

A SPIRAL NEBULA AS A STELLAR SYSTEM MESSIER 33¹

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ABSTRACT

The spiral nebula Messier 33.—This object is the fainter of the two naked-eye spirals. Its great angular diameter and high degree of resolution, suggesting that it is one of the nearest objects of its kind, offer exceptional opportunities for detailed investigation.

Resolution.—Critical tests made with the 100-inch reflector, the highest resolving-power available, show no difference between the photographic images of the so-called condensations in Messier 33 and the images of ordinary galactic stars. Moreover, the application of ordinary methods of stellar research leads to consistent results, similar to those found in other systems of stars.

Variable stars.—Forty-two variable stars have been found in the spiral, in addition to the three previously known; thirty-five of these are typical Cepheids with periods ranging from thirteen to seventy days, and photographic magnitudes at maxima, from 18.0 to 19.1. Of the remaining ten variables, four are irregular, one is probably an eclipsing binary, while the types of five are as yet undetermined.

Novae.—Two novae have been observed, both apparently on the declining branch of their light curves. The maximum observed photographic magnitudes, 17.25 and 17.9, respectively, were brighter than that attained by any of the Cepheids.

Nebulae.—Several patches of diffuse emission nebulosity with blue stars involved are found in the arms of the spiral. The relation between the extent of the nebulosity and the magnitudes of the stars is similar to that in the galactic system. It is inferred that the spectral types of the involved stars are Oe5 and Bo.

Star colors.—A comparison of photovisual with shorter direct exposures indicates that the brightest stars in the nebula are white or blue. No accurate calibration of the photovisual plates has been possible, but an approximate reduction curve was constructed from well-determined photographic magnitudes, corrected by color-indices corresponding to known or probable spectral types of a few exceptional stars.

Star counts.—The numbers of stars in successive intervals of photographic magnitude down to 19.2 have been counted over an area containing about one-fifth of all of the stars in the nebula. Stars begin to appear in the nebula at about 15.5. The form of the luminosity function is similar to the bright end of Kapteyn's function for stars in the vicinity of the sun.

Distance.—The period-luminosity relation is conspicuous among the thirty-five Cepheids and indicates a distance about 8.1 times that of the small Magellanic Cloud. Using Shapley's value for the latter, the distance of the spiral is about 263,000 parsecs. $m-M=22.1$. The order of this distance is supported by the independent evidence of the novae, the blue giants involved in diffuse emission nebulosity, and the form of the luminosity function for the brighter stars.

Dimensions.—The linear scale corresponding to this distance is $1''=1.27$ parsecs. The major diameter of the spiral is about 4600 parsecs, and the minor diameter probably a tenth of this amount. The total absolute magnitude is about -15.1 . The dimensions and the luminosity are comparable with those for the Magellanic Clouds.

The nature of nebulae and their place in the scheme of the universe have been favorite subjects of controversy since the very dawn of telescopic observations. In these later days, when the non-galactic nebulae have been clearly differentiated from the diffuse and the

¹ Contributions from the Mount Wilson Observatory, No. 310.

planetary, the discussion has concentrated around the spectacular forms of the spirals. Some believe them to be subordinate members of the galactic system, and hence moderately small and relatively near; others consider them as comparable with the galactic system itself—*island universes*, scattered through the remote depths of space. The crucial point at issue is the order of their distance, and arguments concerning this quantity have been largely speculative.

The present contribution to the subject consists of observational data concerning the particular spiral, Messier 33. The data lead to a conception of the object as an isolated system of stars and nebulae, lying far outside the limits of the galactic system. To this extent the evidence favors the *island-universe hypothesis*, but, in respect to dimensions and luminosity, the spiral is more closely comparable with the Magellanic Clouds than with the galactic system itself.

The investigations described followed naturally upon the partial resolution of Messier 33 into swarms of actual stars, and ordinary methods of stellar research were employed throughout. The discovery of Cepheid variables¹ furnished a probably reliable criterion of absolute magnitude, and the order of the resulting distance was confirmed by other independent criteria. The same procedure, when applied to another spiral, Messier 31, led to similarly consistent results, strengthened in this case by the absolute-magnitude criterion for the numerous novae. The Andromeda spiral is the subject of a second paper, now in preparation, and the present discussion may be followed with this in mind.

RESOLUTION OF MESSIER 33

The familiar condensations in the arms of spirals have been constantly interpreted, both casually and analytically, as stars in the process of formation. Messier 33 is especially rich in condensations, and its great angular dimensions, exceeded only by those of Messier 31, suggest that it is one of the nearest of all the spirals. For these reasons, Messier 33 affords the best opportunity for investigating the optical, or rather the photographic, nature of the condensations.

¹ A preliminary notice of the discovery of Cepheid variables will be found in *Publications of the American Astronomical Society* (33d meeting), Jan., 1925; reprinted in *Observatory*, 48, 139, 1925.

G. W. Ritchey, basing his judgment on the best material hitherto available, his own splendid photographs made with the 60-inch reflector, described them as soft, starlike condensations and designated them by the term "nebulous stars."¹

The nebulous character, however, was inferred from the appearance of the images on long exposures made with fast reflectors centered on the nucleus of the spiral. The area of best definition was restricted to the central region where a considerable amount of unresolved nebulosity registered as a dense and fairly continuous background. In the outer regions of the nebula, where the background was relatively light, the various aberrations spread the images over considerable areas. Such conditions are not suitable for determining the character of the images. Considerations of this nature, supported by evidence from slitless spectrograms obtained with the 36-inch reflector at the Lick Observatory, led Knut Lundmark to the conclusion that the phenomena could be accounted for by assuming the spiral to consist of great numbers of ordinary stars with clusters of stars and some nebular material.²

¹ *Mt. Wilson Contr.*, No. 47; *Astrophysical Journal*, **32**, 26, 1910. Ritchey states: "All of these [spirals, including Messier 33] contain great numbers of soft starlike condensations which I shall call nebulous stars. They are probably stars in the process of formation." In Messier 33 he counted some 2400 "nebulous stars." This recalls the first description of the condensations in Messier 33 by Isaac Roberts based upon photographs made with his 20-inch reflector: "They are like nebulous stars in the midst of fainter nebulosity"; and again: "hundreds of stars having each a very small nucleus surrounded by fainter nebulosity" (*Photographs of Stars, Star Clusters and Nebulae*, **2**, 66, 1899).

² *Publications of the Astronomical Society of the Pacific*, **33**, 324, 1921. The statements are repeated in somewhat stronger terms in *Monthly Notices*, **85**, 890, 1925. It is, however, difficult to understand how the stellar nature of such faint light-sources can be "proved," as Lundmark claims, from spectrograms. To be assigned with certainty to the nebula, the objects must be of the order of the sixteenth photographic magnitude or fainter, and even prolonged exposures can do little more than distinguish between emission and continuous spectra. Lundmark found the latter and estimated them as approximately of solar type. This, of course, is just what is found for the small non-galactic nebulae scattered over the sky, and they, too, have often been called "nebulous stars." Moreover, there is considerable evidence, presented in the present paper, indicating that the brighter stars in Messier 33 are almost invariably white or blue. The discussion over the condensations in Messier 33, however, concerns the angular diameters of the small images, and, since they give continuous spectra, the spectrograms can have no advantage over direct photography, unless the ratio of camera to collimator is much larger than that ordinarily employed for faint objects.

The subject has been reinvestigated with the highest resolving-power available—the full aperture of the 100-inch reflector working under exceptionally fine conditions of mirror surface and seeing. The plates were centered on the outer regions of the arms as well as on the nucleus, and the exposures were short, not exceeding forty minutes, for the double purpose of avoiding the dense background of nebulosity and possible changes in observing conditions. On several plates, equal exposures were made to the nebula and to the neighboring Selected Area No. 45. This was primarily for the purpose of deriving magnitudes, but it also furnished an opportunity for comparing the images in the two regions.

A study of the plates clearly establishes the stellar appearance of the images of the condensations. They are as small and as sharp as those of ordinary stars of the same magnitude. The two most successful plates,¹ each of thirty minutes' exposure, centered on regions seven minutes of arc south and south-preceding the nucleus, show images with angular diameters smaller than any previously obtained on any astronomical photograph. The means of twenty of the smallest images are about $0''.55$ and $0''.6$, respectively. An enlargement from the central region of one of these photographs is shown in Plate XVI. An equal area in Selected Area No. 45, photographed on the same plate with the same exposure time, shows about sixty stars; hence most of the images in the illustration can definitely be assigned to the nebula.

Occasional patches, which show appreciable dimensions on plates made with smaller instruments, the 100-inch resolved into groups of stars, a few of which are surrounded by what appears to be true unresolved nebulosity. The knots listed as N.G.C. 588, 592, and 604 are conspicuous examples of this structure, and the last has long been recognized as such. The nature of the surrounding nebulosities has been inferred from the emission character of their spectra.

These results, it may be emphasized, were obtained with the

¹ Seed 30 plates were used in order to shorten the exposures and hence avoid changing conditions. It is probable that somewhat smaller images may occasionally be obtained by using plates having a finer grain. With longer exposures, the images of the condensations build up as those of ordinary stars even where both are superposed on an unresolved background. The sharper images of the short exposures, however, offer the more critical test. There are no indications whatsoever of penumbra appearing on long exposures, such as were described by Roberts and suggested by Ritchey.

highest resolving-power at present available. There is no longer any reason for retaining the term "nebulous stars" in referring to the condensations in Messier 33. They may be considered as actual stars and fit subjects for the ordinary methods of stellar research until evidence to the contrary is forthcoming.¹ This alone is an indication of immense distance, for no isolated system is known in which the brightest stars are dwarfs.

VARIABLE STARS IN MESSIER 33

In 1922 J. C. Duncan² announced the discovery of three variable stars within the area covered by Messier 33. His data were insufficient for determining the nature of the light-curves, and he refrained from suggesting any connection between the variables and the nebula. Shortly afterward, M. Wolf,³ at Heidelberg, independently discovered the variability of the brightest of these stars.

The Mount Wilson collection now contains about eighty photographs of Messier 33. A survey of these with the blink-comparator has led to the discovery of forty-two additional variables, making a total of forty-five, besides two novae, within the area covered by the nebula. The similar concentrations of variables in Messier 31, the Magellanic Clouds, N.G.C. 6822, and in the globular star clusters, together with the scarcity of such faint variables in other regions of the sky,⁴ especially in the high galactic latitudes of the spirals,

¹ It is still uncertain how far the resolution can be carried. The stars become more numerous with decreasing luminosity and, in the central region at least, appear to merge smoothly into the unresolved background. The luminosity function for the three brightest magnitudes agrees very closely with Kapteyn's luminosity function for stars in the vicinity of the sun, and the total luminosity of the nebulae is completely accounted for on the assumption that the similarity between the two functions extends throughout the entire range of magnitude. In Messier 31, however, the large central region gives no indication of resolution, although portions of the outer regions of the arms are as clearly resolved as those in Messier 33.

² *Publications of the Astronomical Society of the Pacific*, **34**, 290, 1922.

³ *Astronomische Nachrichten*, **217**, 476, 1923. Duncan's paper was published in October, 1922. Wolf's paper was dated December 20, 1922, and published January 15, 1923. He does not mention Duncan's earlier announcement and hence, while there is no question of priority, Wolf's discovery may be accepted as independent.

⁴ For ten fields well distributed in galactic latitude, other than those of the systems mentioned, there are in the Mount Wilson collection six or more plates showing stars fainter than 19.0 photographic magnitude. An examination of these with the blink-comparator has resulted in the detection of two doubtful cases of faint variables.

sufficiently establish the variables under discussion as connected with the nebula itself.

The stars are so closely crowded on photographs of the nebula that identification of the variables by the usual method of measures referred to the nucleus is unsatisfactory. They have, instead, been marked on the various plates and identified by numbers corresponding to those used in the text and tables.¹ Variables Nos. 1, 2, and 3 are those discovered by Duncan and bear the numbers assigned by him.

Series of comparison stars have been selected for each of the variables, and their photographic magnitudes have been derived from comparisons with Selected Area No. 45, which is conveniently situated some 30' preceding the nucleus of the nebula. Twelve comparisons made with the 100-inch reflector were used in determining the scale and the zero-point. The exposures ranged from 20 to 40 minutes on Seed 30 plates, and were centered on various regions of the nebula in order to reduce uncertainties in the distance corrections. Two additional comparisons with Selected Area No. 21 furnished a satisfactory check.² The adopted magnitudes are based on those of the Selected Area down to about 18.5, but beyond this point they are extrapolations. The measures are very consistent, the average deviation of individual plates from the mean being less than 0.05 mag., and the greatest range for an individual star (on five plates), less than 0.4 mag. For stars in the central region fainter than about 19.0 the magnitudes are not reliable because of the background of unresolved nebulosity. In the other regions the measures are consistent to about 19.2, but beyond this they are, in general, unreliable.³

¹ The variables appear on the following plates: Plate XIV, all variables excepting Nos. 12, 13, 20, 21, 22, 37; Plate XV, variables Nos. 5, 9, 10, 11, 12, 13, 18, 20, 21, 22, 23, 24, 25, 37, 40; Plate XVI, variables Nos. 14, 29, 30, 31, 32, 33, 41, 42, 43, 44, 45; and Plate XVII, variables Nos. 11, 12, 17, 18, 20, 21, 23, 27, 29, 37.

² In addition to these long exposures, ten comparisons with Selected Area No. 45 were made with the 60-inch, using exposures ranging from two to fifteen minutes, for the purpose of deriving magnitudes for the stars brighter than the seventeenth magnitude. Mr. Seares kindly furnished unpublished magnitudes on the international scale for the stars in the Selected Areas.

³ For a discussion of the uncertainties in extrapolated magnitudes based on measures with scale-plates of long exposures with the 100-inch reflector, see *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, 62, 409, 1926.

Magnitudes of variables on individual plates were estimated to the nearest tenth by reference to the sequences of comparison stars, the results being listed in Table I. A few of the stars, No. 21 in particular, are so involved with the unresolved nebulosity that the magnitudes have little or no meaning except at maximum. For most of the stars, however, it is believed that the data are sufficient to give fair values for the periods and the maximum magnitudes and some indications as to the general form of the light-curves. Magnitudes at minima, and hence the amplitudes of variation, are extremely uncertain. There are, in fact, several indications that the scale flattens out beyond about 19.0, and that the fainter magnitudes become increasingly too bright.

An examination of the data in Table I has established the nature of the variation of forty of the stars. Thirty-five are Cepheids, four are irregular, and one is very probably of an eclipsing type. Satisfactory solutions have not been found for the remaining five, but most of them are probably Cepheids.

