HARVARD COLLEGE OBSERVATORY

CIRCULAR 271

THE MAGELLANIC CLOUDS, IV. THE ABSOLUTE MAGNITUDES OF NEBULAE, CLUSTERS, AND PECULIAR STARS IN THE LARGE CLOUD

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The completion of magnitude sequences in the Large Magellanic Cloud and the derivation of its distance, reported in Harvard Circular 268, permit us to determine, with higher accuracy than heretofore possible, the intrinsic luminosities for several important classes of celestial objects. The integrated absolute visual magnitudes of globular clusters were determined provisionally a few years ago at Mount Wilson; and for Class O stars preliminary evidence concerning absolute brightness has been available from proper motions and trigonometric parallaxes. But the integrated absolute magnitudes of diffuse nebulae have not been attempted previously, nor have measures been made of the luminosities of the stars of the P Cygni type.

The accidental errors may be large for the integrated magnitudes of nebulae given below. Some of the nebulous objects are inherently difficult to measure, and many are at inconvenient distances from available magnitude standards. In general, however, the deduced absolute luminosities are much more definite than those ordinarily obtainable for nebulae and special types of stars in the galactic system. The results in the following sections are based on the parallax, $\pi = 0''.000029$. If the distance is decreased or increased by twenty-five per cent, the absolute magnitude should be made fainter or brighter, respectively, by 0.5 to 0.6. Because of the uncertainties yet remaining in the systematic motions of the galactic Cepheids (H.C. 255, p. 3), upon which the estimates of the greatest sidereal distances now largely rest, we must entertain the possibility of considerable future modifications of the absolute magnitudes of stars in the clusters, star clouds, and spirals. That the modifications may be in the direction of somewhat larger parallaxes for galactic Cepheids, and therefore for the Large Magellanic Cloud, is suggested by the peculiarly bright absolute magnitudes of the special types of stars and nebulae discussed in the following sections. But even the greatest allowable correction to the absolute magnitudes of Cepheids still leaves the luminosities in the Magellanic Clouds of the same remarkably high order as here derived.

PRINTED FROM FUNDS RESULTING FROM THE WILL OF JOSIAH QUINCY, JR., 1744–1775

1. P Cygni Type. In Harvard Bulletin 801 Miss Cannon listed the stars in the Large Magellanic Cloud that are known from their spectra to belong to the P Cygni type. The brightest is the variable star S Doradus. The apparent photographic magnitudes, obtained by Miss Cannon with reference to provisional magnitude sequences, have now been reduced to the revised scale and combined with two independent measures by Miss Wilson. Subtracting 17.7 from the mean apparent magnitude (cf. H.C. 268, p. 2), we obtain the following absolute magnitudes for the nine stars:

1	−5.2	4	−8.9	7	−6.5
2	−6.3	5	−4.9	8	−6.1
3	−6.3	6	(−5.2)	9	−5.4

The numbers are those assigned in Bulletin 801. No. 6 was measured by Miss Cannon alone.

The material above gives, unfortunately, very little information concerning the dispersion in luminosity of P Cygni stars (except the upper limit, perhaps), because the spectra of stars fainter than apparent magnitude 12.8 are not clearly enough photographed to make sure of the absence of bright lines. As the data stand, the mean absolute magnitude is -6.02 ± 0.23; or, omitting No. 4, it is -5.74 ± 0.15.

It is very probable that S Doradus (No. 4 in the above list) is a member of the Large Cloud. Nearly all other P Cygni stars now on record are in the Milky Way (cf. H.A., **76**, 31, 1916; H.B. 801, 1924), while the Large Cloud lies in galactic latitudes −30° to −35°. Moreover, the star is closely associated with diffuse nebulosity and lies in an open cluster (H.B. 814). It is brighter than any of the Cepheid variables found by Miss Leavitt, but probably is exceeded in luminosity by several other stars in the Cloud (see Section 4 below).

2. The Class O Stars. Thirty-two stars of Class O with bright bands have been found in the Large Magellanic Cloud. The positions are given by Miss Cannon in Harvard Bulletin 801. The absolute magnitudes, derived in the same way as for the P Cygni stars, are given below.

