thus indicated is approximately linear with a slope of about 0.05 mag. per day. The region of greatest weight, however, is between ten and twenty days after maximum, the earlier and later portions depending largely on linear extrapolations or interpolations from rather meager data. A comparison of the mean magnitudes on the two curves, the composite curve, and that for the six well-observed novae indicates that the latter is somewhat steeper, but that in the region where the former has greatest weight, the two agree very closely. This suggests that the six selected novae are representative cases, and that their behavior near maximum is probably typical.

The composite curve indicates a mean maximum of about 16.6 as against 16.2 for the selected curves. The discrepancy is due to two factors—the inclusion of fainter novae in the composite curve and the linear extrapolations backward from the first observations. The latter is the more serious since it ignores the humps at maxima which are indicated by the well-observed novae. The point is rather important in connection with the frequency distribution of maxima; hence some form of the mean curve in this region must be adopted, even though it be somewhat arbitrary. Fortunately, the limits of the selection are not widely separated, and a simple mean between the two curves will not be grossly in error. With this procedure, the hypothetical mean maximum is 16.4 and the mean magnitudes at three, five, seven, and ten days after maximum are 16.7, 16.8, 16.9, and 17.1, respectively. At ten days after maximum the two curves are in agreement, and from then on the composite curve may be used with its linear slope of about 0.05 mag. per day.

FREQUENCY DISTRIBUTION OF MAXIMA

The maxima of the various novae can be determined with the aid of this standard light-curve by extrapolating backward from the first observations, on the assumption that the maxima occurred midway in the unobserved intervals preceding these observations and that the various individual curves are approximately parallel. In a few cases, departures from the formal procedure, clearly indicated by the data, have led to more probable values for the maxima. The

TABLE VI

MEAN MAGNITUDES ON THE COMPOSITE LIGHT-CURVE AND THE LIGHT-CURVE FOR SIX WELL-OBSERVED NOVAE

Interval in Days after Max.	Composite	Six Novae	Mean
0	(16.6)	16.23	(16.4)
1	....	16.25	(16.5)
3	16.8	16.5	(16.7)
5	16.95	16.65	(16.8)
7	17.0	16.8	(16.9)
10	17.14	17.05	(17.1)
14	17.33	17.3	....
15	17.37	17.4	....
20	17.63	17.7	....
25	17.88	18.0	....
30	18.1	(18.3)	....
40	18.6	(18.6)	....

maxima, observed or hypothetical, are listed in the eighth column of Table V, and exceptional cases are given in the footnotes.

A frequency-curve of seventy-one maxima[1] is shown in Figure 6. In order to smooth the curve somewhat, the numbers of novae have also been summed over intervals of 0.3 mag., centered upon successive tenths. The restricted range, the symmetrical form, and the narrow maximum are unexpected features; but they appear to be definite characteristics, independent of the particular method of analysis. Any reasonable treatment of the data would lead to results of the same general character. The mean magnitude is 16.43, and the most frequent magnitude, about 16.5.

[1] In addition to Nos. 26, 36, and 39, novae Nos. 12, 13, 15, 24, 25, 38, 46, 47, 48, 53, and 73 are omitted because the unobserved intervals preceding the first observations exceed forty days.

Although the general character of the frequency-curve appears to be established, the details depend upon extrapolations of a somewhat arbitrary nature. For this reason a similar curve has been constructed, showing the frequencies of magnitudes fourteen days after maximum, where the extrapolations and interpolations are reduced to a minimum. This curve (see Fig. 7) is of the same general character as that in Figure 6. The mean magnitude is 17.37, and the

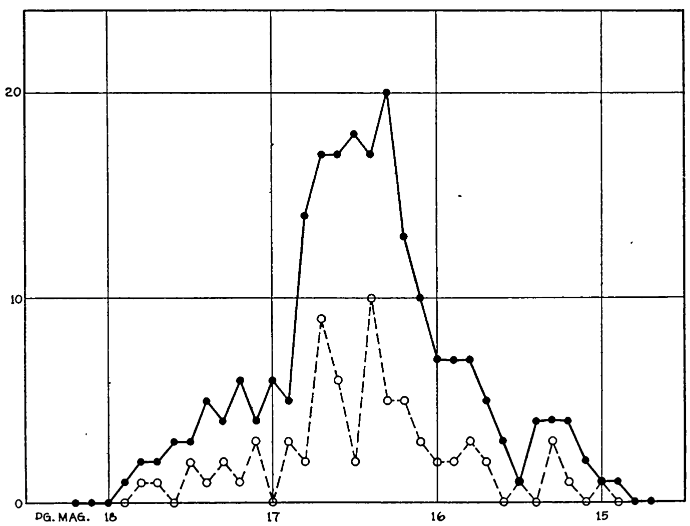

FIG. 6.—Frequency distribution of magnitudes at maxima among 71 novae in M 31. Open circles indicate numbers for each 0.1 mag.; black disks indicate sums over intervals of 0.3 mag., centered on successive tenths. The maxima, in general, have been derived from the mean light-curve of novae in M 31, on the assumption that maxima occurred at the middle of the unobserved intervals preceding the first actual observations of the novae.

most frequent magnitude is about 17.35. The mean magnitude, extrapolated according to the standard curve, gives a maximum of 16.44, in agreement with Figure 6, hence the adopted maximum, 16.5, appears to be a conservative estimate.

These frequency-curves indicate that the novae observed in M 31 are very similar objects. Their maxima, for instance, can be predicted with a probable error of the order of 0.5 mag., and the total range is of the order of 3 or 4 mag. The data indicate only two maxima fainter than 17.5, although the limits of the observations are from 1.0 to 2.5 mag. fainter. It is probable that some faint novae have been missed, especially in the very dense nuclear region; but the wealth of material covering other regions clearly indicates that the number is relatively small. Variables were frequently found whose maxima were around 19.0 and were followed to 20.0 and fainter, but no very faint novae were found except on plates following long unobserved intervals. The relative distribution of maximum magnitudes actually observed among novae and variables is shown in Figure 8.

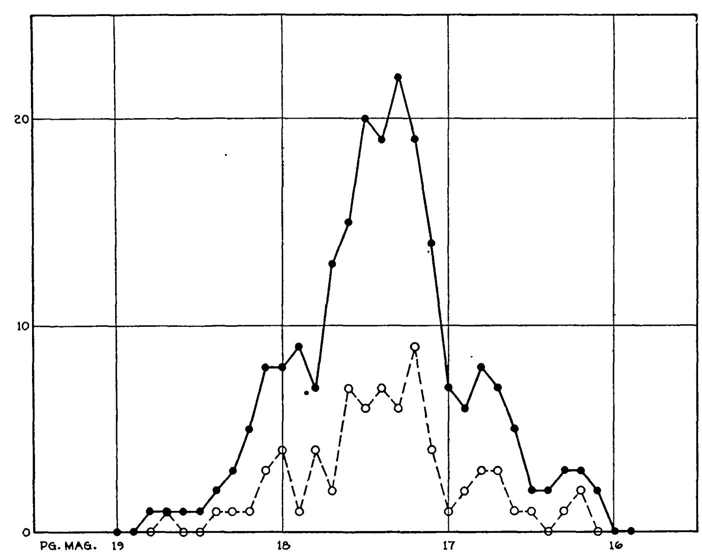

FIG. 7.—Frequency distribution of magnitudes of novae 14 days after maxima. Open circles indicate numbers for each 0.1 mag; black disks indicate sums over intervals of 0.3 mag., centered on successive tenths.