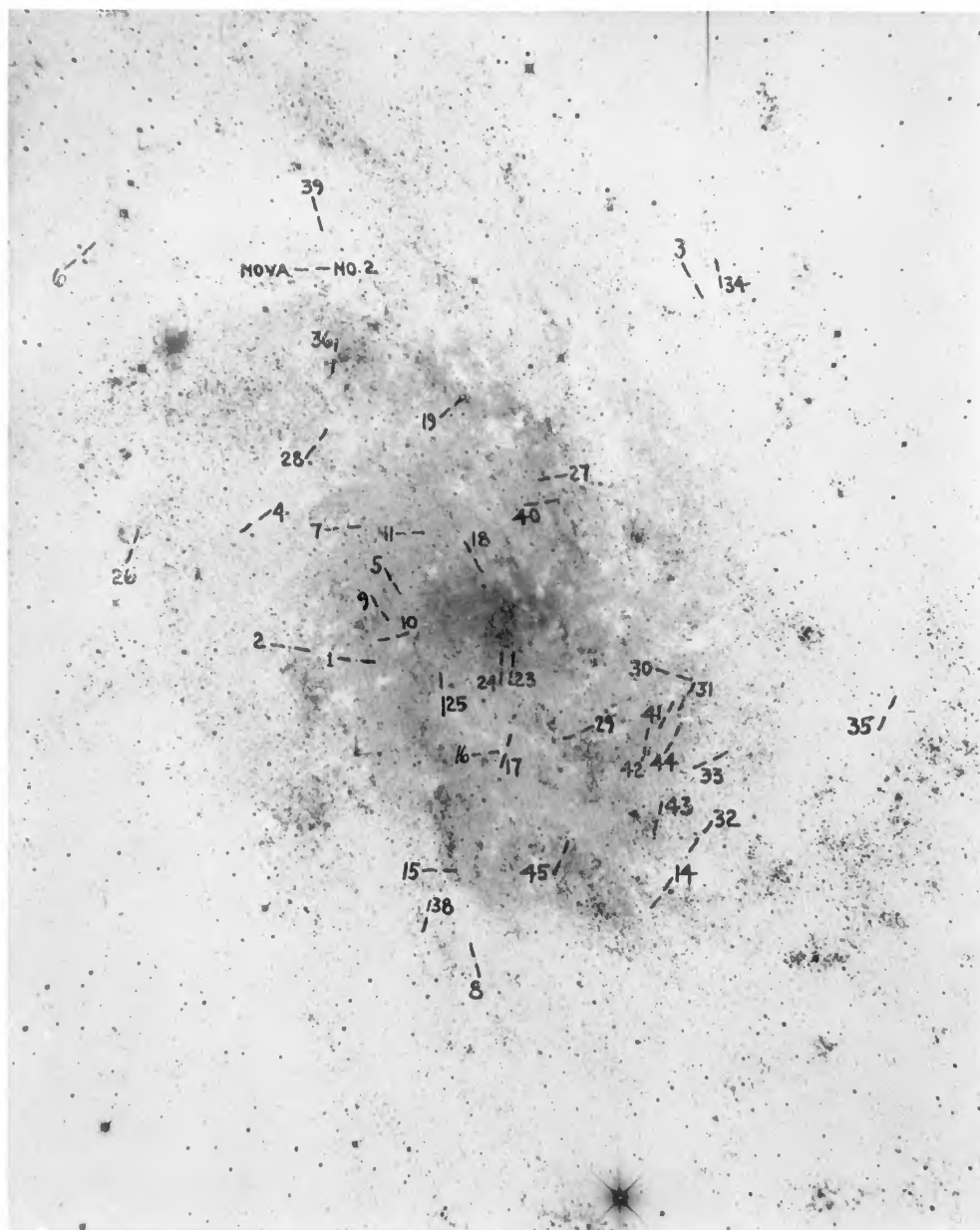
CEPHEID VARIABLES

The criteria used in determining Cepheid variation were: periods between two and one hundred days, amplitudes less than 2 mag., rapid brightening and slower fading, and no conspicuous secondary maxima. The limits for the first two of these are arbitrary, and, indeed, are more generous than necessary for the data under discussion. The maximum amplitude encountered is 1.2 mag., and the periods range from thirteen to seventy days.¹ The magnitudes at maximum range from 18.0 to 19.1. Minimum, and hence median, magnitudes are in general too uncertain for statistical discussion, but, although in several cases the minima are below the limits of the observations, there is no reason to suppose that any of the amplitudes approach the limiting value mentioned above.

In order to emphasize their Cepheid characteristics, several of the better-determined normal curves are illustrated in Figure 1.

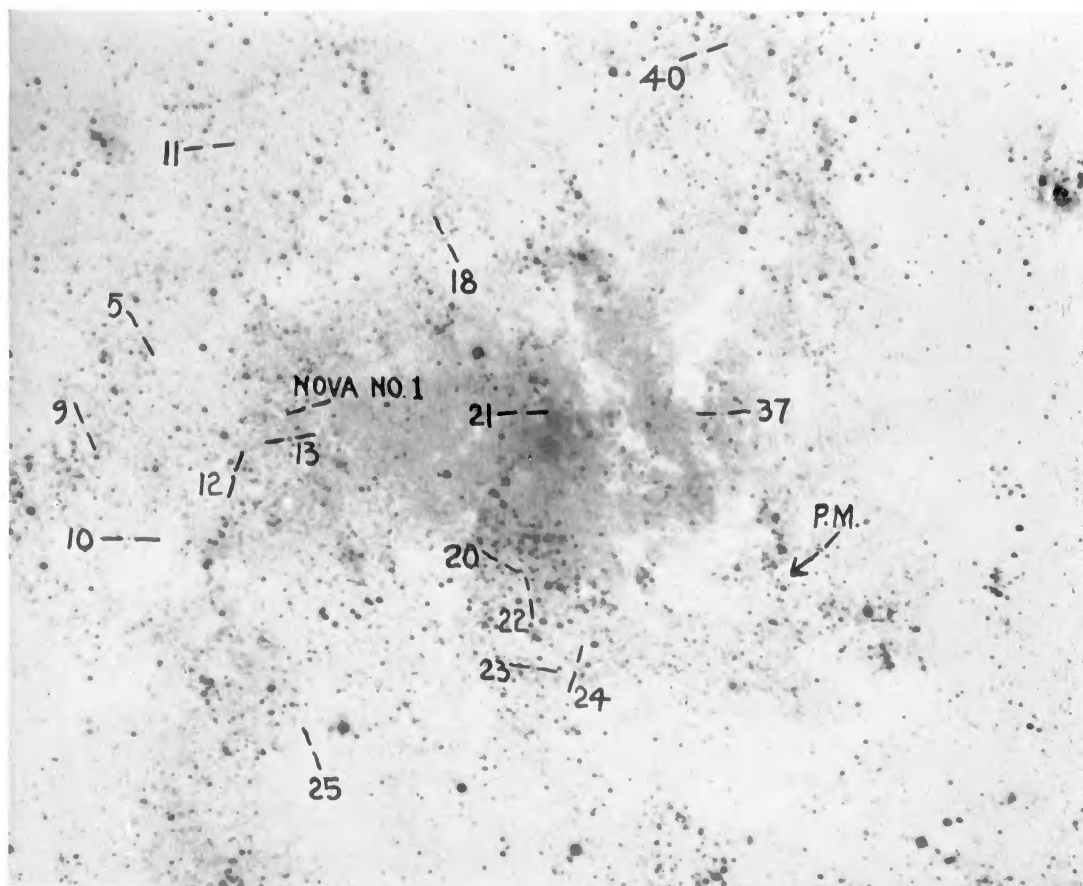
¹ That some or all of the periods might be very close to one day, or some exact submultiple, was fully realized, and sufficient plates were obtained at different hour angles on the same night to eliminate this possibility. Each of the Cepheids was followed through several cycles after the period had been determined, and it is believed that the adopted elements are reliable.

PLATE XIV



Negative Ri 115. Exposure 8.5 hours, Seed 23 plate, 60-inch reflector, August 5, 6, 7, 1910. Scale 1 mm = 14".2. Nova No. 2 (1925) and all variables excepting Nos. 12, 13, 20, 21 22, and 37 are marked.

PLATE XV



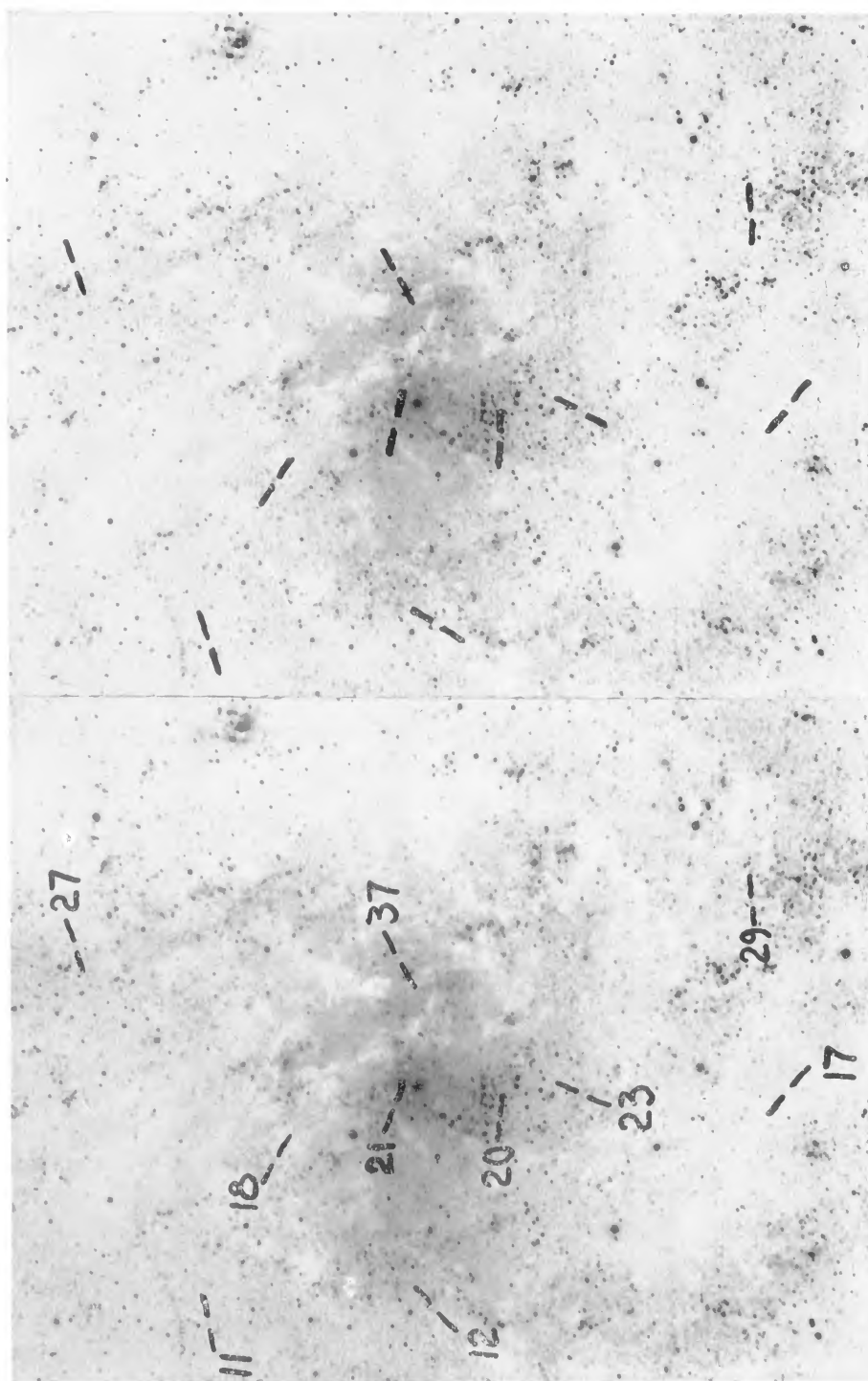
Negative H 584. Exposure 90 minutes, Seed 30 plate, 100-inch reflector, July 26, 1925. Scale 1 mm = 3".8. Nova No. 1 (1919) and variables Nos. 5, 9, 10, 11, 12, 13, 18, 20, 21, 22, 23, 24, 25, 37, and 40 are marked. The star marked P.M., pg. mag. 18.25, is moving about 10" per century in the direction of the arrow.

PLATE XVI



Negative H 485. Exposure 30 minutes, Seed 30 plate, 100-inch reflector, November 26, 1925, centered about 7' south preceding the nucleus of Messier 33. Scale, 1 mm = 4".3. Variables Nos. 14, 29, 30, 31, 32, 33, 41, 42, 43, 44, and 45 are marked. The mean diameter of the smallest star images is approximately 0".5.

PLATE XVII



Light-Changes of Variables in Messier 33. Negatives H 446 (left) and H 475 (right), both made with the 100-inch reflector. Scale, 1 mm = 5".2. All of the variables except No. 21 are Cepheids.