No.	Ab. Mag.	No.	Ab. Mag.	No.	Ab. Mag.	No.	Ab. Mag.
1	−4.9	9	−4.5	17	−5.8	25	−6.1
2	(−4.3)	10	−4.1	18	−4.5	26	−4.4
3	−7.9	11	−5.2	19	−5.7	27	−6.7
4	(−3.8)	12	−3.9	20	−4.5	28	−6.0
5	−5.0	13	−5.2:	21	−3.9	29	−5.3
6	−4.3	14	−5.6	22	−6.3	30	−4.7
7	−5.9	15	−5.2	23	−4.3	31	−4.4
8	([−2.7)	16	−6.5	24	−3.2	32	−5.6

Grouped in half-magnitude intervals, the distribution is as follows:

Magnitude	Number	Magnitude	Number
−7.9 to −7.5	1	−5.4 to −5.0	5
−7.4 −7.0	0	−4.9 −4.5	5
−6.9 −6.5	2	−4.4 −4.0	6
−6.4 −6.0	3	−3.9 −3.5	3
−5.9 −5.5	5	−3.4 −3.0	1

This material, when plotted, shows that a normal error curve, with maximum at about −5.0, can be fitted with sufficient accuracy to the distribution curve for the brighter half of the O stars. The number and distribution of fainter O stars is, of course, unknown because of the magnitude restrictions on spectral classification.

The mean absolute magnitude for the Class O stars listed above (excepting No. 8) is -5.09 ± 0.13; and the extreme absolute magnitudes are −7.9 and −3.2. These values, as might be expected on the basis of selection, are somewhat brighter than the corresponding values found for galactic Class O stars by R. E. Wilson (A.J., **35**, 183, 1924) and J. S. Plaskett (Publ. Dom. Ast. Obs., **2**, 327, 1924).

3. The Brightest Variable Stars. Eight hundred and eight variable stars were found in the Large Magellanic Cloud by Miss Leavitt and published in Harvard Annals **60**, No. 4. Her list by no means contains all of the bright variable stars of the Cloud. A few additional variables have been noted by Shapley and Yamamoto, but not published; and Miss Leavitt's records show a large number for which the variability was not sufficiently well established for inclusion in the published list.

The periods of only a small number have been determined in the Large Cloud, but it is assumed that they are almost exclusively of the Cepheid type. Two or three of the fainter variables may be eclipsing binaries. Irregularity in light variation appears to affect the brightest of the variables, but this may be attributed in part to the difficulty of measurement and the insufficiency of suitable photographs. It is well known, however, that for Cepheid-like variables of high luminosity there is a tendency toward irregularity.

Some of the brightest of Miss Leavitt's variables are near enough the existing magnitude sequences for a preliminary estimate of absolute brightness. In the following list the first column contains the Harvard number of the variable, the second, third, and fourth contain the absolute magnitude obtained from measures by Miss Wilson on plates made with the Bruce and Bache telescopes, the magnitude range noted by Miss Leavitt, and the spectral class where known (H.B. 754):

Harvard Variable	Absolute Magnitude	Observed Range	Spectral Class
884	−5.8	4.1	Mc
900	−3.6	1.4	M
1003	−4.2	1.1	..
2241	−5.3	1.0	..
2251	−6.5	2.4	..
2435	−6.6	0.9	K5
2447	−5.1	0.8	K5
2543	−6.1:	0.7	..
2622	−4.9	0.8	K5
2804	−5.8:	2.2	..
2822	−7.0	0.8	Mc
2827	−5.9:	0.4	..

The recorded ranges were deduced from only a few plates and are probably underestimates in several instances. The absolute magnitudes for Nos. 884, 2251, and 2804 refer to points at or near maximum light. The spectrum and large range of No. 884 indicates that it probably is not a member of the Cloud, but is superposed from the foreground. This may also be the case, of course, for one or two others.[1]

Although both the absolute photographic magnitudes and the spectra of the individual variables listed above are subject to uncertainty, the evidence appears conclusive that all the most luminous stars are of very late spectral class (excluding S Doradus, mentioned in Section 1) and are brighter absolutely than −6 at maximum. The visual absolute brightness, for the variables of known spectra, averages about 1.5 magnitudes brighter than the photographic values tabulated. Their linear dimensions must therefore be far in excess of those of the super-giant red stars near the Sun, such as Alpha Herculis, Betelgeuse, and Antares. If they are normal Cepheids, the periods probably exceed fifty days.

4. The Brightest Invariable Stars. The average apparent magnitude of S Doradus is photographically 8.8. If a member of the Cloud, its absolute photographic magnitude is −8.9 and its light emission is more than half a million times that of the Sun. An inspection of photographs of the Cloud and its vicinity shows that a number of other members of the system are equally luminous, though it is impossible to say that any given star is a member of the Cloud rather than of the foreground. A preliminary survey shows that there are at least twenty stars with absolute photographic magnitudes brighter than −8, and as many more between −8 and −7. The frequency, distribution, and spectra of these remarkable objects will be reported in a later communication.