At the distance indicated by the Cepheids, the most frequent magnitude at maximum, 16.5, corresponds to an absolute photographic magnitude of −5.7. Since the color-indices of novae at maximum are negligible, the visual magnitude is about the same. Absolute magnitudes at maximum are reliably determined for only two galactic novae—Nova Persei (1901) at −5.0 and Nova Aquilae (1918) at −9.2. The various discussions of the mean magnitude of galactic novae at maxima, mainly by Lundmark, have led to values ranging from −3 to −9, the last published value[1] being −6.1. This

[1] "Studies of Anagalactic Nebulae," *Meddelanden från Astronomiska Observatorium, Upsala*, No. 30, 1927.

agrees as closely as can be expected with the value for novae in M 31 and suggests no considerable revision of Shapley's zero point in the period-luminosity curve for Cepheids.

Aside from the possible uncertainty in this zero point, the absolute magnitudes of novae in M 31 are determined with a much greater precision than those in the galactic system. Hence, if the novae in the two systems are objects of the same sort, the frequency-curves for those in M 31 may be used to advantage in studying the distribution of novae in the galactic system. The approximate agreement in

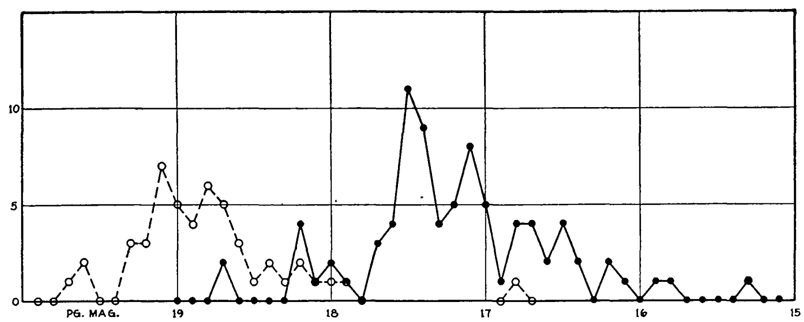

FIG. 8.—Frequency distribution of observed maxima of novae and variable stars in M 31. Black disks refer to novae; open circles, to variable stars. The points indicate numbers for each 0.1 mag. The diagram emphasizes the *completeness* of the data for novae, and hence the reality of the restricted range in magnitudes at maxima indicated by Figures 6 and 7.

the mean magnitudes at maximum, the characteristics of the light-curves, and the fragmentary evidence of color and spectrum suggest very strongly that the two groups actually are similar. The range in magnitude at maximum among galactic novae is unknown at present, and no definite conclusion can be formulated as to its value until the number of reliable individual distances is sufficient to permit a statistical treatment of the data. If the use of the frequency distribution of maxima in M 31 should lead to wholly inconsistent results for the distances of galactic novae, the question of similarity would be definitely settled in the negative.

Four novae have been found thus far in M 33, but each has first appeared on plates following unobserved intervals of several months. Two of these are discussed in an earlier paper, and data for the two later objects are given in the footnote below.[1] All four were obviously on the descending branch of their light-curves when first observed, hence no certain information is available concerning their maxima. The first observations give 17.2, 17.9, 18.1, and 17.9 mag. The mean, 17.7, is about the same as the mean of the ten similar cases in M 31, namely, 17.6, and leaves little doubt that the novae in the two spirals are similar objects. This evidence, weak as it is, materially strengthens the analogy between the spirals and the galactic system based upon the observations of Cepheids.

The one nova thus far observed in the Magellanic Clouds[2] reached an absolute magnitude of at least −5.0, but, as far as can be judged from the records, probably did not exceed −7.0.

The occasional novae which have appeared in the smaller extragalactic nebulae and which have attained luminosities that are respectable fractions of the total luminosities of the nebulae themselves are clearly a different sort of object from the normal novae in M 31 and 33. They are generally classed with S Andromedae, the nova of 1885 in M 31, as a rare and peculiar type.

FREQUENCY OF NOVAE

The numbers of novae for the various observing seasons are given in Table VII. The more systematic spacing of the plates accounts for the larger numbers of novae discovered during the last five seasons,

[1] *Mt. Wilson Contr.*, No. 310; *Astrophysical Journal*, **63**, 236, 1926. Nova No. 3 appeared 6′.6 south following the nucleus of M 33; No. 4 appeared 1′.9 south and 0′.4 following variable No. 34. The magnitudes are as follows:

Plate	J.D.	No. 3	No. 4
H619	2,424,444.5	....	....
623	2,424,493.3	18.1	
673	2,424,610.6	18.6	
621	2,424,918.3		
817	2,425,091.6	....	17.7
834	2,425,124.5	....	18.1
847	2,425,147.6	....	19.2
868	2,425,211.3		

After the present paper was prepared for publication, W. Baade announced the discovery on October 15, 1928, of a nova in M 33, which was observed at the sixteenth magnitude. This fifth nova strengthens the analogy with M 31 in a very evident manner.

[2] *Harvard College Observatory Bulletin*, Nos. 847 and 851, 1927.

hence these data may be regarded as representative. Comparison of the numbers of novae with the months covered by the observations indicates a frequency of sixteen or seventeen novae per year. This, however, neglects the very considerable gaps in the observations. By assuming that each plate shows all novae which appeared during the preceding ten days, the average number per year is found to be about thirty. If the preceding interval is put at fifteen days, the annual average is 21.5; for an interval of twenty days, the average is 18.5. Since the ten-day interval is almost certainly too short and the twenty-day interval is probably too long, the intermediate value may be accepted as a reasonable approximation.