TABLE I
PHOTOGRAPHIC MAGNITUDES OF VARIABLES IN MESSIER 33

PLATE*	QUAL- ITY	J.D.†	CEPHEIDS‡						
			3	4	5	7	9	10	11
R 15.....	F	18560.6	18.6	19.3	19.2	19.3	19.3	19.1	19.15
I 15.....	E	18890.6	18.3	19.3	19.4+	18.7	18.95	19.0	19.15
D 34.....	P	22197.6	19.0	19.3	19.0	19.2	19.0	18.9	18.8
P 33.....	F	2307.4	18.45	19.3+	19.3+	19.2	18.8	19.15	19.2+
I 34.....	P	2311.4	18.45	19.0	19.3+	19.1	19.2	19.2	18.95
I 38.....	G	2314.4	18.7	18.1	18.8	18.75	19.3	19.2	18.75
I 39.....	P	2347.8	18.25	18.7	19.3	18.9	18.95	18.9	19.2
D 48.....	G	2550.6	19.0	19.15	19.3+	19.3	18.7	18.8	18.85
I 83.....	P	2611.0	19.0	19.2+	19.2+	18.6	.....	.....	.....
I 86.....	F	2612.5	18.95	19.3	19.3+	18.8	19.0	18.65	19.15
I 108.....	P	2669.4	.....	18.1	.....	.....	19.0	19.15	18.9+
I 119.....	F	2694.3	18.95	19.3+	18.85	.....	19.2+	18.5	18.9
I 130.....	G	2698.3	19.1	18.2	19.3	19.2	19.3	18.95	.....
I 198.....	G	2903.2	18.9	19.3	19.3+	18.85	19.3	18.9	18.8
I 205.....	G	2907.2	18.9	19.15	19.4+	18.85	19.3	18.95	19.0
A 4.....	F	2966.5	19.2	.....	.....	19.1+	18.75	18.65	18.95
I 8.....	G	3000.4	19.1	18.1	18.85	19.2	19.3	19.15	19.3
I 40.....	G	3319.6	19.0	19.15	19.3	19.3	19.3	18.7	18.8
B 65.....	G	3322.1	19.0	19.4	18.85	19.1	19.3	18.95	18.9
M 335.....	G	3344.5	18.9	19.2+	19.3+	19.15	18.7	19.1	18.9
H 17.....	E	4004.7	19.3	19.4	19.3+	19.3	18.9	18.5	19.1
D 239.....	G	4024.6	18.8	19.3	19.1	19.15	18.65	19.0	18.9
I 245.....	G	4025.6	18.9	19.3	19.2	19.2	18.75	18.9	18.9
S 354.....	F	4026.6	18.85	19.3	19.1+	19.3	18.9	18.95	18.95
I 357.....	F	4027.6	18.9	19.3	19.1+	19.2+	19.0+	18.95	18.9+
I 363.....	G	4030.6	19.1	19.2+	19.1+	19.3	19.2	19.1	19.0
H 422.....	G	4031.6	19.1	19.4	19.3+	19.2	19.3	19.0	19.15
I 428.....	F	4033.6	19.0	19.4+	19.4+	19.2	19.3	19.0	19.15
S 367.....	P	4049.6	19.1	19.0	.....	18.9	.....	.....	18.85
I 373.....	P	4050.6	19.2	19.2	19.1	19.1	.....	19.15	18.9
H 433.....	F	4054.6	18.35	19.3+	18.9	19.1	19.1+	19.1	19.0
S 375.....	F	4055.6	18.45	19.25	19.05	19.3	19.3	19.15	19.1
I 383.....	F	4056.5	18.4	19.3	19.1+	19.2	.....	19.1	19.0
H 441.....	F	4058.5	18.45	19.25	19.1+	18.9+	.....	.....	.....
I 446.....	E	4059.5	18.45	19.15	19.25	19.2	19.0	19.15	19.15
I 452.....	P	4085.5	19.3	19.5	19.2+	19.2	18.95	18.7	19.2+
S 399.....	P	4089.5	19.2	19.3	19.1+	19.3+	19.0+	18.85	19.1+
H 458.....	F	4090.5	19.3	19.0	19.3+	19.3+	19.3	18.85	18.9
I 465.....	F	4092.5	19.2	18.4	19.1+	18.8+	19.3	18.95	18.85
I 497.....	F	4108.4	18.6	19.4	19.3	19.3	19.1	19.0	19.2
I 472.....	F	4109.4	18.65	19.5	19.2	19.2	19.4+	19.0	19.3+
S 407.....	F	4113.4	18.7	19.3	19.1+	19.3	19.0+	19.15	19.15
H 475.....	E	4115.4	18.75	19.35	19.3	19.2	19.3	19.15	19.0
I 486.....	E	4116.3	19.0	19.3	19.3	19.3	19.0	.....	18.75
I 503.....	F	4147.3	18.8	18.45	19.3+	18.6	19.2	18.6	19.1
I 509.....	G	4149.3	18.8	18.6	19.2+	18.7	19.2	18.6	19.0+
I 517.....	F	4171.3	19.1	19.15	19.2	19.2	19.3	18.95	19.0
I 577.....	G	4348.6	18.3	19.4	19.2	19.2	18.9	18.95	19.1
D 253.....	F	4351.6	18.4	19.4	19.2	19.2	19.0	18.7	18.9
H 584.....	E	4357.6	18.6	19.5	19.1	19.2	19.3	18.55	19.0
S 497.....	P	4358.6	18.65	.....	18.9	.....	.....	.....	.....
H 588.....	G	4377.6	19.3	19.1	19.1	19.15	19.3	18.95	18.8
I 593.....	G	4378.6	19.3	19.25	19.2	19.2	19.3	18.95	18.9
I 600.....	G	4379.6	.....	19.3+	.....	.....	.....	.....	18.9
D 277.....	E	4384.6	19.2	19.4	19.4	18.9	18.7	19.0	19.25
I 288.....	E	4387.6	18.45	19.5	18.8	18.6	18.9	19.1	19.2
H 606.....	P	4405.5	18.85	19.1	19.3	19.2	18.75	19.05	19.0
I 611.....	G	4414.5	19.1	19.35	19.25	18.6	19.4	18.85	19.2+

* The prefixed letters refer to the observers: R=Ritchey, D=Duncan, P=Pease, A and B=Humberson, M=van Maanen, S and H=Hubble.

† Add 2,400,000 to the first three dates, and 2,420,000 to the others. The decimal indicates Pacific Mean Time. In order to conform to the change to Civil Day Time, 0.5 must be added to each date.

‡ A plus sign following a magnitude indicates that the variable was invisible, but certainly fainter than the value indicated.

TABLE I—Continued

PLATE	QUAL- ITY	J.D.	CEPHEIDS						
			12	16	17	18	19	20	22
R 15.....	F	18560.6	19.0+	19.0	18.95	18.8	18.1	B	.....
115.....	E	18890.6	19.0	18.8	19.2	18.55	18.2	18.55	19.4
D 34.....	P	22107.6	.....	18.7	19.15	18.75	18.9	.....	.....
P133.....	F	2307.4	19.2+	19.2	19.4+	19.05	18.7	18.65	19.1
134.....	P	2311.4	19.0	19.2	18.75	19.05	18.7	18.75	19.3
138.....	G	2314.4	18.6	19.3+	18.95	19.05	18.7	18.9	19.2+
139.....	P	2347.8	19.2+	19.2	19.4+	19.05	18.7	18.75	.....
D 48.....	G	2550.6	.....	19.1	19.4	19.0	18.1	B	19.1+
83.....	P	2611.0	.....	.....	.....	.....	18.4	.....	.....
86.....	F	2612.5	19.2+	19.3	19.4	18.95	18.35	.....	.....
108.....	P	2669.4	.....	.....	19.2+	18.7	18.5	.....	.....
119.....	F	2694.3	19.2+	19.2+	19.2+	18.7	18.8	.....	18.85
130.....	G	2698.3	19.2+	19.3	19.4+	18.55	18.6	18.4	19.0
198.....	G	2903.2	18.9	19.3	19.4+	18.65	18.8	18.9	19.1+
205.....	G	2907.2	19.3+	19.3	19.4	18.8	18.7	18.85	19.3+
A 4.....	F	2966.5	18.8	18.75	19.1	18.7	18.85	18.9	19.2+
8.....	G	3000.4	19.4	18.8	19.4	18.7	18.5	19.0	19.0
40.....	G	3319.6	19.4	19.1	19.2	18.75	18.4	19.0	19.3+
B 65.....	G	3322.1	19.3	19.3	19.4	18.8	18.4	18.9	19.4
M335.....	G	3344.5	19.4	19.4	19.4	18.5	18.8	18.3	19.4
H417.....	E	4004.7	18.6	19.3	19.4+	18.9	18.7	19.0	18.9
D239.....	G	4024.6	18.6	19.2	19.4	18.5	18.0	18.2	18.95
245.....	G	4025.6	18.6	19.2	19.4+	18.55	18.2	18.3	18.9
S354.....	F	4026.6	.....	19.2+	19.4+	18.6	18.1	.....	.....
357.....	F	4027.6	18.75	19.0+	19.2+	18.7	18.3	.....	.....
363.....	G	4030.6	18.9	19.1+	19.4+	18.75	18.35	18.6	.....
H422.....	G	4031.6	19.1	19.2	19.4+	18.75	18.35	18.6	19.2
428.....	F	4033.6	19.1	18.6	19.4+	18.8	18.4	18.65	19.3
S367.....	P	4049.6	.....	.....	19.3+	.....	18.85	.....	.....
373.....	P	4050.6	.....	18.7	19.4+	.....	18.8	.....	.....
H433.....	F	4054.6	19.3+	19.05	19.4+	18.9	18.7	18.9+	19.3
S375.....	F	4055.6	.....	19.1	19.4+	18.75	18.8	18.9+	19.3
383.....	F	4056.5	.....	19.1	19.4+	18.5	18.7	.....	19.3
H441.....	F	4058.5	19.3+	.....	18.75	18.45	18.7	.....	.....
446.....	E	4059.5	19.4	19.2	18.75	18.55	18.75	18.6	19.35
452.....	P	4085.5	19.1+	18.8	19.15	19.0	18.25	19.0	19.3+
S399.....	P	4089.5	18.9	19.0+	19.1+	.....	18.35	.....	.....
H458.....	F	4090.5	18.6	19.1	19.3	19.55	18.3	19.1	18.9
465.....	F	4092.5	.....	19.2+	19.3+	18.5	18.45	19.1	19.05
467.....	F	4108.4	19.3+	19.05	19.0	19.0	18.7	18.65	19.2+
472.....	F	4109.4	19.3	19.2	19.15	18.9	18.7	18.85	19.4
S407.....	F	4113.4	.....	19.2+	19.4+	.....	18.8	.....	.....
H475.....	E	4115.4	18.95	19.5	19.4+	19.0	18.7	19.0	19.05
486.....	E	4116.3	19.1	19.4	19.4	19.05	18.7	19.0	19.1
503.....	F	4147.3	19.1+	19.2	.....	19.1	18.45	.....	.....
509.....	G	4149.3	19.4	19.2	19.4+	19.1	18.55	18.9	19.4
517.....	F	4171.3	19.4	19.2	.....	18.8	18.65	18.2	19.4
577.....	G	4348.6	19.3+	18.7	19.3+	19.1	18.0	18.1	19.4
D253.....	F	4351.6	18.8	18.85	19.4+	19.1	18.1	18.45	19.1
H584.....	E	4357.6	19.1	19.4	19.45	19.0	18.3	18.6	19.2
S497.....	P	4358.6	.....	.....	.....	.....	18.15	.....	.....
H588.....	G	4377.6	19.1	19.4	19.4+	18.85	18.7	19.0	19.2
593.....	G	4378.6	19.1	19.4	19.4+	18.9	18.8	19.0	19.2
600.....	G	4379.6	19.1+	19.4	.....	.....	18.8	19.0	.....
D277.....	E	4384.6	19.1+	18.75	18.8	18.9	18.7	18.3	19.5
288.....	E	4387.6	19.4	19.2	19.0	18.9	18.7	18.4	19.4
H606.....	P	4405.5	19.1+	19.1	19.4+	18.75	18.0		
611.....	G	4414.5	18.8	19.4+	19.1	18.9	18.2	19.0	19.35

THE SPIRAL M33 AS A STELLAR SYSTEM

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TABLE I—Continued

PLATE	QUALITY	J.D.	CEPHEIDS						
			23	24	25	26	27	28	29
R 15.....	F	18560.6				19.2	19.05	19.6	18.8
115.....	E	18890.6	18.95	19.3	19.3	19.6	19.3	19.7	19.2
D 34.....	P	22197.6	.....	.....	.....	19.4+	19.2	19.5+	19.0
P133.....	F	2307.4	19.15	19.3	.....	19.4+	19.0	19.6+	19.25
134.....	P	2311.4	.....	.....	19.6+	19.5+	19.1	19.6+	19.2+
138.....	G	2314.4	19.3	18.8	19.6+	19.4+	19.2	18.85	19.3
139.....	P	2347.8	19.2+	19.4+	19.4	19.1	19.2	19.6+	19.3
D 48.....	G	2550.6	19.2+	19.4	19.3	19.4+	18.75	19.5+	18.5
83.....	P	2611.0	.....	.....	.....	.....	.....	18.8	19.2+
86.....	F	2612.5	19.2+	19.1	19.4	19.5+	19.3	19.1	19.3
108.....	P	2669.4	.....	.....	.....	.....	.....	.....	.....
110.....	F	2694.3	.....	.....	18.85	.....	.....	.....	19.2
130.....	G	2698.3	19.2+	19.4+	19.3	19.4	19.2	19.5+	19.1
198.....	G	2903.2	19.3	.....	19.5+	19.4	19.2	19.7	18.6
205.....	G	2907.2	19.0	19.2	19.5+	19.2	19.3	19.6+	19.3
A 4.....	F	2966.5	19.2+	.....	19.2	.....	19.2	.....	19.3
8.....	G	3000.4	18.85	19.3	19.7	19.35	18.7	19.6	19.1
40.....	G	3319.6	19.4+	19.1	.....	19.2+	19.2	19.1	19.1
B 65.....	G	3322.1	19.4	18.9	19.6+	19.2	19.3	19.6	19.1
M335.....	G	3344.5	19.3+	19.3+	19.5+	.....	19.1	.....	19.3
H417.....	E	4004.7	19.0	19.05	19.5+	19.5	19.4	19.5	18.7
D239.....	G	4024.6	19.3	19.4+	19.1	19.4	19.3	18.75	19.3
245.....	G	4025.6	19.4	19.4+	19.15	19.3	19.3	19.0	19.3
S354.....	F	4026.6	.....	.....	.....	19.5+	19.3	19.3	19.2+
357.....	F	4027.6	.....	.....	.....	.....	.....	19.5	.....
363.....	G	4030.6	.....	.....	.....	19.4+	19.2	19.5+	19.2+
H422.....	G	4031.6	18.8	19.1	19.5+	.....	19.2	.....	19.3
428.....	F	4033.6	19.1	19.2	19.5+	19.4+	18.7	19.5+	19.3
S367.....	P	4049.6	.....	.....	19.3	19.4+	.....	19.5+	.....
373.....	P	4050.6	.....	.....	19.1	19.4+	.....	19.6+	.....
H433.....	F	4054.6	.....	.....	.....	.....	18.75	.....	19.2
S375.....	F	4055.6	.....	.....	19.45	19.6+	18.7	19.7	19.2
383.....	F	4056.5	.....	.....	.....	19.4+	18.75	19.6+	19.3
H441.....	F	4058.5	.....	.....	.....	.....	.....	.....	.....
446.....	E	4059.5	19.0	19.35	19.6	19.4+	19.1	19.5+	19.3
452.....	P	4085.5	18.85	19.4	19.6	19.4+	19.3+	19.5+	19.1
S399.....	P	4089.0	.....	.....	.....	19.1	19.2+	19.6+	19.2
H458.....	F	4090.5	19.3	19.4+	19.4	19.0	19.2	19.6+	19.2+
465.....	F	4092.5	19.2+	19.2	18.9	19.1	19.3	.....	19.2+
467.....	F	4108.4	19.4	19.2	19.4+	19.4+	19.0	19.5+	19.3
472.....	F	4109.4	19.4	.....	.....	19.4+	19.25	19.5+	19.2
S407.....	F	4113.4	18.7	.....	.....	19.2	.....	19.5+	18.5
H475.....	E	4115.4	19.2	19.5	19.7	19.2	19.3	19.6	18.7
486.....	E	4116.3	19.25	19.4+	19.4	19.1	19.2+	18.9	18.75
503.....	F	4147.3	19.4	19.2	19.4	19.4+	18.9	19.5+	18.65
509.....	G	4149.3	19.4	19.2	19.4	.....	19.0	.....	18.6
517.....	F	4171.3	19.4+	18.85	18.85	19.4+	18.95	19.5+	19.3
577.....	G	4348.6	19.4+	19.4+	19.35	19.2	18.9	19.5+	19.2
D253.....	F	4351.6	19.2+	18.8	19.4+	19.4+	19.1	19.5+	19.3
H584.....	E	4357.6	18.8	19.4	19.7	19.6	19.25	19.1	19.3
S497.....	P	4358.6	.....	.....	.....	19.4+	.....	18.9	.....
H588.....	G	4377.6	19.4	18.95	19.5+	19.4+	19.2	19.0	19.0
593.....	G	4378.6	19.4	18.95	19.5+	19.4+	.....	19.0	19.0
600.....	G	4379.6	19.3+	.....	.....	19.4+	19.0+	19.3	19.1
D277.....	E	4384.6	18.95	19.5+	19.6	19.6+	19.3	19.7+	19.2
288.....	E	4387.6	19.25	19.5+	18.9	19.6+	19.2	19.7	19.35
H606.....	P	4405.5	19.0+	18.9	.....	19.4+	.....	19.5+	18.65
611.....	G	4414.5	19.0+	19.2+	18.9	19.1	18.7	18.85	19.2