[1] *Note added to proof:* Hertzsprung has just shown that H.V. 2435 is a short period variable, probably a dwarf not connected with the Large Cloud (B.A.N., 2, 218, 1925).

5. Globular Clusters. The positions and angular diameters are given in Harvard Bulletin 775 for seven clusters in the Large Magellanic Cloud. Their integrated apparent magnitudes measured on a special small scale photograph, Bo 907, are as follows:

N. G. C.	Photographic Magnitude
1651	12.0
1783	8.0
1806	10.4
1831	8.3
1846	8.9
1866	7.2
1978	10.3

The first and sixth objects in the list are not certainly globular clusters; the dispersion on the best Harvard photographs with the Bruce telescope is hardly sufficient to decide that the first is not a nebula and that the sixth is not a nebulous open cluster. For the other five, which appear to be typical globular clusters, the mean apparent photographic magnitude is 9.2, corresponding to the absolute photographic magnitude −8.5.

The mean absolute *visual* magnitude for globular clusters outside the Magellanic Clouds was determined some years ago to be -8.8 ± 0.5. (Mt. W. Contr. 190, 6, 1920.) The integrated spectrum of globular clusters is close to Class G, perhaps a little earlier, and therefore five or six tenths of a magnitude should be subtracted to reduce from photographic to visual brightness; that is, $-8.5 - 0.6 = -9.1$ gives the absolute visual magnitude of clusters in the Cloud. The agreement between these two independent determinations of the average absolute magnitude of globular clusters is all that can be expected. It indicates that the clusters in the Magellanic Cloud are probably of the dimensions usual for globular clusters. We had previously found that the angular diameters of these clusters, assuming them to be comparable with those outside the Cloud, led to a parallax of the Large Magellanic Cloud in exact agreement with the value deduced subsequently and independently from the Cepheid variables (Cf. H.B. 775 and H.C. 268).

The percentage dispersion in the absolute magnitudes of the globular clusters is noted as much greater than the percentage dispersion in the measures of their angular diameters.

6. Open Clusters — Absolute Luminosity and Linear Dimensions. Of the scores of open clusters in the Large Magellanic Cloud, six of the brightest and most compact have been measured for the present survey. N.G.C. 1856 may be

a globular cluster. The catalogue numbers, positions, integrated apparent magnitudes, and diameters in parsecs are given in the following tabulation:

N. G. C.	R. A. 1900 h m s	Dec. 1900 ° ′	Apparent Magnitude	Linear Diameter
1854 (1855)	5 9 49	−68 58.3	7.1	8.7
1856	5 10 05	−69 15.1	7.0	15.7
1986	5 28 35	−70 3.2	8.0	11.3
2058	5 38 00	−70 13.3	7.7	10.0
2065	5 38 45	−70 17.2	7.8	10.0
2100	5 42 52	−69 15.4	6.3	19.0

The apparent magnitudes are means of four measures on plates B 20846 and Bo 907. The angular scales of these two plates differ in the ratio of five to one, but the integrated magnitudes are in very satisfactory agreement. The mean apparent magnitude for the six clusters is 7.3, with an average deviation of 0.5. The corresponding absolute magnitude is −10.4.

It is of some significance that these open clusters are conspicuously brighter than the globular clusters in Section 5. If they are typical systems, this result would tend to throw doubt on the hypothesis that the open clusters of the Milky Way have been derived from globular systems.

The average diameter of the open clusters, each measured in three position angles, is about thirteen parsecs, which is of the same order as the measured dimensions of the globular clusters in the Cloud. For both types of clusters the angular measures of course fail to show the wide dispersion of fainter stars.

7. Diffuse Nebulae and Nebulous Groups. Among the scores of diffuse nebulae in the Large Magellanic Cloud there are about twenty, the spectra of which contain bright lines, and probably a large number of the nebulae fainter than the limit of the present spectrum analysis are also gaseous. Several of these nebulae, as Hinks noted in Monthly Notices, **71**, 694, 1911, have been assigned numbers in the Index Catalogue as well as in the N.G.C. But Hinks erroneously identifies I.C. 2115 with N.G.C. 1763.