TABLE VII

FREQUENCY OF OBSERVED NOVAE

Season	Novae	Interval	Season	Novae	Interval
1909–1910	3	3.0 mo.	1923–1924	8	7.5 mo.
1917–1918	7	6.0	1924–1925	11	8.0
1918–1919	4	7.0	1925–1926	15	8.0
1919–1920	5	7.0	1926–1927	12	8.5
1920–1921	5	7.0	1927——	7	7.0
1921–1922	1	7.0			
1922–1923	4	8.5			
Total	29	45.5	Total	53	39.0

The resulting annual average of 21.5 must be increased to include novae which have been missed in the study of the plates, those which have been below the limits of plates made under exceptionally poor conditions, and still others which have appeared in regions not covered by the plates. The first and last of these sources of error are believed to be of minor importance. Thus, during the re-examination of the entire series, eight additional novae were found on plates prior to the season 1923–1924, but none on the more recent plates. In the outer region of the nebula, novae appear to be very rare; in Region 4, 48′ from the nucleus, only one example has been found on the sixty-five plates covering four observing seasons. Allowance for losses arising from these two sources might perhaps increase the annual average to twenty-five.

Loss from the second cause is believed to be more important, especially during the winter months when the observing conditions are frequently bad, but the amount is difficult to evaluate. It suggests, however, that thirty per year is a reasonable estimate of the frequency of novae in M 31.

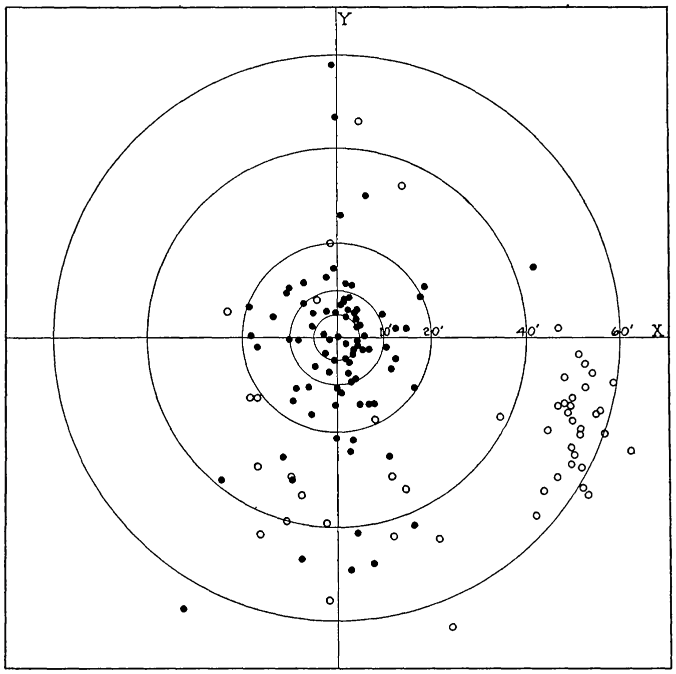

FIG. 9.—Distribution of novae and variables observed in M 31. Black discs refer to novae; open circles, to variable stars. X and Y are the major and minor axes of the nebula. The Y co-ordinates have been corrected to represent the plane of the spiral as perpendicular to the line of sight. The blank region to the left of $X = -30'$ is accounted for by lack of observations. The preponderance of negative signs among the larger numerical values of Y appears to be significant.

DISTRIBUTION OF NOVAE

The distribution of novae over the image of the nebula is shown on Plates IV, V, VII, where positions are marked. The positions are given diagrammatically in Figure 9, the Y co-ordinates being corrected to represent the spiral as perpendicular to the line of sight. Few novae have been found in the great rifts between the spiral arms, nor do they show any conspicuous relation to the numerous small dark markings. In general, the distribution of novae follows the distribution of luminosity in the nebula. The concentration in the nuclear region is conspicuous, although it is noteworthy that only three novae besides S Andromedae have been found less than 4′ from the center. This does not appear to be wholly a result of limitations set by the dense nebulous background. The zone from 4′ to 8′ from the center is the most prolific, having produced twenty-eight novae, or about one-third of the total number observed. From 4′ outward, the total numbers in 5′ zones diminish steadily, and the numbers per unit area diminish even more rapidly, as may be seen in Table VIII.

Beyond the nuclear region there is an apparent asymmetry in the distribution in the sense that the observed novae are more numerous in the half of the nebula south following the major axis than in the north-preceding half. For $4Y > 15'$, there are only three novae in addition to the doubtful No. 39 in the north-preceding half, while in the south-following half there are eighteen besides the doubtful No. 26. When other variable stars are considered, the discrepancy is even greater—six objects as against thirty-one. In the north-preceding half, the nebula is less luminous, the rifts between the arms more pronounced, and, in general, the mottling due to dark markings is more conspicuous. This suggests a correlation with some form of obscuration, but the relation is not definitely indicated. The mean magnitude of the three novae in the north-preceding half, Nos. 27, 56, and 77, is 17.6 for the observed, and 16.95 for the computed maxima. These are somewhat fainter than the corresponding values for the novae in general, but the data are too limited for the differences to be regarded as significant.

Among the novae, as among the Cepheids, there is no definite relation between luminosity and distance from the nucleus. The data are shown in Table VIII.

These results indicate the absence of any considerable absorption by the unresolved luminous portions of the nebula, although obscuration by well-defined dark markings is conspicuous. The fact that the nucleus is sharply visible, although buried to a depth of many hundreds of parsecs of nebular material, points in the same direction.

The observational data bearing on the composition of the nuclear region are (1) the lack of absorption, (2) the infrequency of very bright giants ($M < -3.2$), (3) the appearance of novae, and (4) the characteristic dwarf solar-type spectrum with broad fuzzy lines. A superficial interpretation of these data suggests a star cloud in which bright giants are rare, in contrast with the outer arms of the spiral, where giants are abundant. The Cepheids would then follow the distribution of the giants, while the novae would follow that of the fainter stars, or possibly that of the stars in general.

From the observed shapes of nebulae, however, Sir James Jeans has concluded that the nuclear regions of spirals, as well as the elliptical nebulae, must be gaseous.[1] The lack of resolution is thus

TABLE VIII

FREQUENCY OF NOVAE AT DIFFERENT DISTANCES FROM THE NUCLEUS

Zone	Novae	Mean Distance	Mean Maximum	
			Obs.	Cal.
0′– 5′	12	4′0	17.32	16.51
5 –10	25	7.2	17.04	16.31
10 –15	19	12.9	17.35	16.59
15 –30	13	19.5	17.03	16.34
30	13	44.5	17.38	16.69

accounted for, and since the densities are low—of the order of 10^{-21}, the lack of appreciable absorption is also explained. The novae and the spectrum raise difficulties, but these, according to Jeans, are not unsurmountable. The novae, for instance, might possibly be explained as due to the penetration into the gaseous region of stars from the outer portions. This would also account for the lower frequency of novae in highly resolved nebulae (e.g., M 33, N.G.C. 6822, and the Magellanic Clouds), where the unresolved regions are relatively small.