TABLE I—Continued

PLATE	QUAL- ITY	J.D.	CEPHEIDS						
			30	31	33	34	35	36	37
R 15.....	F	18560.6	18.9	18.3	.....	19.4	19.4	18.85	.....
115.....	E	18890.6	19.1	19.3	19.7+	19.1	19.2	19.1	19.4+
D 34.....	P	22197.6	18.7	19.3	.....	19.2	.....	19.0	.....
P 133.....	F	2307.4	19.15	19.0	19.3	19.2	19.2	18.8	.....
134.....	P	2311.4	.....	19.1	19.7	19.3	19.3	18.45	19.4+
138.....	G	2314.4	19.2	19.15	19.5+	19.4	19.3	18.65	19.5+
139.....	P	2347.8	19.15	19.15	19.3+	19.1	19.4	18.65	.....
D 48.....	G	2550.6	19.1	19.15	18.8	19.0	19.3	19.1	.....
83.....	P	2611.0	18.6	.....	.....	18.9	19.4	19.0	.....
86.....	F	2612.5	18.9	19.15	.....	18.95	19.45	19.0	.....
108.....	P	2669.4	.....	.....	.....	.....	.....	.....	.....
119.....	F	2694.3	18.3	19.15	.....	18.75	18.7	19.0	19.2+
130.....	G	2698.3	18.45	.....	19.5	18.85	18.9	19.0	.....
198.....	G	2903.2	19.15	19.0	19.3+	19.3	18.65	19.0	19.3+
205.....	G	2907.2	19.15	19.0	19.7	19.3	18.7	19.0	19.5+
A 4.....	F	2966.5	18.65	18.2	19.4	.....	18.7	19.0	19.05
8.....	G	3000.4	19.15	18.35	18.75	19.4	18.9	18.75	19.4+
40.....	G	3319.6	19.15	19.0	19.7+	18.85	19.2+	18.7	18.75
B 65.....	G	3322.1	19.15	19.3	19.7+	19.2	19.4	18.8	19.0
M 335.....	G	3344.5	18.5	18.5	19.7+	19.1	19.2+	19.1	19.4
H 17.....	E	4004.7	19.1	19.2	18.75	18.75	18.8	18.8	19.1
D 239.....	G	4024.6	18.8	19.0	19.5	18.55	19.4+	18.9	19.0
245.....	G	4025.6	18.45	19.15	18.75	18.6	19.4+	18.8	19.0
S 354.....	F	4026.6	18.3	19.15	.....	18.6	19.4	18.8	.....
357.....	F	4027.6	18.3	19.15	.....	.....	.....	18.7	.....
363.....	G	4030.6	18.5	19.2	19.1+	19.2	18.8	18.55	19.3
H 422.....	G	4031.6	18.4	19.2	19.2	19.1+	18.65	18.5	19.5
428.....	F	4033.6	18.45	19.1	19.5+	19.0	18.65	18.5	19.4
S 367.....	P	4049.6	19.1	18.3	.....	18.6	.....	19.0	19.1+
373.....	P	4050.6	.....	18.4	.....	18.6	19.2+	19.0	.....
H 433.....	F	4054.6	19.1	18.4	.....	.....	.....	19.0	19.3+
S 375.....	F	4055.6	19.1	18.45	19.7+	19.1	19.5	19.1	19.1+
383.....	F	4056.5	19.2	18.55	19.3+	19.2	19.2+	19.0	19.3+
H 441.....	F	4058.5	.....	.....	.....	.....	.....	.....	18.95
446.....	E	4059.5	19.15	18.95	19.7+	19.5	19.2	19.1	18.85
452.....	P	4085.5	18.9	18.2	19.6+	19.4	19.4+	19.0	19.3+
S 399.....	P	4089.5	19.0	18.4	.....	19.1	19.2	19.0	19.2+
H 458.....	F	4090.5	19.1	18.45	18.9	18.75	19.1	19.0	19.3+
465.....	F	4092.5	19.1	18.8	19.4	18.6	18.6	.....	19.35
467.....	F	4108.4	19.2	19.1	18.75	19.3	19.3	18.65	19.3
472.....	F	4109.4	19.25	19.2	18.9	19.4	19.4+	18.7	19.4+
S 407.....	F	4113.4	19.15	19.2	19.1+	18.55	19.45	19.0	.....
H 475.....	E	4115.4	18.95	19.2	19.7	18.6	19.45	19.0	19.0
486.....	E	4116.3	18.8	19.3	19.5	18.75	19.45	19.0	19.0
503.....	F	4147.3	19.2	19.3	19.5	19.2	.....	18.8	18.85
509.....	G	4149.3	19.2	19.15	19.0	19.2	.....	18.8	19.0
517.....	F	4171.3	18.5	18.85	19.1	19.2	19.4	18.5	19.3+
577.....	G	4348.6	18.3	18.3	19.3+	19.3	19.2	18.7	19.2+
D 253.....	F	4351.6	18.45	18.5	19.3	19.3	19.2	18.7	19.3+
H 584.....	E	4357.6	18.5	18.85	19.1	18.45	19.2	18.6	18.9
S 497.....	P	4358.6	.....	.....	.....	18.5	.....	18.6	.....
H 588.....	G	4377.6	19.2	19.2	19.0	19.2	19.0	19.0	18.9
593.....	G	4378.6	19.25	19.15	19.1	18.7	.....	19.0	18.9
600.....	G	4379.6	19.2	.....	19.2	.....	.....	19.1	19.2
D 277.....	E	4384.6	19.25	18.2	19.7	18.9	19.4	18.6	19.3
288.....	E	4387.6	19.25	18.5	19.8+	19.15	19.3	18.45	19.5
H 606.....	P	4405.5	18.9	19.1	19.3+	18.7	18.9	19.0	
611.....	G	4414.5	19.0	19.3	19.0	19.2	19.4	19.1	19.05

THE SPIRAL M33 AS A STELLAR SYSTEM

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TABLE I—Continued

PLATE	QUAL- ITY	J.D.	CEPHEIDS						
			38	39	40	41	42	43	44
R 15.....	F	18560.6	18.7	19.2	19.1+	19.1	18.45	18.8	
115.....	E	18890.6	19.1	19.5	19.2	19.25	19.0	19.3	19.2
D 34.....	P	22197.6	18.8	19.1+	19.1	.....	.....	.....	.....
P133.....	F	2307.4	19.1	19.1	19.4+	19.2	18.9	19.6	19.4
134.....	P	2311.4	18.2	19.3	19.0	18.7	19.0	18.7	19.2
138.....	G	2314.4	18.5	19.2+	19.3	19.1	19.0	18.95	18.6
139.....	P	2347.8	19.1	19.2+	19.4+	18.7	19.0	19.4+	19.1
D 48.....	G	2550.6	19.1	19.1	19.3+	19.25	19.0	19.6	19.4
83.....	P	2611.0	18.6	18.9	.....	.....	.....	.....	.....
86.....	F	2612.5	18.3	18.8	19.35	19.3	18.9	19.6	.....
108.....	P	2669.4	.....	.....	.....	.....	.....	.....	.....
119.....	F	2694.3	18.6	.....	19.4+	19.2	18.8	19.15	.....
130.....	G	2698.3	19.1	19.0+	19.3+	19.25	18.8	18.7	19.4
198.....	G	2903.2	18.95	18.8	19.4	19.1	18.6	19.4	19.3
205.....	G	2907.2	19.1	19.3	18.9	18.75	18.7	19.7	19.35
A 4.....	F	2966.5	18.6	.....	19.4+	19.25	18.8	19.4	19.2
8.....	G	3000.4	19.1	18.9	19.45	19.1	18.9	18.8	19.4
40.....	G	3319.6	18.6	19.2+	18.9	18.9	19.0	18.7	19.3
B 65.....	G	3322.1	18.8	19.2	19.3	19.1	18.9	18.8	19.4
M335.....	G	3344.5	18.6	.....	19.4	19.25	19.0	19.1	.....
H417.....	E	4004.7	19.0	19.1	18.95	18.95	18.9	18.95	18.8
D239.....	G	4024.6	19.0	19.2+	19.35	19.2	18.6	19.1	19.4
245.....	G	4025.6	18.9	19.2+	19.35	19.25	18.7	18.7	19.4
S354.....	F	4026.6	19.0	19.2+	.....	.....	18.7	18.7	19.3
357.....	F	4027.6	19.0	19.0+	.....	19.2	18.8	18.65	19.2
363.....	G	4030.6	19.0	19.2+	18.95	19.2	18.8	19.1	18.8
H422.....	G	4031.6	19.1	.....	19.15	19.25	18.9	19.3	18.6
428.....	F	4033.6	19.1	18.8	19.35	19.3	18.8	19.3	18.6
S367.....	P	4049.6	19.0	18.9	19.1+	19.1+	18.8+	19.0	19.3+
373.....	P	4050.6	18.8	19.0	19.1+	19.1	18.6	19.1	19.3
H433.....	F	4054.6	19.1	.....	19.3	18.6	18.45	19.4	19.3
S375.....	F	4055.6	19.1	19.2+	19.2	18.75	18.6	19.7	19.4
383.....	F	4056.6	.....	19.1+	18.9	18.75	18.45	19.3	19.4
H441.....	F	4058.5	.....	19.1+	19.1+	19.1	18.7	19.4	19.3
446.....	E	4059.5	19.1	19.0+	19.25	19.1	18.9	19.7	18.65
452.....	P	4085.5	19.15	19.1	19.3	19.25	18.6	19.3	19.3
S399.....	P	4089.5	18.2	19.2+	.....	19.2	.....	19.1	19.3
H458.....	F	4090.5	18.3	19.1+	19.35	18.6	18.8	18.8	18.8
465.....	F	4092.5	18.5	.....	19.4	18.8	18.8	18.95	18.6
467.....	F	4108.4	19.1	19.1+	18.95	18.7	18.9	18.7	19.4
472.....	F	4109.4	19.1	19.2+	19.15	18.7	18.8	18.9	19.4
S407.....	F	4113.4	18.4	19.1+	19.2+	18.95	18.45	.....	.....
H475.....	E	4115.4	18.35	18.8	19.35	19.1	18.6	19.2	19.5
486.....	E	4116.3	18.45	.....	19.3+	19.1	18.45	19.4	19.4
503.....	F	4147.3	18.8	18.75	19.0	18.9	18.6	18.6	.....
509.....	G	4149.3	19.1	.....	19.25	19.2	18.7	18.6	19.1
517.....	F	4171.3	18.7	19.1+	19.25	19.25	18.85	18.7	19.4
577.....	G	4348.6	18.8	19.3+	19.35	19.1	19.0	18.7	19.3
D253.....	F	4351.6	19.1	19.2+	19.15	19.2	18.85	19.1	19.6
H584.....	E	4357.6	19.1	18.8	19.35	19.2	18.55	19.35	19.6
S497.....	P	4358.6	.....	18.75	.....	.....	.....	.....	.....
H588.....	G	4377.6	19.1	19.1	19.25	18.65	19.0	19.4	19.4
593.....	G	4378.6	19.1	19.2+	18.95	18.65	19.0	19.7	19.4
600.....	G	4379.6	19.1	19.1+	19.0	18.7	19.0+	19.7	19.3
D277.....	E	4384.6	19.3	19.3+	19.45	19.2	18.85	19.5	19.3
288.....	E	4387.6	18.8	19.2+	19.5	19.3	18.6	19.1	19.6
H606.....	P	4405.5	19.1	18.8	19.1	19.1	19.0	19.7	19.2
611.....	G	4414.5	18.25	19.3	19.5+	18.7	18.85	19.2	19.6

TABLE I—Continued

PLATE	QUALITY	J.D.	IRREGULAR				ALGOL
			1	2	6*	13	
R 15.....	F	18560.6	17.7	17.3	18.4	18.4	18.6
115.....	E	18890.6	17.2	17.4	18.6	18.25	18.6
D 34.....	P	22197.6	18.6	16.4	18.5	18.15	18.8
P 33.....	F	2307.4	18.6	16.4	18.6	18.15	18.6
134.....	P	2311.4	18.55	16.3	18.6	18.05	18.8
138.....	G	2314.4	18.6	16.4	.....	17.95	18.7
139.....	P	2347.8	18.4	16.3	18.7	18.15	18.7
D 48.....	G	2550.6	18.6	16.5	18.6	18.1	18.7
83.....	P	2611.0	18.5	16.5	.....	18.2	18.7
86.....	F	2612.5	18.45	16.5	18.7	.....	18.7
108.....	P	2669.4	.....	16.6	.....	.....	.....
119.....	F	2694.3	.....	16.5	.....	18.05	18.7
130.....	G	2698.3	18.4	16.3	.....	18.1	18.8
108.....	G	2903.2	18.55	16.1	18.8	18.0	18.7
205.....	G	2907.2	18.45	16.0	18.7	18.1	18.7
A 4.....	F	2966.5	18.7	16.1	.....	18.05	18.7
8.....	G	3000.4	18.7	15.8	18.8	17.9	18.7
40.....	G	3319.6	18.5	16.3	.....	17.8	18.7
B 65.....	G	3322.1	18.5	16.1	18.8	17.9	18.8
M335.....	G	3344.5	18.4	16.3	.....	17.8	18.7
H417.....	E	4004.7	18.55	15.5	18.8	17.75	18.6
D239.....	G	4024.6	18.5	15.6	.....	17.9	18.75
245.....	G	4025.6	18.4	15.6	18.8	18.0	18.8
S354.....	F	4026.6	18.4	15.5	18.8	18.1	18.7
357.....	F	4027.6	18.5	15.5	.....	18.05	18.7
363.....	G	4030.6	18.4	15.5	18.8	18.15	18.7
H422.....	G	4031.6	18.6	15.5	.....	17.75	18.8
428.....	F	4033.6	18.55	15.6	18.8	17.7	18.75
S367.....	P	4049.6	18.4	15.5	.....	18.1	18.75
373.....	P	4050.6	18.3	15.6	18.8	18.1	18.75
H433.....	F	4054.6	18.4	15.6	.....	18.0	18.7
S375.....	F	4055.6	18.4	15.6	18.8	18.1	18.7
383.....	F	4056.5	18.4	15.5	.....	17.9	19.15
H441.....	F	4058.5	18.4	15.5	.....	17.75	18.6
446.....	E	4059.5	18.45	15.5	18.8	17.75	18.75
452.....	P	4085.5	18.3	15.5	18.8	18.1	18.7
S399.....	P	4089.5	18.3	15.6	18.8	18.15	18.75
H458.....	F	4090.5	18.5	15.5	.....	17.95	18.6
465.....	F	4092.5	18.3	15.6	.....	17.9	18.6
467.....	F	4108.4	18.3	15.5	18.8	17.9	18.7
472.....	F	4109.4	18.4	.....	18.8	17.95	18.7
S407.....	F	4113.4	18.35	15.6	18.8	18.0	18.6
H475.....	E	4115.4	18.5	15.5	18.8	17.8	18.75
486.....	E	4116.3	18.5	15.5	.....	17.75	18.7
503.....	F	4147.3	18.6	15.6	18.8	17.8	18.5
509.....	G	4149.3	18.5	15.5	18.8	17.9	18.6
517.....	F	4171.3	18.4	15.5	18.8	17.75	18.75
577.....	G	4348.6	18.4	15.7	18.8	17.9	18.7
D253.....	F	4351.6	18.45	15.7	18.8	17.85	18.7
H584.....	E	4357.6	18.3	15.9	18.8	17.8	18.6
S497.....	P	4358.6	18.5	15.6	.....	17.8	18.7
H588.....	G	4377.6	18.3	15.9	18.8	17.8	19.1
593.....	G	4378.6	18.4	15.9	18.8	17.75	18.6
600.....	G	4379.6	18.35	15.8	18.8	17.8	18.7
D277.....	E	4384.6	18.3	15.9	18.8	17.8	18.7
288.....	E	4387.6	18.4	16.0	18.8	17.85	19.2
H606.....	P	4405.5	18.3	15.9	18.8	17.8	18.7
611.....	G	4414.5	18.3	15.9	18.8	17.9	18.7

* Var. No. 6. Magnitudes are estimated.

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TABLE I—Continued

PLATE	QUALITY	J.D.	UNDETERMINED				
			14	15	21	32	45
R 15.....	F	18560.6		19.3+			18.8
115.....	E	18890.6	19.2	19.2	18.75	18.8	18.55
D 34.....	P	22107.6	.....	19.25	.....	.....	.....
P 33.....	F	2307.4	19.35	19.35	18.5	19.1	19.0
134.....	P	2311.4	18.8	19.45	18.5	18.6	18.9
138.....	G	2314.4	18.9	19.35	18.65	19.35	18.9
139.....	P	2347.8	19.3+	19.25	18.85	19.2+	18.45
D 48.....	G	2550.6	19.2	19.35	18.85	18.85	19.0
83.....	P	2611.0	.....	.....	.....	.....	.....
86.....	F	2612.5	19.35	19.5	18.9	19.1	18.8
108.....	P	2669.4	.....	.....	.....	.....	.....
119.....	F	2694.3	.....	19.25	18.85	19.2	.....
130.....	G	2698.3	19.1	19.45	18.85	19.5+	19.0
108.....	G	2903.2	19.4	19.1	18.7	19.5+	19.0
205.....	G	2907.3	19.4	19.45	18.55	19.25	18.95
A 4.....	F	2966.5	19.05	.....	18.8	19.2+	18.7
8.....	G	3000.4	19.4	19.0	18.7	19.5	19.0
40.....	G	3319.6	19.2	19.3	18.45	19.5	18.4
B 65.....	G	3322.1	19.4	19.45	18.65	19.5	18.5
M335.....	G	3344.5	19.4	19.3+	18.9	19.4+	18.55
H417.....	E	4004.7	19.6	19.45	18.75	19.5+	18.45
D239.....	G	4024.6	19.05	19.4+	18.9	19.5+	18.95
245.....	G	4025.6	19.0	19.5	18.85	19.25	18.9
S354.....	F	4026.6	19.0	19.4+	.....	.....	.....
357.....	F	4027.6	.....	.....	.....	.....	.....
363.....	G	4030.6	19.0	.....	.....	.....	19.0
H422.....	G	4031.6	19.2	19.25	18.85	19.4	18.9
428.....	F	4033.6	19.2	19.45	18.85	19.0	19.0
S367.....	P	4049.6	19.2	.....	18.5	.....	.....
373.....	P	4050.6	.....	.....	18.5	.....	18.95
H433.....	F	4054.6	.....	19.4	18.55	.....	18.75
S375.....	F	4055.6	19.6+	19.1	18.55	19.2	18.9
383.....	F	4056.5	19.4+	19.1	18.55	19.2	18.9
H441.....	F	4058.5	.....	.....	18.55	.....	18.35
446.....	E	4059.5	19.2	19.4	18.55	19.5+	18.5
452.....	P	4085.5	19.2	19.45	18.75	19.4	18.55
S399.....	P	4089.5	.....	19.4+	.....	.....	.....
H458.....	F	4090.5	19.3	19.3+	18.75	18.9	18.7
465.....	F	4092.5	19.05	19.4+	18.75	19.2	18.6
467.....	F	4108.4	19.4	19.15	18.75	18.8	18.95
472.....	F	4109.4	.....	19.3	18.75	18.75	18.95
S407.....	F	4113.4	.....	19.3+	.....	.....	19.0
H475.....	E	4115.4	19.2	19.3	18.7	19.4	19.0
486.....	E	4116.3	19.2	.....	18.5	19.5	19.0
503.....	F	4147.3	19.5	19.4	18.7	18.6	18.5
509.....	G	4149.3	.....	19.3	18.75	18.8	18.3
517.....	F	4171.3	19.2	19.4	18.85	19.0	18.9
577.....	G	4348.0	18.8	19.4	18.8	18.6	18.8
D253.....	F	4351.6	18.95	19.2	18.8	19.4	18.7
H584.....	E	4357.6	19.05	19.1	18.75	19.4	18.25
S497.....	P	4358.6	18.9	.....	.....	.....	18.4
H588.....	G	4377.6	19.6	19.45	18.8	19.5	18.4
593.....	G	4378.6	19.4	19.5	18.85	19.5	18.45
600.....	G	4379.6	19.4+	19.3	18.7	18.8	18.5
D277.....	E	4384.6	19.3	19.5	18.65	19.45	18.5
288.....	E	4387.6	19.5	19.5	18.85	18.7	18.5
H606.....	P	4405.5	18.9	19.2	18.9	19.2	19.0
611.....	G	4414.5	19.1	19.3	19.0	19.4	19.1

The necessary data for the construction of light-curves for all the Cepheids are given in Table II. The period-luminosity relation is conspicuous among these Cepheids, and is illustrated in Figure 2, where logarithms of the periods are plotted against magnitudes at maximum. Long exposures on Cramer Iso plates through a visual filter, while not accurately calibrated as yet, indicate moderately large color-indices, quite consistent with solar-type spectra, for those Cepheids which could be identified.¹

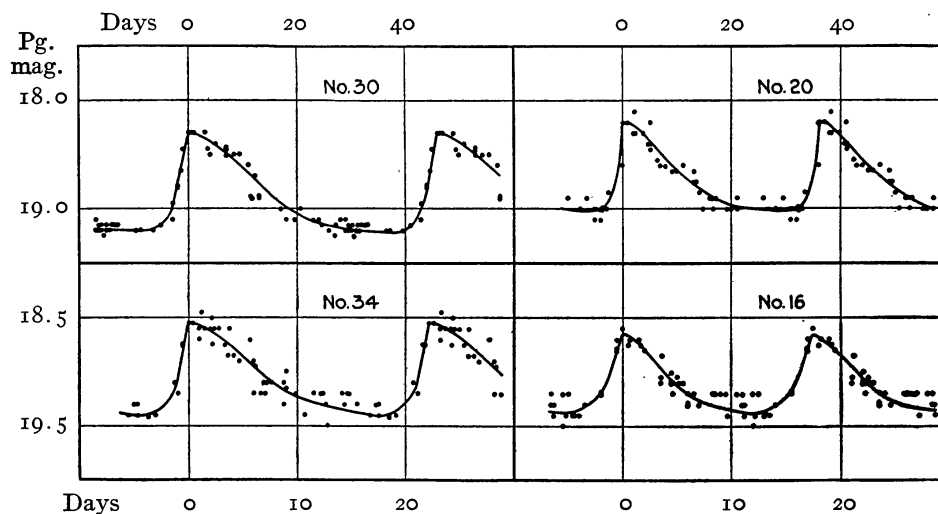


FIG. 1.—Mean light-curves for four Cepheids in Messier 33. The magnitudes are photographic.

These considerations all indicate that the variables are ordinary Cepheids, such as are known in the galactic system, the Magellanic Clouds, and the globular clusters, and hence that they can be employed for determining the distance of the spiral. An examination of Figure 2 suggests that the data are reasonably complete for maximum magnitudes down to about 18.8, but that for fainter maxima they are occasional and probably not representative.² This restriction, together with the limited range and considerable scattering, de-

¹ This conclusion is based on the fact that for stars having the same order of photographic magnitude the Cepheids fall about midway between the brightest and faintest photovisual images.

² Eighteen of the Cepheids are within 5' of the nucleus, and seventeen are more distant. The two groups are thoroughly intermingled on the plot in Fig. 2, and show no appreciable difference that can be attributed to the influence of unresolved nebulosity.

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 TABLE II
 CEPHEIDS IN MESSIER 33

VAR. No.	PERIOD		PG. MAG.		EPOCH J.D.	DISTANCE FROM NUCLEUS	POSITION ANGLE†	IDENTIFICATION PLATES
	Days	Log P	Maximum	Range*				
10† ...	69.50	1.842	18.55	(0.6)	2424004.5	188"	105°	XIV, XV
19....	54.706	1.738	18.0	.8	4018.0	346	15	XIV
30....	46.03	1.663	18.3	.9	4026.0	301	250	XIV, XVI
3....	41.68	1.620	18.35	0.9	4054.5	633	330	XIV
31....	37.33	1.572	18.25	1.0	4084.0	337	245	XIV, XVI
29....	36.31	1.560	18.55	(0.8)	4111.5	237	210	XIV, XVI, XVII
20....	35.95	1.556	18.2	(.8)	4024.0	53	160	XV, XVII
36....	35.80	1.554	18.5	(.5)	4028.0	506	35	XIV
18....	34.00	1.531	18.5	(.6)	4057.0	104	30	XIV, XVII
35....	30.514	1.484	18.65	(.8)	4031.0	665	255	XIV
42....	30.34	1.482	18.45	(.5)	4051.0	323	225	XIV, XVI
44....	30.123	1.479	18.6	0.8	4029.5	353	230	XIV, XVI
4....	27.366	1.437	18.25	1.2	4091.5	444	70	XIV
7....	26.556	1.424	18.6	(0.7)	4147.0	296	60	XIV
38....	25.04	1.398	18.2	.9	4089.0	523	165	XIV
11....	23.43	1.370	18.8	(.5)	4116.0	201	50	XIV, XV, XVII
17....	23.297	1.367	18.8	(.9)	4058.5	220	180	XIV, XVII
26....	23.258	1.366	19.1	(.7)	4089.5	618	80	XIV
27....	22.448	1.351	18.7	(.6)	4054.5	233	340	XIV, XVII
34....	22.16	1.346	18.55	(.9)	4024.5	668	325	XIV
22....	21.816	1.339	18.9	(.5)	4002.5	64	175	XV
12....	21.681	1.336	18.6	(0.9)	4024.5	140	95	XV, XVII
33....	20.50	1.312	18.75	(1.1)	4004.5	430	235	XIV, XVI
43....	20.166	1.305	18.7	1.0	4025.5	424	215	XIV, XVI
9....	18.90	1.277	18.7	(0.6)	4023.0	204	90	XIV, XV
28....	18.58	1.269	18.85	(.8)	4116.5	412	50	XIV
41....	17.98	1.255	18.65	(.6)	4090.5	321	235	XIV, XVI
37....	17.602	1.246	18.9	(.8)	4058.0	77	280	XV, XVII
16....	17.50	1.243	18.7	(.7)	4033.0	239	170	XIV
39....	16.166	1.208	18.8	(.7)	4114.0	722	25	XIV
5....	14.60	1.165	18.85	(.6)	4051.5	186	75	XIV, XV
23....	13.564	1.132	18.85	(.6)	4112.5	96	180	XIV, XV, XVII
25....	13.438	1.129	18.95	(.8)	4386.0	169	140	XIV, XV
40† ...	12.922	1.111	18.95	(.5)	4003.5	188	340	XIV, XV
24....	12.894	1.110	18.85	(0.7)	3990.0	96	190	XIV, XV

* The amplitudes, in general, are very uncertain; the few which seem to be fairly reliable are printed without parentheses.

† In the preliminary notice (*Publications of the American Astronomical Society*, 4, 261, 1925) the periods of Nos. 10 and 40 were given as 19.6 and 26.0 days, respectively. New observational data have led to the revised values listed above. The period previously published for No. 15 was also found to be erroneous.

‡ Position angles are measured from the north through the east (following side). The accuracy of both position angles and distances is sufficient only to indicate the regions in which the variables are located. Identification may be made on the various plates.

tracts materially from the significance of correlation curves computed from the data, and recourse was had to a direct cut-and-try method for determining $m - M$, the modulus of the distance.

Shapley's period-luminosity curve,¹ expressing the relation between $\log P$ and median photographic magnitude for more than a hundred Cepheids in a single system, the small Magellanic Cloud, is

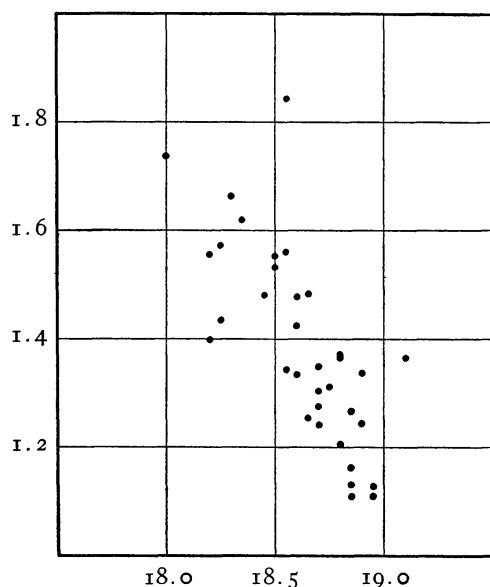


FIG. 2.—Period-luminosity relation among Cepheids in Messier 33. Photographic magnitudes at maximum (abscissae) are plotted against logarithms of period in days.

the latest and most reliable standard for comparison. The individual points were replotted, using magnitudes at maxima instead of median magnitudes,² and a corresponding diagram on transparent paper was constructed, to the same scale, for the Cepheids in Messier 33. The latter was laid upon the former so that the ordinates for $\log P$ were superposed and then adjusted to the best fit by shifting along the magnitude axis. This method assumes that the amplitudes of the Cepheids in the two systems are similar; otherwise, an error amounting to half the systematic difference in the amplitudes is introduced. In general, the two diagrams are comparable, although the scattering among the Cepheids in the spiral appears to be slightly less than among those in the cloud, while the deficiencies in the spiral for the fainter magnitudes and shorter periods are strikingly evident.

The best fit, illustrated in Figure 3, appears to be for a difference of 4.55 mag. in the moduli of the two systems, and the adjustment is sensibly unbalanced by a shift of 0.1 mag. in either direction. The

¹ *Harvard Circular*, No. 280, 1925.