THE BRIGHT NON-VARIABLE STARS

No general investigation of the luminosity function of the giant stars in M 31 has been undertaken, but measures have been made of stars in the cluster N.G.C. 206, which appears to belong to the spiral. This is an open cluster in Region 4, about 41′ south preceding the nucleus along the major axis ($X = 40'.8$; $Y = +4'.4$). Its dimensions are about $6' \times 2'$, and the elongation is roughly north-south. About ninety stars are brighter than photographic magnitude 18.5, twelve

[1] *Astronomy and Cosmogony*, p. 336, 1928.

of which may be attributed to the galactic foreground. At the distance indicated by the Cepheids, the dimensions of the cluster would be of the order of 480×160 parsecs, and apparent magnitude 18.5 would correspond to absolute magnitude -3.7. There are no definite indications of stars brighter than -5.5, but at -5.0 they begin to be fairly numerous. Preliminary inspection of other fields in the nebula suggests the possibility of a few stars brighter than -6.0, but that large numbers do not appear until -5.0 is passed.

Very bright stars appear to be relatively more numerous in M 33, where, in general, they seem to be white or blue. In M 31 the brightest stars appear to have a slightly larger color-index, averaging perhaps $+0.3$ or $+0.4$ mag. The stars in N.G.C. 206 have been measured on Cramer Iso plates, exposed with the 100-inch reflector for two hours through a visual color-filter, the scale being established by three comparisons with the North Polar Sequence made with the 60-inch reflector. The various plates are not of the best quality; but the internal agreement is rather good, and the results probably indicate the order of the colors. The faintest photovisual magnitudes represent an extrapolation of about 1.5 mag. beyond the standard stars.

A plot of the color-indices against the photographic magnitudes is shown in Figure 10. The galactic latitude of the cluster, $+22°$, is only 6° less than that of the North Pole, hence the distribution of the colors among the foreground stars should approximate that among stars in the Polar Sequence, although the polar stars may be expected to average slightly redder. A probable lower limit to the color-indices of the foreground stars similar to that used in discussing the color-indices in M 33,[1] may be derived from these data. This limit has been indicated in the figure by a dotted line, and the numbers of stars above the line are roughly the numbers of foreground stars to be expected within the area. The area is too small to inspire any confidence in statistical conclusions, but the results suggest that red stars are not frequent among the brighter stars in the cluster and that the average color-index of the latter is about 0.35 mag.

Photovisual plates of other regions, notably Region 4, about 10′ south of N.G.C. 206, appear to be consistent with these conclusions, but the scales have not been sufficiently well established to permit

[1] *Mt. Wilson Contr.*, No. 310; *Astrophysical Journal*, **63**, 236, 1926.

numerical comparisons. The Cepheids, however, clearly have larger color-indices than the general average of the other stars in this region of the nebula, and appear to be approximately of the solar type. Great clouds of dark material occur in these outer regions, but the normal residuals from the period-luminosity curve of the Cepheids suggest that absorption, either general or selective, is not appreciable beyond the observed limits of these clouds.

No patches of luminous diffuse nebulosity have been found in M 31, although they appear, along with blue giants, in several of the

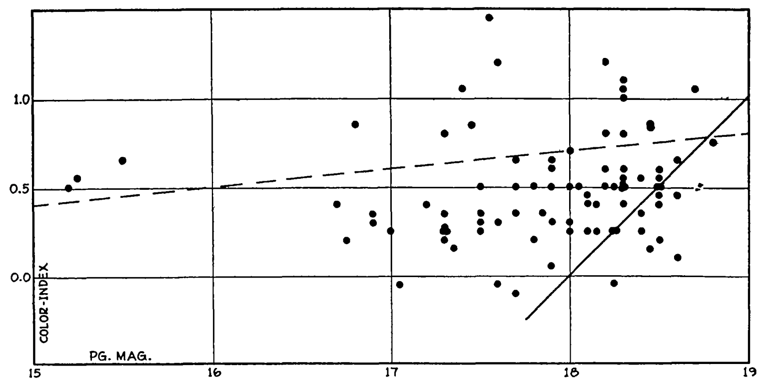

FIG. 10.—Color-indices of the brighter stars in N.G.C. 206, an open cluster in M 31. The diagram includes all stars down to 18.5 pg. mag. The dotted line indicates the probable lower limit of color-index among the foreground stars. The number of stars above this line is about the number of foreground stars to be expected. The data on color indices are complete to the full line with a slope of 45°; below this line, the photovisual magnitudes are incomplete.

most conspicuous of the late-type spiral and irregular nebulae. Diffuse nebulosities with emission spectra are the most easily identified, and these seem normally to accompany the characteristic of high apparent resolution. In general, such resolution implies an abundance of super-giant stars, and it is possible that the presence of emission nebulosities may indicate the relative frequencies of blue stars among these super-giants. The argument is rather speculative, but, since emission nebulosity is found only in highly resolved nebulae, it encourages the idea of a progressive tendency toward blueness among the brightest stars along the normal sequence of nebular types, such as is suggested by the comparison of color-indices in M 31 and 33.

Another suggestion arising from the comparison, namely, that brighter absolute photographic magnitudes are attained in the late-type spiral M 33 than in that of the intermediate type M 31, seems also to be an example of a more general relation. The evidence, scanty and rather ambiguous, is found in the slight systematic decrease along the sequence of nebular types, and in the difference between the luminosities of the brightest stars and the total luminosities of the nebulae in which they are involved. In an earlier discussion of such differences, a mean value was derived for all available nebulae, of whatever type, in which stars could be detected. A closer inspection of these data, supplemented by additional material, suggests the systematic effect above mentioned.[1]

MASS AND LUMINOSITY DENSITIES IN M 31

Some notion of the conditions within the nebula may be derived from rough estimates of the density both of mass and of luminosity. At a distance of 275,000 parsecs, the scale is $1' = 80$ parsecs, and the radius of the spiral, $80'$, is 6400 parsecs. By analogy with spirals of the same type seen edge on,[2] the semi-minor axis is assumed to be one-eighth of the radius, or 800 parsecs. The order of the volume can be approximated by supposing the figure to be generated by an isosceles triangle with an altitude four times the base, rotated around the base. This gives

$$V = \tfrac{2}{3}\pi \, \frac{(6400)^3}{8} = 6.9 \times 10^{10} \text{ cubic parsecs} .$$

The mass of the inner region, out to $2\overset{'}{.}5$ from the nucleus, can be estimated on the assumption that the spectrographic rotation represents motions in circular orbits in a gravitational field. Then,[3] since

[1] *Mt. Wilson Contr.*, No. 324; *Astrophysical Journal*, **64**, 321, 1926. No stars have been found in any of the Sa spirals, or in any of the elliptical nebulae except M 87 (N.G.C. 4486), where the difference between the nebula and the brightest stars is about 10 mag. For 14 Sb spirals, the average difference is about 9.6 mag., and for 12 Sc spirals, about 9.0.

[2] *Mt. Wilson Contr.*, No. 324; *Astrophysical Journal*, **64**, 321, 1926.