² In two cases, where the amplitudes were not specifically stated, probable values were derived from a curve expressing the relation between amplitude and $\log P$.

latest value¹ for the modulus of the cloud is 17.55; hence for Messier 33

$$m-M=22.1$$

$$\pi=0''.000,0038$$

$$\begin{aligned}\text{Distance} &= 263,000 \text{ parsecs} \\ &= 850,000 \text{ light-years.}^2\end{aligned}$$

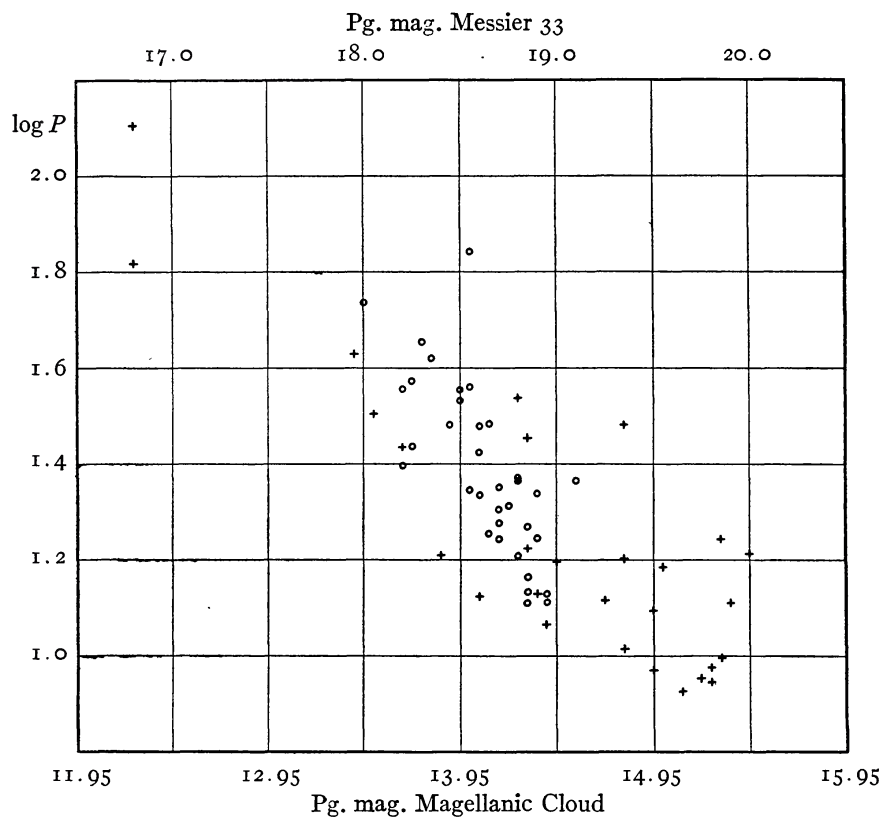


FIG. 3.—Comparison of period-luminosity relations for Cepheids in Messier 33 (circles) and in the Small Magellanic Cloud (crosses).

The accuracy of the results, the universal validity of the Cepheid criterion being assumed, depends largely upon the accuracy of the

¹ *Harvard Circular*, No. 280, 1925.

² The values published in the preliminary notice, derived from twenty-two Cepheids and Shapley's unrevised period-luminosity relation, were: $m-M=22.3$; distance=930,000 light-years. The difference is due almost entirely to the revised form of the period-luminosity curve in the portion covering the Cepheids in the spiral.

zero-point of Shapley's period-luminosity curve.¹ It is hoped that the probable error arising from the system of magnitudes and the comparison with the Cepheids in the Magellanic Cloud is not greater than 0.2 mag. in the modulus, or 10 per cent in the distance.

Hitherto, wherever Cepheids have been found in isolated systems, the criterion has led to distances entirely consistent with other characteristics that could be observed. The latest application has been to N.G.C. 6822, a system very similar to the Magellanic Clouds,

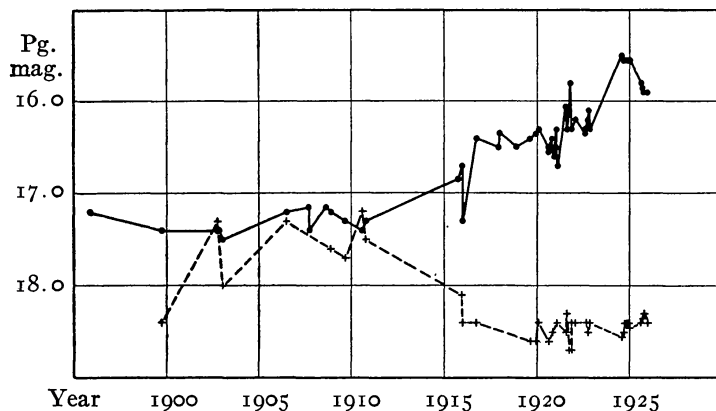


FIG. 4.—Two irregular variables in Messier 33; No. 1, crosses; No. 2, points

but at a distance of about 214,000 parsecs, comparable with that of Messier 33 itself.² Here, also, the period-luminosity relation functioned normally, and the order of the resulting distance was confirmed by several independent criteria. A presumption is thus raised in favor of the general validity of the Cepheid criterion which only strong and cumulative evidence to the contrary will destroy.

IRREGULAR VARIABLES

The four irregular variables are Nos. 1, 2, 6, and 13. A number of observations of Nos. 1 and 2 from early plates, not included in Table I, were published by Duncan³ and by Wolf.⁴ These, together with a

¹ Recent results on radial velocities and proper motions of galactic Cepheids indicate the possibility of a moderate correction to the zero-point, but until the new data have been discussed in a definitive manner, it seems preferable to use the current value, with full realization, however, of the possibility of a subsequent revision

² *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, 62, 409, 1926.

³ *Publications of the Astronomical Society of the Pacific*, 34, 290, 1922.

⁴ *Astronomische Nachrichten*, 217, 476, 1923.

few additional data, are listed in Table III. The magnitudes have been reduced to the photographic system derived from comparisons with Selected Areas Nos. 21 and 45, and differ appreciably from those

TABLE III
ADDITIONAL MAGNITUDES FOR VARIABLES NO. 1 AND NO. 2

DATE	Obs.†	VARIABLE	
		No. 1	No. 2
1895 Nov. 14*	R	17.3‡	17.2
1899 Sept. 12*	K	18.4	17.4
1902 Sept. 5*	Ri	17.3	17.4
Sept. 26	W	.....	17.4
1903 Jan. 16*	R	18.0?	17.5
1906 *	L	17.3?	17.2
1907 Aug. 8	W	.....	17.15
Aug. 12	W	.....	17.4
1908 July 25	W	.....	17.15
Nov. 17	P	17.6	17.2
1910 Oct. 24	C	17.5	17.3
1915 Oct. 1*	M	.....	16.85
Oct. 30*	L	18.1	16.7
Nov. 5	C	18.4	17.3
1916 Sept. 28*	L	18.4	16.4
1917 Dec. 10	W	.....	16.5
Dec. 16	W	.....	16.35
1918 Nov. 11*	M	.....	16.5
1920 Aug. 15	W	.....	16.55
Oct. 4*	M	.....	16.4
1921 Aug. 30	Lu	18.3	16.3
Nov. 28	Lu	18.4	16.3
1922 Jan. 20	Lu	18.4	16.2
Aug. 14	W	.....	16.35
Aug. 25	W	.....	16.35
Aug. 25*	D	18.4	16.3
Oct. 14*	M	.....	16.1
Oct. 15*	M	.....	16.3

* Plates from which magnitudes have been independently determined. Otherwise the magnitudes are those published by Duncan and by Wolf, reduced to the system of the international photographic scale.

† The photographs were made by the observers indicated in the second column: R=Isaac Roberts, K=Keeler, Ri=Ritchey, W=Wolf, L=Lamp-land, P=Perrine, C=Curtis, M=van Maanen, Lu=Lundmark, D=Duncan.

‡ Limit of the plate. Variable No. 1 was not visible.

published by the above-mentioned investigators.¹ Independent estimates of the magnitudes have been made on such of the original plates as were available.

¹ Magnitudes of a sequence of comparison stars were derived from four short-exposure comparisons with Selected Area No. 45 in addition to those found from the available long exposures.

Light-curves of these two variables, based on Tables I and III, are shown in Figure 4. Number 2 appears to have remained quiescent at about 17.4 mag. from 1895 to somewhere between 1911 and 1915. By 1915, the variable had entered upon a period of activity which is still in progress. It brightened gradually, with minor fluctuations, until it reached a maximum of 15.55, which it maintained during the season 1924-1925. It was then the brightest star which could definitely be assigned to the nebula, the absolute photographic magnitude corresponding to the distance indicated by the Cepheids being -6.55 . A faint slitless spectrogram was obtained during this period with two prisms and a 3-inch camera at the Newtonian focus of the 100-inch reflector. The continuous spectrum held up well into the violet, suggesting an early type, and a bright $H\beta$ could be seen. Several other bright lines, including $H\gamma$ and $H\delta$, were suspected. The spectrum can best be described as an early type with bright lines, and this is consistent with the photovisual plates which indicate a very small color-index. During the summer and autumn of 1925, the star faded about 0.5 mag. Variation of this type is not sufficiently known among galactic stars for analogies to be traced.

Variable No. 1 is similar in many respects to No. 2. Its normal magnitude appears to be near 18.4, but about 1900 it entered upon a seventeen-year period of activity, during which it attained a maximum magnitude of at least 17.2. By 1917 it was back to normal, and since then has shown only slight evidence of unrest. The mean magnitude during 1924-1925, however, was 18.3 as against 18.5 for the period 1920-1922. Photovisual observations indicate a moderate positive color-index of the order of 0.5 mag.

Variable No. 6 has remained steady at about 18.8 since 1921. Plates for 1910, 1911, and 1919 indicate, however, a luminosity some 0.3 or 0.4 mag. brighter. Variable No. 13 is fainter on the early plates than on the later. In 1910-1911 it was about 18.4; in 1919-1921, about 18.0; in 1924-1925, about 17.7. The color-index during the last epoch was of the order of $+0.8$ mag.

OTHER VARIABLES

Variable No. 8 appears to be an eclipsing star. On three plates it was 19.1 or fainter; otherwise it has remained steady at about 18.6. The minima were

	Photographic Magnitude
J.D. 2424056.49.....	19.15
4377.59.....	19.1
4387.60.....	19.25

The images on these plates have been critically examined, and there seems to be no reason for supposing them defective.

No periods have been found for variables Nos. 14, 15, 21, 32, and 45. The small amplitudes and recurring maxima suggest, however, the Cepheid type of variation, and it is probable that more and better observations will establish it for several of the stars.

NOVAE

Two novae have been observed in the spiral, the first about 1'8, and the second about 10'8, from the nucleus, both in the north following quadrant. Nova No. 1 was found on four plates obtained by Pease in the winter of 1919-1920. The position, indicated on Plate XV, was about 1".5 south of a star of 18.15 mag., and the photographic images of the two overlapped. This detracted from the reliability of the estimates of magnitude. Moreover, an interval of one hundred and ten days separated the plate on which the nova was first seen from the next preceding plate, and thus the date and the magnitude of maximum are unknown.

Nova No. 2, whose position is marked on Plate XIV, appeared on the first photograph obtained in the season 1925-1926. It was obviously on the declining branch of its light-curve, although it was followed for some two months longer. The data of observation for both novae are given in Table IV, in which are included absolute magnitudes computed from the distance indicated by the Cepheids, and also the dates of the photographs next preceding and following those on which the novae were visible.

The observed portions of the two light-curves are shown in Figure 5. The data are insufficient to serve as a reliable criterion of

distance, and would be so even were the frequency distribution of absolute magnitudes attained by galactic novae definitely known. Among those in Messier 31, however, of which some sixty have been observed,¹ there is a sharply defined maximum frequency about

TABLE IV
APPARENT AND ABSOLUTE PHOTOGRAPHIC MAGNITUDES OF
NOVAE IN MESSIER 33

PLATE	DATE	<i>m</i>	<i>M</i> †
Nova No. 1			
D 34*	1919 Aug. 26	.....	.....
P 133	Dec. 14	17.25	-4.85
134	Dec. 18	17.25	4.85
138	Dec. 21	17.8	4.3
139	1920 Jan. 23	18.0	-4.1
D 48*	Aug. 13	.....	.....
Nova No. 2			
H 517*	1925 Jan. 17	.....	.....
577	July 17	17.9	-4.2
D 253	July 20	18.0	4.1
H 584	July 26	18.4	3.7
588	Aug. 15	19.2	2.9
600	Aug. 17	19.25	2.85
D 277	Aug. 21	19.4	2.7
288	Aug. 24	19.5	2.6
H 606	Sept. 12	19.5	2.6
611	Sept. 21	19.7	-2.4
S 507*	Oct. 18	.....	.....

* The photographs next preceding that of the first appearance and next following the last appearance are also listed.

† Absolute magnitudes are derived from the distance indicated by the Cepheids in Messier 33.

apparent magnitude 17.0. The Cepheids in the two spirals have the same apparent magnitudes for corresponding periods, and it is to be expected that the novae, also, will show a similar behavior. The fragmentary observations of the two novae in Messier 33 are consistent with this supposition. They indicate, at least, that the novae are brighter than the Cepheids, a relation that holds in both Messier 31 and in the galactic system. The lack of data on the magnitudes at maxima is a serious handicap, but on the very reasonable

¹ This number includes those discovered up to December, 1925. Nos. 23-60 have been found by the writer; details will be published later.

assumption that the apparent magnitudes attained in Messier 33 are similar to those in Messier 31, the mean absolute magnitude of the novae, at the distance indicated by the Cepheids, would be -5.1 , which is of the same order as that for novae in the galactic system.¹

DIFFUSE NEBULAE IN MESSIER 33

Several patches of diffuse nebulosity with stars involved are found in the outer arms of Messier 33. The brightest of these, cata-

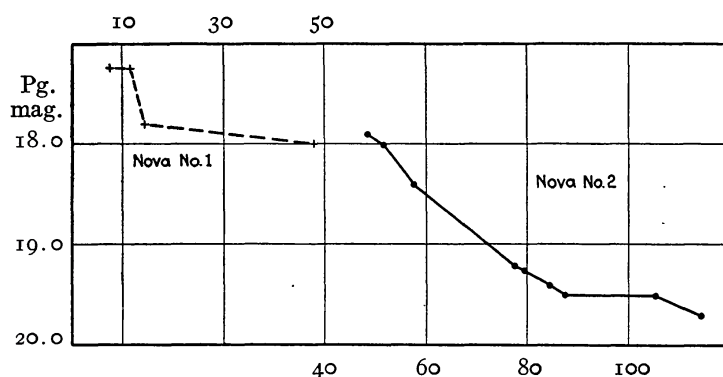


FIG. 5.—Light-curves of two novae in Messier 33. The Julian dates may be found by adding to the abscissae, 2422300 for Nova No. 1, and 2424300 for Nova No. 2.

logued separately as N.G.C. 588, 595, and 604, show emission spectra. Slit spectrograms are available for N.G.C. 604, and show that $H\beta$ is brighter than N_2 , a relation characteristic of diffuse emission nebulosity in the galactic system. Photovisual observations indicate that the brighter stars involved are blue.² Moreover, as will be shown later, the relation between the apparent magnitudes of the involved stars and the angular extent of the nebulosities is the same as that among diffuse galactic nebulae.³

These various features offer strong cumulative evidence that the patches in Messier 33 are indeed diffuse emission nebulae similar in

¹ Lundmark (*Monthly Notices*, 85, 885, 1925) has made use of the reverse procedure. Combining a mean apparent magnitude of 16.34 for twenty-two novae in Messier 31 with a mean absolute magnitude of -6.9 for galactic novae, he derived a distance of 1.4×10^6 light-years for the spiral.

² The photovisual images are as small as, or smaller than, those of any other stars in the nebula of the same order of photographic magnitude.

³ *Mt. Wilson Contr.*, No. 250; *Astrophysical Journal*, 56, 400, 1922.

every respect to those in the galactic and other systems. On this assumption, the brighter stars involved are blue giants¹ of spectral types Bo or Oe5, and can be used to test the order of the distance derived from the Cepheids. The photographic magnitudes of the brighter stars in the three groups² are given in Table V along with the absolute magnitudes computed from the modulus $m - M = 22.1$.

TABLE V*
MAGNITUDES OF STARS INVOLVED IN EMISSION NEBULOSITY
IN MESSIER 33

N.G.C. 588		N.G.C. 595		N.G.C. 604	
<i>m</i>	<i>M</i>	<i>m</i>	<i>M</i>	<i>m</i>	<i>M</i>
16.55	-5.55	16.6	-5.5	15.75	-6.35
16.85	5.25	16.7	5.4	15.8	6.3
17.5	4.6	16.8	5.3	15.9	6.2
17.7	-4.4	16.9	5.2	15.95	6.15
		17.0	5.1	16.0	6.1
		17.2	4.9	16.15	5.95
		17.5	4.6	16.15	5.95
		17.6	4.5	16.3	5.8
		17.6	4.5	16.45	5.65
		17.7	-4.4	16.55	5.55
				16.55	5.55
				16.75	5.35
				16.8	5.3
				16.85	-5.25

* The table contains photographic magnitudes, both apparent and absolute, of the brighter stars involved in three patches of diffuse nebulosity having emission spectra, in the arms of Messier 33. The lists are complete to the faintest star measured in each group.

These absolute magnitudes must be compared with those of the brightest blue giants known in other systems. The most recent estimates of mean absolute photographic magnitude for the blue giants in the galactic system are

$$\text{Bo (sharp lines)} = -3.5 \text{ (Adams)}^3$$

$$\text{O (absorption lines)} = -4.4 \text{ (Plaskett)}^4.$$

¹ *Mt. Wilson Contr.*, No. 241; *Astrophysical Journal*, 56, 162, 1922.

² N.G.C. 592, the only other knot in the arms of Messier 33 which is catalogued separately, is an open group of stars with no trace of diffuse nebulosity. One star, about 15.5 and thus considerably brighter than the others, is red and may be a field star. The three next brightest, ranging from about 16.5 to 16.8, are of early types, blue or white.

³ *Mt. Wilson Contr.*, No. 262; *Astrophysical Journal*, 57, 294, 1923.

⁴ *Publications of the Dominion Astrophysical Observatory*, 2, No. 16, 1924.

The original values, expressed in visual magnitudes, have been corrected for a mean color-index of -0.4 mag. in each case. Plaskett suggests a dispersion of the order of 3 mag. for the O stars, which would make the upper limit about -5.9 , less than a half-magnitude fainter than the brightest star in Table V. When we consider the influence of selection on the stars in the spiral, the probability that some of the brightest images are clusters rather than single stars,¹ and the uncertainty in the dispersion among the galactic stars, the discrepancy becomes unimportant, so that the two sets of absolute magnitudes may be regarded as comparable. The blue giants in Messier 33 therefore confirm the order of the distance derived from the Cepheids.

Dimensions of the nebulosities themselves, measured on long exposures with the 100-inch reflector, together with the linear dimensions in parsecs are as follows:

	Seconds of Arc	Parsecs
N.G.C. 588	30×25	40×30
595	55×32	70×40
604	65×55	80×70

The brighter portion of N.G.C. 604, in which the stars are closely crowded, is about $50''$, or 65 parsecs, in diameter. These dimensions are comparable with those of the largest nebulae in other systems. N.G.C. 2070 in the large Magellanic Cloud is about 80 parsecs;² nebula No. III in N.G.C. 6822 is about 55 parsecs;³ and in the galac-

¹ Groups of stars in Messier 33 one second (1.27 parsecs) or less in diameter would certainly appear as ordinary images of single stars on all but limiting exposures under excellent observing conditions, and hence would be counted as single stars. Groups of such dimensions are fairly numerous in the galactic system, especially among the blue giants involved in nebulosity. Within this limit, for instance, are included such aggregations as five of the six brightest stars in the Pleiades, all the brighter stars in the Orion nebula, the major portions of the clusters in Messier 8 and N.G.C. 2237, and such multiple stars as those in Messier 20 and N.G.C. 281. Phenomena of a similar nature would readily account for several of the excessively bright objects listed as single stars in Messier 33, especially among those in the crowded cluster involved in N.G.C. 604. The excess of very bright stars, all apparently blue, over those to be expected from an analogy with Kapteyn's luminosity function also can be explained, in part at least, along these lines.

² Shapley, *Harvard College Observatory Bulletin*, No. 816.

³ *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, 62, 409, 1926.

tic system the great exterior loop in the constellation of Orion is about 40 parsecs in diameter.¹

Among the diffuse nebulae in the galactic system, the following relation has been established for measures on Seed 30 plates exposed sixty minutes with a reflector of focal ratio 1:5;

$$m + 5 \log a = 11.1$$

$$\text{Mean deviation} = 0.8,$$

where m is the apparent photographic magnitude of the associated star or group of stars and a is the angular distance, in minutes of arc, to which the luminous nebulosity can be traced.² For the nebulae in Messier 33, using integrated magnitudes from Table V and measuring the extent of the nebulosity from the center of gravity of the stars, we find

	m	a	$m + 5 \log a$
N.G.C. 588.....	15.5	0.15	11.4
595.....	14.6	0.33	12.2
604.....	13.2	0.5	11.7
Mean.....	.....	.....	11.8

These results are sufficiently consistent with the foregoing relation to support the assumption that the stars and nebulae in the spiral are similar to those in the galactic system.

LUMINOSITY FUNCTION

In order to determine the upper limit of luminosity for the stars in Messier 33, counts were made over three areas, each about six minutes of arc square, centered on the nucleus and on points six minutes north and eight minutes south, respectively. The sum of the areas is 107 square minutes of arc, which was estimated to contain about one-fifth of the stars in the nebula. The same method

¹ Measured on long exposures with small cameras. The original plates are in the Mount Wilson collection.

² *Mt. Wilson Contr.*, No. 250; *Astrophysical Journal*, 46, 400, 1922.

was employed as in making counts¹ in N.G.C. 6822, the final results being expressed as numbers of stars in successive intervals of apparent photographic magnitude. Field stars were eliminated by means

TABLE VI
LUMINOSITY FUNCTION FOR MESSIER 33

Pg. Mag.	Stars Counted	Normal Number Gal. Lat. 30°5	$\phi(m)^*$ Messier 33	$\phi(M)^\dagger$ Galaxy	M
19.2-19.0.....	990	16	974	972	-3.0
18.9-18.7.....	540	14	526	580	3.3
18.6-18.4.....	340	12	328	341	3.6
18.3-18.1.....	265	10	255	197	3.9
18.0-17.8.....	233	9	224	114	4.2
17.7-17.5.....	110	8	102	64	4.5
17.4-17.2.....	45	7	38	35	4.8
17.1-16.9.....	29	6	23	19	5.1
16.8-16.6.....	25	5	20	10.4	5.4
16.5-16.3.....	17	4.3	12.7	5.5	5.7
16.2-16.0.....	10	3.5	6.5	2.9	6.0
15.9-15.7.....	4	2.9	1.1	1.5	6.3
15.6-15.4.....	6	2.4	3.6	0.8	6.6
15.3-15.1.....	2	2.0	0	0.4	6.9
15.0-14.8.....	3	1.7	1.3	0.2	7.2
14.7-14.5.....	1	1.4	-0.4	0.1	-7.5
14.4-14.2.....	1	1.1	- .1		
14.1-13.9.....	1	.9	0.1		
13.8-13.6.....	2	.7	1.3		
13.5-13.3.....	2	.5	1.5		
13.2-13.0.....	2	.4	1.6		
12.9-12.7.....	0	.3	-0.3		
12.6-12.4.....	0	.2	- .2		
12.3-12.1.....	0	.2	-0.2		

* $\phi(m)$ represents the numbers of stars in successive intervals of apparent photographic magnitude in a portion of Messier 33. The intervals are 0.3 mag., and the area over which the counts were made is estimated to include about one-fifth of the stars in the nebula.

† $\phi(M)$ gives the numbers of stars in successive intervals of absolute visual magnitude in a volume of space 3.6×10^3 cubic parsecs in which stars are distributed according to Kapteyn's luminosity function for the vicinity of the sun. The intervals are the same as for $\phi(m)$, namely, 0.3 mag. The median absolute magnitudes of the intervals in both functions are given in the last column. These are visual for Kapteyn's function and photographic for that of the nebula. The latter absolute magnitudes are based on the distance indicated by the Cepheids.

of the stellar distribution tables recently published by Seares and van Rhijn.²

The data are collected in Table VI and are represented diagrammatically in Figure 6. The results for the brighter stars have little weight because of the small numbers in so restricted an area,

¹ *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, 62, 409, 1926.
² *Proceedings of the National Academy of Sciences*, 11, 358, 1925.

but it is evident¹ that the stars in the nebula begin about 15.5 mag. For the distance derived from the Cepheids, this corresponds to an absolute magnitude of -6.6 .

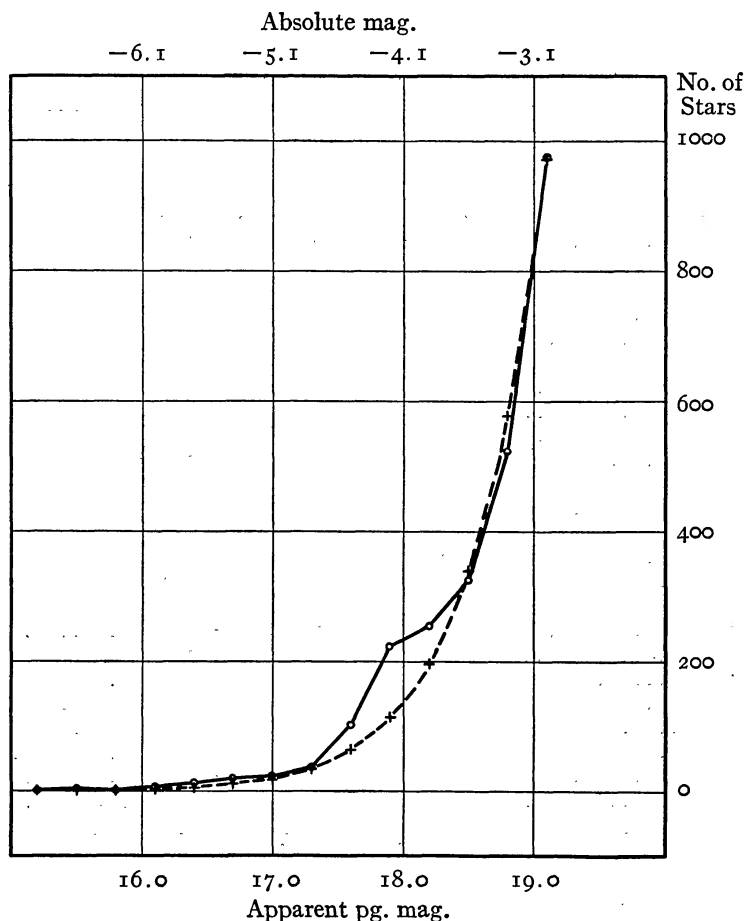


FIG. 6.—Luminosity function for the brighter stars in Messier 33, compared with Kapteyn's luminosity function.

Such a value for the upper limit of stellar luminosity is consistent with the conception of Messier 33 as a great isolated system, and is

¹ There are about six stars between 13.0 and 15.5 in excess of the number to be expected from the distribution tables. These are readily explained as accidental deviations incident upon the restricted areas counted, or resulting from the counting of close groups as single stars; but it is possible that they may indicate the presence of a few extremely luminous stars in the nebula. More extensive counts will be required in order to settle the question.

comparable with the corresponding limits for other systems.¹ The brightest Cepheid, at maximum, is about 2.5 mag. fainter than this limit and, indeed, has been outshone by several of the irregular variables. One of the latter, No. 2, practically reached the limit when, during the recent maximum, it attained an absolute magnitude of -6.55 . Among the stars of constant luminosity, the five brightest of the blue giants in N.G.C. 604 are all within a half-magnitude of the limit.

The nucleus, if it were truly stellar, would be an exception. The apparent magnitude is about 14.1, or -8.0 absolute. Since the spectral type is G5, the absolute visual magnitude, -9.0 , would rival that of S Doradus in the large Magellanic Cloud. The image of the nucleus as shown on short exposures is not sharp, however, and suggests a small, highly concentrated globular nebula rather than a star. This is consistent with the behavior of nuclei in other spirals, among which the only ones that appear to be truly stellar have planetary spectra.²

The plot of the luminosity function, shown in Figure 6, exhibits a striking similarity to the corresponding section of Kapteyn's luminosity curve for stars in the vicinity of the sun, even though the latter is expressed in visual magnitudes, while the former is photographic. Kapteyn's function³ is drawn as a dotted curve. The minor discrepancies between this and the full broken line, representing the data for Messier 33, can be explained partly as due to clusters in the nebula having been counted as single stars of higher luminosity and partly on the assumption, for which observational evidence will be adduced in the following section, that the brightest stars in the nebula are blue, and that the mean color-index increases as the magnitudes grow fainter.

¹ Upper limits of luminosity for other systems, in photographic magnitudes, are as follows: galactic system, -5.5 (brightest reliable measure, β Orionis); large Magellanic Cloud, -8.0 (*Harvard Circular*, No. 271); small Magellanic Cloud, -4 to -7 (*ibid.*, No. 260); N.G.C. 6822, -5.9 (*Mt. Wilson Contr.*, No. 304); and globular clusters, -4.0 (*Proceedings of the National Academy of Sciences*, 6, 293, 1920).

² N.G.C. 4051 and 4151 are examples. The emission spectra are confined to the nuclei and do not represent the light from the body of the nebulae.

³ The data are found in *Mt. Wilson Contr.*, No. 229; *Astrophysical Journal*, 55, 242, 1922.

Since the star counts are estimated to include about one-fifth of all the stars in the nebula down to the limit of the counts, the volume coefficient applied to Kapteyn's function as shown in Figure 6 must be increased fivefold in order to include all the stars in the nebula in the successive intervals of absolute magnitude. The resulting value is 1.8×10^9 cubic parsecs.

The integration of Kapteyn's function over the entire range of magnitudes gives a space density of 8.16 absolute visual magnitudes per cubic parsec.¹ For the volume coefficient corresponding to the counts in Messier 33, the total magnitude would be

$$\begin{aligned} 8.16 - 2.5 \log (1.8 \times 10^9) &= -15.0 \text{ (absolute)} \\ 22.1 - 15.0 &= 7.1 \text{ (apparent)} . \end{aligned}$$

The apparent visual magnitude of the spiral has been measured by Holetschek² and by Kritzing³, and both find the same value, 7.0. This excellent agreement immediately suggests that the similarity between Kapteyn's luminosity function and that for the stars in Messier 33, although actually observed for only the three brightest magnitudes, extends throughout the range of magnitudes significant in determining integrated luminosities. The lower limit of this range is about the fourth absolute magnitude.⁴ Fainter stars contribute less than 0.2 mag. to the total luminosity.

¹ Seares, *Mt. Wilson Contr.*, No. 191; *Astrophysical Journal*, 52, 162, 1920.

² *Annalen der Wiener Sternwarte*, 20, 1907.

³ *Sirius*, 48, III, 1915.