[3] The formula Mass $\odot = 235av^2$, where a is the distance from the center in parsecs and v is the velocity of rotation in km/sec., is derived from the familiar formula for circular orbits in the solar system, Mass $= v^2rk^{-2}$.

the velocity of rotation at $2'.5$, or 200 parsecs, from the nucleus is about 72 km/sec.,

$$\text{Mass} = 235 \times 200 \times 72^2 \odot = 2.4 \times 10^8 \odot .$$

The total mass of the nebula follows from the arbitrary assumption that it is ten or twelve times that of the inner region. A value previously used, $3.5 \times 10^9 \odot$, is probably of the right general order.[1]

The absolute visual magnitude, -17.2, which follows from Holetschek's value for the apparent magnitude, 5.0, is probably a lower limit, but may be used for the rough calculations.

With these values, the mean luminosity density, in absolute visual magnitudes, is 9.9 per cubic parsec, and the mean mass density is about one sun per 20 cubic parsecs. Both densities are of the same order as those for the galactic system in the vicinity of the sun. In M 33,[2] the luminosity density is slightly brighter, 9.3 per cubic parsec, but the estimated mass density, 3 $\odot$ per cubic parsec, is about sixty times greater, and the discrepancy suggests the inadequacy of the methods used in determining the masses, especially in the case of M 33.

In terms of the sun's mass and luminosity, the relation

$$\text{Mass} = 5.5\,L ,$$

which holds in M 31, has a coefficient about twice that for the relation in the vicinity of the sun. The inaccuracy of the data, however, justifies only the conclusion that the coefficients are of the same order in two cases. The coefficient for the relation in M 33, 160, again suggests the inadequacy of the estimated mass of that spiral.

The central sphere, with a radius of $2'.5 = 200$ parsecs, which appears to rotate like a rigid body, has a mass, as previously computed, of $2.4 \times 10^8 \odot$ and a volume of 3.4×10^7 cubic parsecs. The mean mass density is about 7 $\odot$ per cubic parsec, or 5×10^{-22} in c.g.s. units. If the central sphere is assumed to be 2 mag. fainter than the entire nebula, the absolute visual magnitude is -15.2 and the mean

[1] *Mt. Wilson Contr.*, No. 324; *Astrophysical Journal*, **64**, 321, 1926.

[2] *Mt. Wilson Contr.*, No. 310; *Astrophysical Journal*, **63**, 236, 1926. The radial component of the velocity of rotation of M 33 is derived from the difference between the radial velocities of the nucleus and of a patch of emission nebulosity in one of the arms. The velocity of the nucleus depends upon one spectrogram on a very small scale and is very uncertain.

luminosity density is 3.6 M per cubic parsec. The relation between mass and luminosity,

$$\text{Mass} = 2.3\,L\,,$$

is of the same order as for the nebula as a whole, but this result follows from the tacit assumption involved in estimating the whole mass, namely, that in the outer regions, the distribution of mass tends to follow the distribution of luminosity.

As the nucleus is approached, however, the mass density remains constant (according to the assumption of uniform angular rotation), while the luminosity density is observed to increase rapidly. The nucleus itself, on the shortest exposures, is sensibly round, with a diameter of about $3''$, or 4 parsecs, and an apparent photographic magnitude about 14.0, or -9.2 on the absolute visual scale. Since the volume of the sphere is about 34 cubic parsecs, the mean luminosity density is of the order of $-5.4\,M$ per cubic parsec. The mass density, on the assumption of uniform angular rotation, is 5×10^{-22}, or 7 $\odot$ per cubic parsec as given above.

The relation between mass and luminosity is now of the order

$$\text{Mass} = 0.001L\,,$$

which clearly does not represent the relation to be expected in a star or a cluster of stars giving a dwarf spectrum. Inaccuracies in the data will not seriously affect the order of the luminosity density, hence the uncertainties must be referred to the estimation of mass. If the latter approximates the proper order of magnitude, the mass-luminosity relation becomes significant and suggests that the nuclear material is in a gaseous state.

The nucleus of M 33 is very similar to that of M 31. The two show about the same spectral type, diameter, and absolute magnitude. The mean luminosity densities are not very different from those in the central regions of the more compact globular clusters. M 3, for instance, has a total absolute magnitude of -9.1, and the central sphere, with a diameter of 4 parsecs, is possibly 2 mag. fainter. The mean luminosity density of this inner region is therefore about $-3.3\,M$ per cubic parsec, or about one-seventh as bright as in the nuclei of the spirals. Nothing definite is known concerning the masses of globular clusters, hence comparisons of mass densities cannot be made. The similarity in the luminosity densities suggests an analogy which is not encouraged by the mass-luminosity relation in the nuclei of the spirals.

A comparison of M 31 with the galactic system involves even greater uncertainties than those encountered above. Seares's[1] recent discussion of the galactic system, based upon star counts in the Selected Areas, suggests that it resembles a very late-type spiral, from 60,000 to 90,000 parsecs in diameter, in which the nucleus, 15,000–20,000 parsecs distant according to Shapley, is hidden from the earth by the obscuring clouds which form the great rift in the Milky Way. The sun is perhaps halfway out from the nucleus to the border, in one of the condensations represented by the local cluster, hence the density in our vicinity would be of the same general order as, or perhaps somewhat greater than, the mean density of the system. This lends some significance to the comparison of mass and luminosity densities in the vicinity of the sun with those for M 31.

If a diameter of 80,000 parsecs is assigned to the galactic system and a ratio of diameters of 1 to 10, the volume is of the order of 1.3×10^{13} cubic parsecs. The most plausible estimate of the mass is perhaps that suggested tentatively by Eddington,[2] based on the assumption that the observed motion of the system of the globular clusters is in reality a reflection of the rotation of the galaxy. Using Shapley's minimum value of the distance of the sun from the center of the system, he finds a mass of $2.7\times10^{11}\ \odot$. These figures lead to a mean mass density of one sun per 50 cubic parsecs as compared with one sun per 20 cubic parsecs in M 31.

Some notion of the order of magnitude of the total luminosity of the system can be derived by estimating the luminosity of the visible region and applying a reasonable correction for the invisible. Kapteyn's very generalized representation of stellar distribution out to star densities one one-hundredth that in the vicinity of the sun provides about the only data available. The numbers of stars to this limit (out to a distance of 8465 parsecs in the galactic plane) are

[1] *Mt. Wilson Contr.*, No. 347; *Astrophysical Journal*, **67**, 123, 1928.