⁴ In a system of stars whose luminosities are distributed according to Kapteyn's function, the luminosity contributed by stars fainter than magnitude M , expressed as a correction which must be applied to the result of integration over the range $-\infty$ to M in order to obtain the total magnitude of the entire system, is as follows:

M	Correction	M	Correction
-3.....	3.52 mag.	+3.....	0.32 mag.
2.....	2.65	4.....	.17
-1.....	1.93	5.....	.08
0.....	1.35	6.....	.036
+1.....	0.90	7.....	.013
+2.....	0.56	+8.....	0.004

For stars fainter than about $M=8$, Seares (*Mt. Wilson Contr.*, No. 273; *Astrophysical Journal*, 59, 310, 1924) has shown that Kapteyn's function does not represent the observed distribution in the vicinity of the sun. Probable differences for this part of

The total luminosity of the spiral is thus fully accounted for on the assumption that it is a system of stars, the ten brightest magnitudes of which are distributed in a manner similar to that observed in the neighborhood of the sun. This assumption is supported by the directly observed similarity in the distribution of the three brightest magnitudes. It is tempting to extrapolate and argue that, since the ten brightest magnitudes appear to be similarly distributed in the two systems, the fainter magnitudes also should conform. There are, however, no observational controls for such a venture. Even the first assumption is by no means established. For instance, it might well be suggested that stars beyond the limits of observation are entirely lacking and that the luminosity which would otherwise be derived from them is supplied by true nebulosity which would ultimately produce the stars. This, of course, would be a forced interpretation, but would conform, in a measure, to current speculations on the evolution of spirals.

The volume of space filled by Messier 33 can be approximately derived by considering it as an ellipsoid of revolution with the minor axis one-tenth the major axis. The true form is probably a lens shape, but the order of the volume can be obtained on the simpler assumption. Since the maximum diameter is about sixty minutes of arc and the linear scale, at the distance indicated by the Cepheids, is $1'' = 1.27$ parsecs, the volume will be of the order of

$$\frac{4}{3}\pi(2.3)^3 \times 10^8 = 5 \times 10^9 \text{ cubic parsecs.}$$

This is about three times the volume coefficient derived by adjusting Kapteyn's luminosity function to fit the star counts in the nebula. It indicates that the average space density for the nebula as a whole is about one-third that in the vicinity of the sun, or about 9.26 absolute visual magnitudes per cubic parsec. The space density in the nuclear region and in the arms would, of course, be much greater.

An approximation for the mass of the spiral can be obtained from the difference in the radial velocities of the nucleus and the patch

the curve have, however, no appreciable effect on the integrated luminosity. When stars no fainter than $M = 15$ are considered, the radically different form of the function which Seares has suggested for the faint stars corresponds to a difference in the integrated luminosities of less than 0.002 mag.

of emission nebulosity, N.G.C. 604, some $700''$ from the nucleus in the general direction of the major axis. The measures are

	Km/sec.
Nucleus ¹	— 70
N.G.C. 604 ²	— 270
Difference	200

The ratio of minor to major axis appears to be about 2:3; the tilt is therefore about 42° , and the differential velocity of 200 km/sec. can be interpreted as the radial component of a linear velocity of rotation about the nucleus of

$$200 \sec 42^\circ = 270 \text{ km/sec.}$$

This corresponds to a period of rotation of the order of twenty million years at a distance of 1.83×10^8 astronomical units from the nucleus. The mass within this orbit, in terms of the sun's mass,³ will be

$$M = \frac{a^3}{p^2} = 1.5 \times 10^{10}.$$

The additional mass for the outer regions is probably less than the errors involved in the determination.

The mean density on these assumptions is approximately $3 \odot$ per cubic parsec, or about twenty times that in the vicinity of the sun. This suggests the possibility of large quantities of non-luminous material in the central region of the nebula, but until more accurate data are available no emphasis can be placed on the numerical values. The method employed in calculating the mass is very sensitive to errors in the radial velocities—the mass varying directly with the square of the linear velocity of rotation. The radial velocity

¹ Pease, *Publications of the Astronomical Society of the Pacific*, 28, 33, 1916.

² Mean of two determinations, by Pease and by Slipher. One, -278 km/sec., is given in the paper just cited; the other, -260 km/sec., is quoted by Strömberg, *Mt. Wilson Contr.*, No. 292; *Astrophysical Journal*, 61, 353, 1925.

³ When the distance from the nucleus, a , is expressed in parsecs, and the linear velocity of rotation, v , in km/sec., then $M \odot = 235 av^2$. The mass varies directly as the distance from the observer and as the square of the linear velocity. Due to the uncertainty in the latter quantity and the possibility that something more is observed than simple rotation around the nucleus, the computed mass may be in error by as much as a factor of 10.

of N.G.C. 604 was derived from narrow emission lines and should be fairly reliable. That for the nucleus,[†] however, depends upon three absorption lines measured on a single plate of very small dispersion, -0.9 mm from $H\gamma$ to K. The result represents only the order of the velocity, and the probable error is a large fraction of the difference between the velocities of the nucleus and N.G.C. 604. Moreover, it is by no means certain that even an accurate differential velocity would represent merely the line-of-sight component of rotation about the nucleus.

COLORS OF STARS IN MESSIER 33

Some information concerning the colors of the brighter stars in Messier 33 has been derived from isochromatic plates exposed through a visual color-filter. One of these, an exposure of three hours with the 100-inch reflector, shows stars which are estimated to be fainter than the eighteenth photovisual magnitude, including many of the Cepheids. Comparisons on the blink-comparator with appropriate direct exposures suggest that most of the brighter stars in the nebula are white or blue. The conclusion is based on the differences in the photovisual images of stars of approximately equal photographic magnitudes. For example, in the central region of the nebula, twenty-eight stars have photographic magnitudes between 16.5 and 17.5. On the plates examined, twenty-five of these show photovisual images that are comparable with the photographic images, while the remaining three stars have much larger photovisual images. From the well-determined photographic scale, which in this region appears to be not very different from the photovisual, the color-indices of the three outstanding stars were estimated to be about a magnitude greater than those of the other twenty-five. Moreover, two faint stars in the immediate neighborhood, having conspicuous proper motions,[†] are obviously much redder than the

[†] Six stars within $11'$ of the nucleus show conspicuous proper motions on the blink-comparator on plates of fifteen years' interval made with the 60-inch reflector. The photographic magnitudes of two have been measured as 17.3 and 18.25, the proper motions being of the order of $13''$ and $10''$ per century, both toward the south-following quadrant. The brighter of these is No. 367 in van Maanen's measures of Messier 33 for rotation (*Mt. Wilson Contr.*, No. 260; *Astrophysical Journal*, 57, 264, 1923). The magnitudes of the other four are estimated to be 14.2, 15.8, 16.4, and 17.8, with proper motions between $5''$ and $10''$ per century.

three just mentioned. The most reasonable interpretation of these observations is that the proper-motion stars are red dwarfs, that the three exceptional stars are yellow, and that the twenty-five other stars are white or blue. Moreover, since faint stars of early spectral types are extremely rare in this galactic latitude, it is probable that such stars belong to the nebula.

Although it has not yet been possible to calibrate the photovisual plates by direct comparisons with the polar sequence, an approximate reduction curve, connecting photovisual magnitudes with scale measures, has been constructed by correcting the photographic magnitudes for color-indices corresponding to known or probable spectral types. For the bright end of the curve, the nucleus itself and a star $1'.8$ north following were used. Photovisual magnitudes of 13.1 and 12.3 , respectively, were derived from the observed spectral types G5 and F8. Seven Cepheids gave a point for the faint end at about 18.3 . A mean spectral type of G0 was assumed, in accordance with data from spectrograms of sixteen typical galactic Cepheids having periods ranging from ten to twenty-seven days with a mean of about seventeen days. The mean period of the seven Cepheids in Messier 33 is twenty-three days, but this larger value is balanced, to a certain extent, by the fact that most of the Cepheids were observed near maximum. The midpoint of the curve, the most important for the present purpose, depends upon a single star. This has a proper motion of the order of $10''$ per century and a photographic magnitude of 18.25 . It is obviously very red, and has been assumed to be a dwarf M with a color-index of $+1.8$. It is improbable that the color-index is greater than this amount, and hence the photovisual luminosities derived from this region of the reduction curve, together with the resulting color-indices, can be considered as upper limits.

By means of the reduction curve, color-indices have been determined for one hundred and ten stars, all but one[†] of which are within $2'$ of the nucleus. The results are exhibited in Figure 7, where color-indices are plotted against photographic magnitudes. The data are practically complete to the eighteenth magnitude. The dotted

[†] The exception is the faint proper motion star used in determining the reduction curve. It is about $2\frac{1}{2}'$ south preceding the nucleus, and is identified on Plate XV.

curve represents the minimum values of color-indices for stars of corresponding magnitudes in the polar sequence.¹ Since the galactic latitude of the pole is only 2° less than that of the spiral, it is reasonable to assume that field stars will be confined to the region above the dotted line in Figure 7. This region includes nine stars brighter than the eighteenth magnitude, one of which, the irregular variable No. 13, 17.85 mag., +0.8 color-index, certainly belongs to the nebula. The number of field stars to be expected on the basis of the mean distribution tables of Seares and van Rhijn² is seven.

The restricted area and the small number of stars do not permit definite conclusions to be drawn from this close agreement. The in-

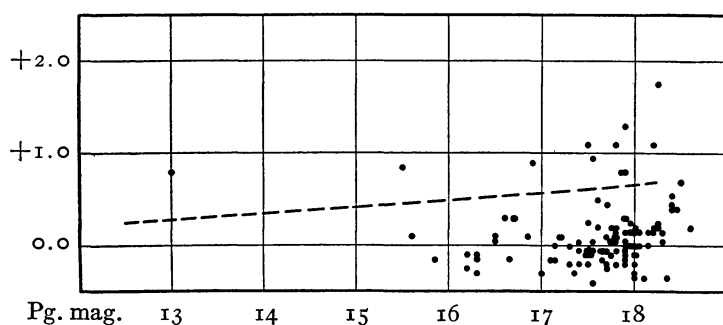


FIG. 7.—Color-indices (ordinates) of stars in the central region of Messier 33. The dotted line indicates the probable minimum color-index of stars outside the nebula.

dications are, however, that all the stars brighter than the eighteenth magnitude, having color-indices less than, say 0.5 mag., belong to the nebula. Moreover, no star, excepting the variable, brighter than this limit, with a color-index greater than 0.5 mag., can with certainty be assigned to the central region of the nebula. The mean color-index of the stars assigned to the nebula is slightly negative, but since this probably represents an upper limit, the stars may actually be blue giants. It is possible that the brightest red stars in the spiral are all variables.

These results, although approximate and possibly subject to serious errors and limitations, are sufficient to differentiate the brighter stars in the central region of Messier 33 from those in the globular

¹ Seares, *Mt. Wilson Contr.*, No. 81; *Astrophysical Journal*, **39**, 361, 1914.

² *Mt. Wilson Contr.*, No. 301; *Astrophysical Journal*, **62**, 320, 1925.

clusters and in the irregular nebulae such as N.G.C. 6822, and probably from those in the Magellanic Clouds, all of which appear to be red. This contrast, which may be important, invites speculation on the larger problems of cosmic evolution.

In this connection, attention may be called to Seares's results¹ on the distribution of colors in Messier 51, 94, and 99. These are all well-developed spirals in which the arms are partially resolved into stars. The central regions of unresolved nebulosity (and also the amorphous mass at the end of an arm of Messier 51) were found to be much redder than the outer arms. Messier 33 exhibits the same phenomenon. The unresolved nebulosity around the nucleus is much stronger on photovisual than on unfiltered plates, as compared with star images both in the central region and in the outer arms. This agrees with the fact that the nucleus and the surrounding remnant of apparently unresolved nebulosity give a spectrum of the solar type, while the brighter stars have no appreciable color-index. The contrast in color between stars and nebulosity is in harmony with Seares's results for the other spirals, which in turn suggest that there is no conspicuous difference in color between the brighter stars in the central region and those in the outer arms of spirals. An inspection of the images in the arms of Messier 33 appears to support this latter suggestion, but, since the photovisual exposures were centered on the nucleus, the aberrations of the images in the outer regions prevented any reliable quantitative conclusions.

The observational data are insufficient to determine whether the unresolved central nebulosity with its solar type spectrum and considerable color-index is actually amorphous nebulosity or a cluster of faint stars. If the latter is the case, the color-indices must be assumed to increase as the luminosities of the stars decrease, after the manner of stars in the galactic system. It is well known, however, that spirals can be arranged in a series in which the arms build up at the expense of the unresolved nuclear region, unwinding and breaking up into condensations as they grow. The nuclear region of such late-type spirals as Messier 33 can be thus considered as the remnant of much larger central masses, such, for instance, as seen in Messier 31 or N.G.C. 4594. The nuclear regions of these in turn are

¹ *Proceedings of the National Academy of Sciences*, 2, 553, 1916.

almost indistinguishable from the elliptical nebulae (possibly pre-spiral forms) such as N.G.C. 3115 and Messier 32. In all these cases, the apparently unresolved nebulosity is associated with approximately solar-type spectra and appropriate color-indices. Even in Messier 31, however, which is highly resolved in the outer arms, the nuclear region shows not the slightest trace of resolution with the 100-inch reflector working under exceptionally fine observing conditions.

CONCLUSION

The present investigations indicate that Messier 33 is an extremely distant system of stars and nebulae, similar in many respects to the Magellanic Clouds. It differs, however, in two important characteristics: The great majority at least of the brightest stars are of early spectral types, and there is a symmetrical arrangement of material with respect to a dominating nucleus. Detailed study of the stars within the limits of observation—the three or four brightest magnitudes—indicates that they are normal giants such as are known in other systems. The application of all available criteria leads to this one interpretation of the data.

The distance, derived from the period-luminosity relation applied to thirty-five apparently normal Cepheids, is about 8.1 times that of the small Magellanic Cloud, or, using Shapley's distance for the latter, about 263,000 parsecs. The order of this distance is confirmed by evidence from independent sources—novae, emission nebulosity with blue stars involved, and the luminosity function. The distance being known, the apparent dimensions of the spiral can be converted into absolute dimensions, assuming the form, from analogy with other spirals, to be lenticular, with a minor axis about one-tenth of the major axis. These dimensions are listed in Table VII with those of the two Magellanic Clouds for comparison.¹

It is evident that Messier 33 must be considered as comparable in size with the Clouds rather than with the galactic system. It is not, however, of an entirely different order from the latter, and, in this connection, it may be mentioned that in size the other great spiral, Messier 31, occupies an intermediate position. Including the Magel-

¹ *Mt. Wilson Contr.*, No. 304; *Astrophysical Journal*, 62, 409, 1926.

lanic Clouds, which are most readily interpreted as irregular non-galactic nebulae, five systems are now known which are believed to be distinct from the galactic system. The diameters range from

TABLE VII
ABSOLUTE DIMENSIONS OF MESSIER 33 AND THE MAGELLANIC CLOUDS

	MESSIER 33	MAGELLANIC CLOUDS	
		Large	Small
Distance*	263,000	34,500	31,600
Total magnitude	-15.1 pv.†	-16.5 pg.	-15.5 pg.
Diameter	4600	4300	2000
Volume	5×10^9	4.2×10^{10}	4.2×10^9
Density	9.3	10.0	8.5

* Distances and diameters are expressed in parsecs, volumes in cubic parsecs, and densities in absolute magnitudes per cubic parsec.

† The total magnitude of Messier 33 is expressed in visual absolute magnitudes, but, since the brighter stars in the spiral are white or blue, it is thought that the total photographic magnitude will not be very different.

1250 parsecs for N.G.C. 6822 to about 14,000 parsecs for Messier 31. The ratio is about 1 to 11. The multiplication of the dimensions of Messier 31 in the same ratio would include the galactic system, even as outlined by the globular clusters.

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