[2] *Monthly Notices, R.A.S.*, **88**, 331, 1928.

equivalent to the numbers in a volume of 1.45×10^{10} cubic parsecs of unit density.[1] Since the unit density corresponds to $8.16M$ per cubic parsec, the absolute magnitude of Kapteyn's system is

$$8.16-2.5\log 1.45\times10^{10}=-17.24\ .$$

The larger system, with an assigned diameter of 80,000 parsecs, has a volume about twenty-seven times that of Kapteyn's, hence, if the latter were representative, it would be about 3.6 mag. fainter than the former. The great amount of obscuration along the galactic plane, especially between us and the central region, probably more than balances the influence of the local cluster and suggests that the magnitude difference should be materially increased. Possibly the round number $-22\,M$ may represent the luminosity of the galactic system within 2 or 3 mag. This leads to a mean luminosity density of $10.8\,M$ per cubic parsec as compared with $9.9\,M$ in M 31. The relation between mass and luminosity, $\text{Mass}=5.2\,L$, is also about the same as in the spiral.

These comparisons indicate a general similarity which further data are not likely to disprove. The outstanding discrepancy between the two systems is in their dimensions. According to the present figures, the galactic system is five or six times the diameter of the spiral, although the latter is the largest of the extra-galactic systems whose distances are reliably known. M 31, however, is in an intermediate state of concentration in the observed sequence of spiral forms, and could be spread through a much greater volume without losing the characteristics of an extra-galactic system.

Moreover, while the galactic system is very large, the outer regions, as viewed from a distant source, are very faint. Seares,[2] using a method independent of the spatial distribution of stars, finds that the surface brightness of our region, as viewed from a direction perpendicular to the galactic plane, is about 22.93 in visual magnitudes per square second of arc. Beyond a certain lower limit, this, of course, is independent of distance. Photographic magnitude 23.5 per square

[1] *Mt. Wilson Contr.*, No. 230; *Astrophysical Journal*, **55**, 302, 1922. See also Sir James Jeans, *Astronomy and Cosmogony*, p. 15, 1928, where Kapteyn's data are given in fuller detail.

[2] *Mt. Wilson Contr.*, No. 191; *Astrophysical Journal*, **52**, 162, 1920.

second of arc represents about the limiting faintness that can be registered by long exposures with reflectors of focal ratio 1 to 5, and this, corrected by a reasonable color-index, is of the same order as Seares's result. Viewed from a direction in the galactic plane, the surface brightness would be considerably greater, but it is improbable that photographs from a distant point would show the full dimensions suggested by the investigations of Seares and Shapley. This, together with the greater concentration in M 31, tends to reduce the apparent disparity in size between the two systems very materially. The galactic system must be considered as much larger than M 31, but the ratio is not greater than that between M 31 and other known extra-galactic systems.

Carnegie Institution of Washington
Mount Wilson Observatory
December 1928

DESCRIPTION OF PLATES

PLATE III

South Preceding End of Messier 31

Plate by Duncan, August 24, 1925; 100-inch reflector, exposure 2 hrs. on Eastman 40 plate. Scale 1 mm = 15''1. Top is north. The bright patch 34 mm to the right of the brightest star (B.D. +39°158) is a defect.

PLATE IV

Messier 31

Plate by Ritchey, 24-inch reflector at Yerkes Observatory, September 18, 1901. Scale 1 mm = 39''1. Novae are indicated by crosses; variables, by lines and a V preceding the number. V1, 15, and 19 can be seen on the plate. The open cluster N.G.C. 206 is 3 mm below nova No. 46. Variables in Region 4, centered 13 mm to the right of N.G.C. 206, and novae near the nucleus are not marked.

PLATE V

Central Region of Messier 31

Plate by Duncan, 100-inch reflector, 9 hrs. exposure, September 16–17, 1920. Scale 1 mm = 16''4. Novae are indicated by crosses, excepting Nos. 36 and 80, which are visible and enclosed in circles; variables, by a V preceding the number. V2, 3, 7, 9, and 13 are near maxima.

PLATE VI

Variables in Messier 31

Plates with 100-inch reflector; scale 1 mm = 8''0. *Top.*—V1 near minimum, August 4, 1924. At maximum it equals the brighter of the two stars above and to the left. *Middle.*—V5 near maximum; V10 near minimum, August 5, 1924. The large object is M 32. *Bottom.*—V12 near maximum; V7 and 9 near minimum, July 30, 1924. The bright star is B.D. +40°151.

PLATE VII

Messier 31, Region 4

From same negative as Plate III. Scale 1 mm = 14''2. The patch 36 mm to the right of the brightest star, B.D. +39° 158, is a defect. The cross marked 40, a mistake for 46, indicates the only nova observed in this region. All other numbers refer to variables. V48 to the left of V25 should read V47. V40 is on the edge of a small compact cluster, of the same order of dimensions as a globular cluster. V23, 24, 28, 30, 34, 37, 38, 39, and 46 are near maxima.

PLATE VIII

Variables in Region No. 4

Plates with 100-inch reflector. Scale 1 mm = 6''5. Right-hand plate, October 26, 1924; left-hand plate, August 24, 1925. Variation is conspicuous in V25, 26, 30, and 39.

PLATE III

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PLATE IV

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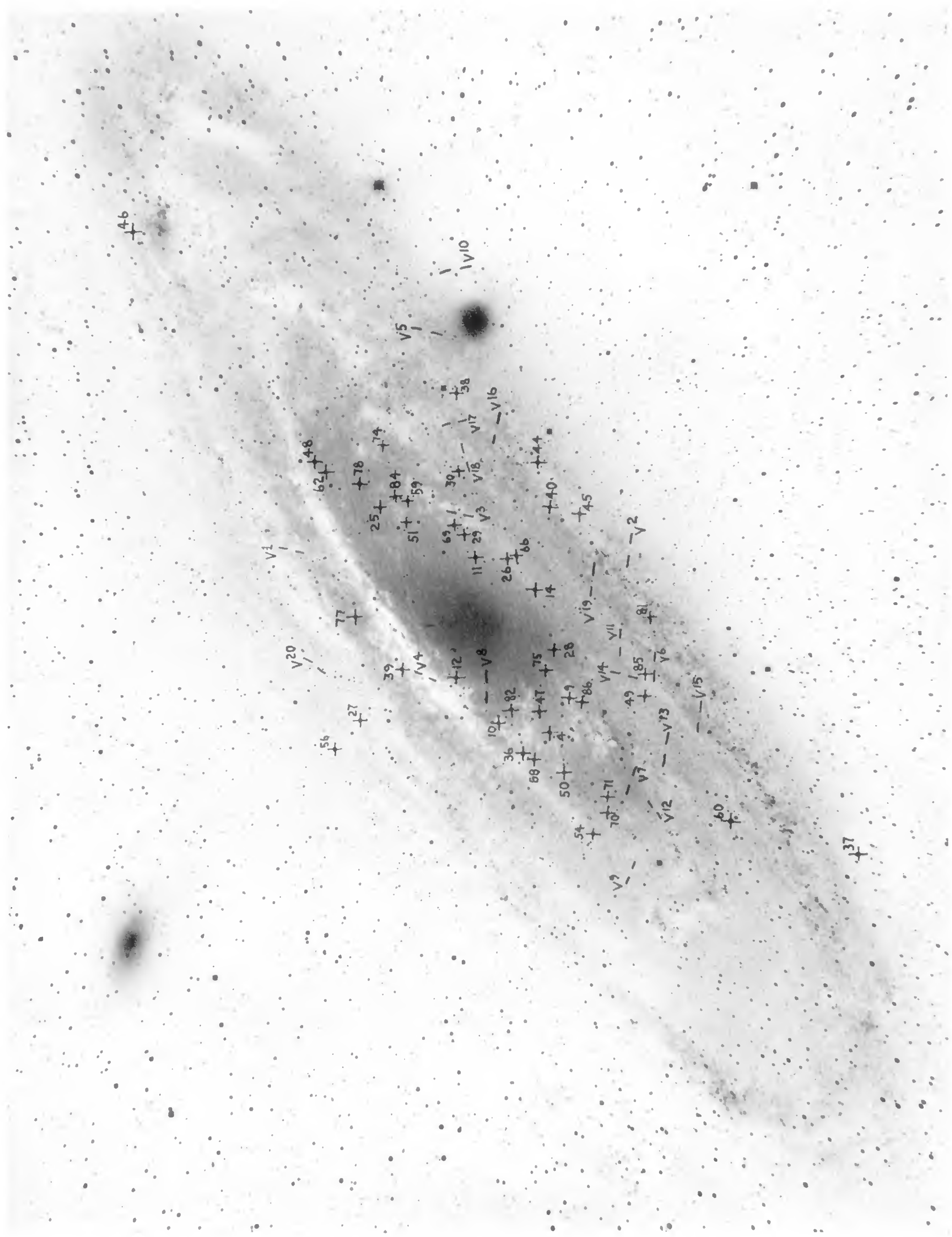

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PLATE V

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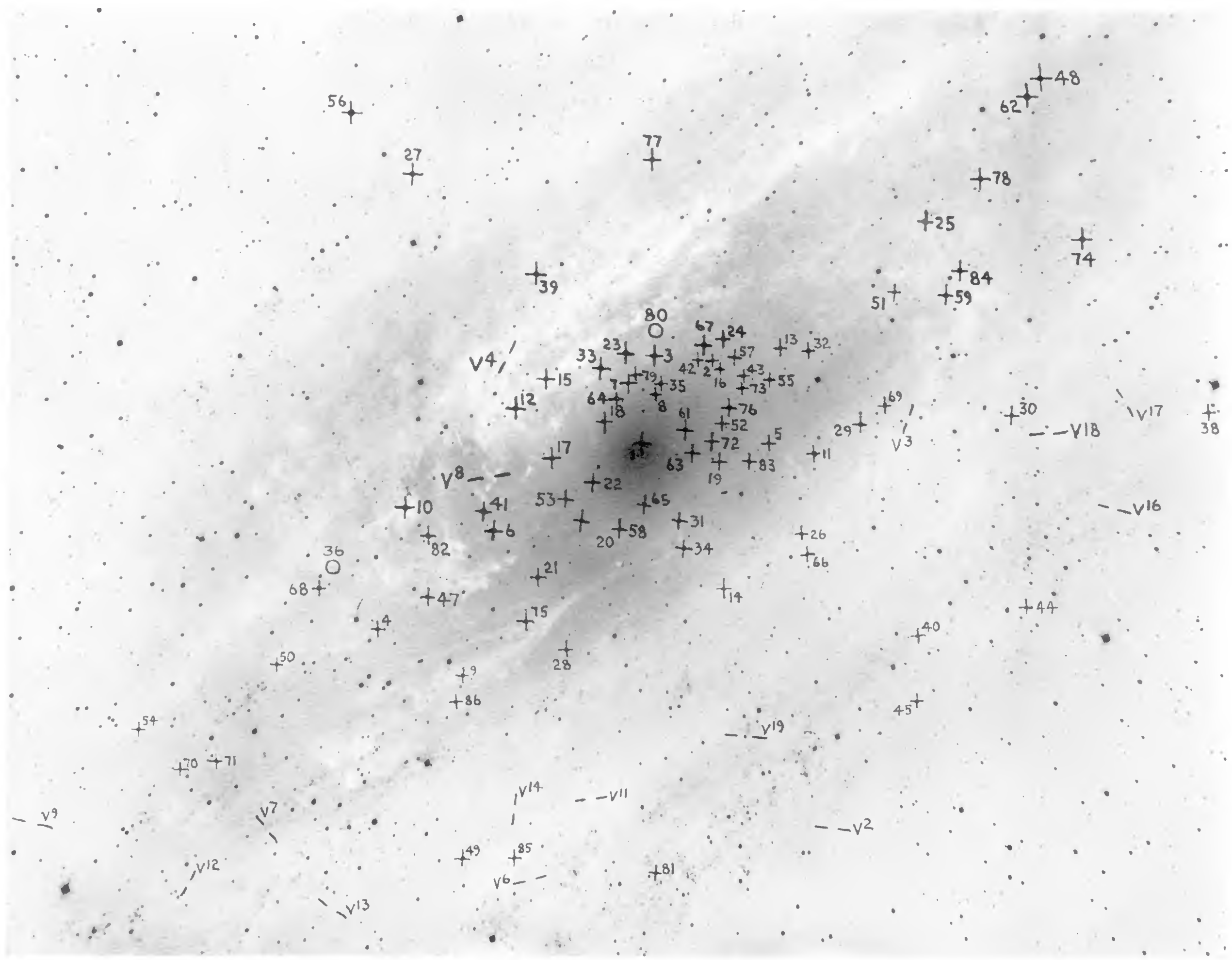

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PLATE VI

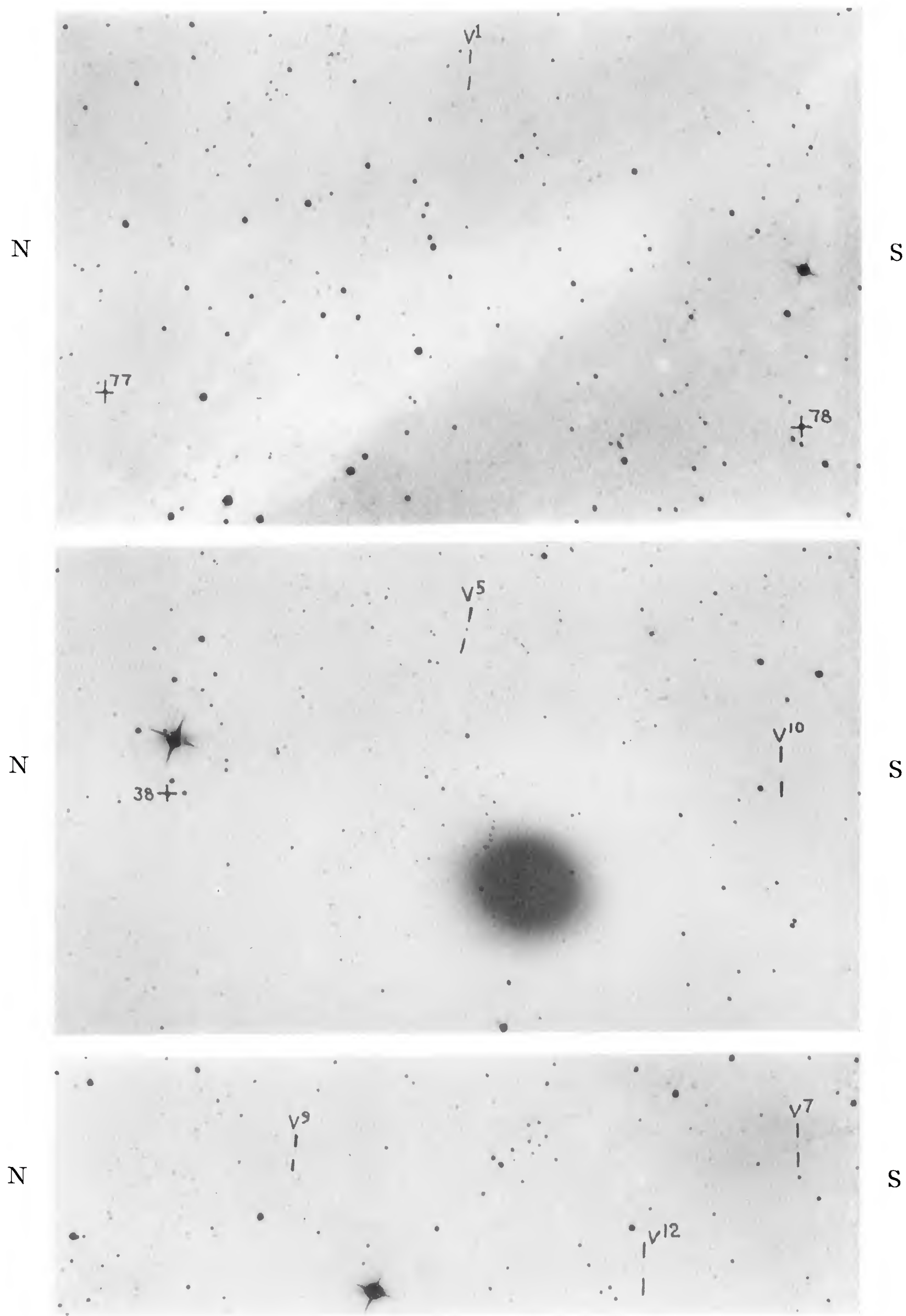

PLATE VII

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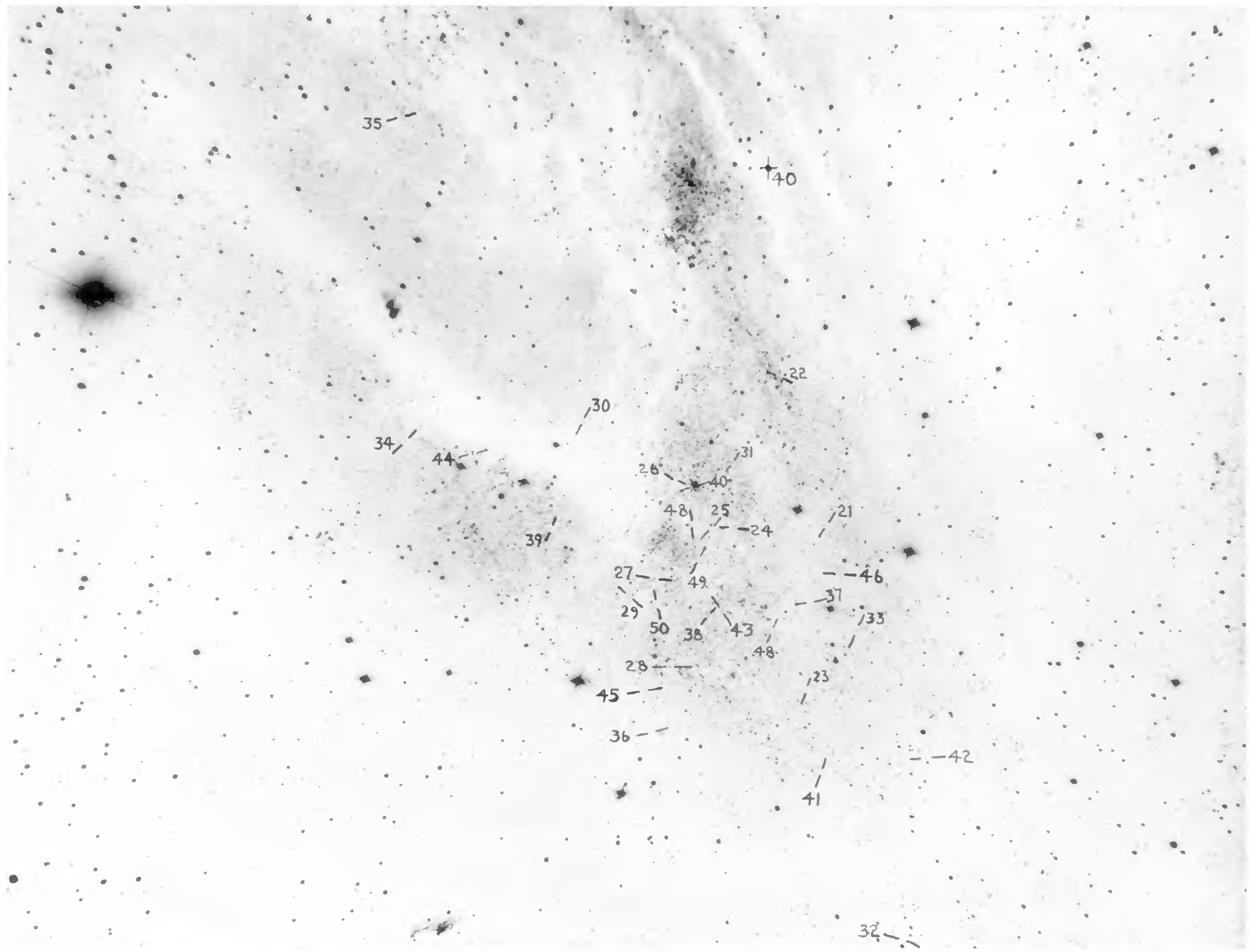
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PLATE VIII