The radial velocities in kilometers a second are those determined by the Lick Observatory. The integrated absolute magnitudes are very high, but it should be specially noted that in many cases involved stars that may not be physically connected with the nebulosity are included in the integration. Such cases are specially noted in the remarks. The descriptions include estimates of linear dimensions, expressed in parsecs.

GASEOUS NEBULAE

N. G. C.	R. A. 1900 h m	Dec. 1900 ° ′	Vel.	Integrated Abs. Mag.	Description
1698	4 49.9	−69 21	+293	− 6.1	Stellar, planetary
1714	4 52.0	−67 6	+309	− 7.9	Nebulous mass, planetary
1722	4 52.6	−69 33	+265	− 6.6	Nebulous mass
1743	4 54.6	−69 21	+260	− 7.5	Nebulous mass with central star
1748	4 55.1	−69 21	+256	− 6.7	Preceeding of two stars, second star not nebulous
1763	4 56.6	−66 34	+296	− 7.7	Nebulous group, 30×20, 80°
2115	4 56.8	−66 32	+292	− 6.4	Stellar, planetary
1769	4 57.3	−66 33	..	−11.3	Diffuse, 20×15, 135°, around three stars
1770	4 57.5	−68 35	..	− 6.6	Faint, stellar, planetary
1791	5 0.3	−70 20	..	− 6.7	Nebulous wisp about star
1935	5 22.2	−68 03	+299	− 8.7	Diam. 6.5, nebulous group of stars
1936	5 22.5	−68 4	+292	− 8.7	Min. diam. 5, not quite round, two nebulous condensations
1949	5 25.6	−68 33	+260	− 6.5	Diam. 2, round, strong central condensation, planetary
2029	5 35.6	−67 39	+297	−11.1	Large, irregular nebula, min. diam. 10, limits vague
2032	5 35.6	−67 38	..	−10.3	Similar to 2029
2070	5 39.4	−69 9	+275	−14.0	30 Doradus, see Section 8 below
2075	5 39.6	−70 44	..	− 7.8	Nebulous group, irregular, diam. 5 to 10
2077	5 40.5	−69 42	+259	−11.1	Forms with N.G.C. 2080 a nebulous group, diam. approx. 6
2080	5 40.6	−69 42	..		
2079	5 40.6	−69 49	+255	− 7.9	Diam. 5, well defined, small, round, planetary
2085	5 41.0	−69 43	+264	− 6.7	Diam. 2, stellar, planetary
2086	5 41.4	−69 43	+271	− 6.9	Diam. 5, planetary, nucleus on following edge

REMARKS

1722. Two stars, 11.2, 11.6, included in integrated magnitude are superposed on B plates, but are not part of the nebula.
1743. Central star too involved in nebulosity to measure separately.
1748. Impossible to separate these two stars for estimate of magnitude.
1763. About fifteen stars, 11.5 and fainter, included in integrated magnitude.
1769. Two stars, [12.7, and one 10.8, included in integrated magnitude.
1770. The number in N.G.C. refers to this nebula and the large open cluster of which it is a part.
1791. Star too involved in nebulosity to measure.
1935. Stars 11.6, 11.8; others too involved to measure separately.
2029. Stars 13.4, 14.0 included in integrated magnitude.
2032. Stars 12.0, 13.4, and 14.0 included in integrated magnitude, but brightest may not be part of the nebula. N.G.C. 2029 and 2032 are actually parts of a single large nebula, twenty parsecs in diameter. The parts are separated by an irregular dark nebula with diameter approximately five parsecs.
2075. Star 13.0, and four fainter stars, included in the integrated magnitude.
2077 and 2080. Approximately same brightness; too close to measure separately; two nebulous condensations may be involved stars.
2079. Sharp central condensation.

The above group is representative only of the brightest gaseous nebulae in the Cloud, some of which are abnormally luminous. In fact, all of these objects, with possibly two exceptions, are brighter than the Orion Nebula, for which the

absolute magnitude is approximately −3. After allowing for the light of involved stars and excluding 30 Doradus, the average absolute magnitude of the nebulae listed above is roughly estimated as −5. The apparent areas vary from nearly stellar points to irregular patches of two or three square minutes of arc.

8. 30 Doradus. The nebula N.G.C. 2070, 30 Doradus, is by far the largest and brightest gaseous nebula now known, and one of the most remarkable in structure. On most of the Harvard plates it is too bright and large for accurate measures of the integrated magnitude.

Estimates of the magnitude of the nuclear region, which shows suitably on plates made with a 1-inch Cooke telescope, range from 4.9 to 7.0. Frequently plates of the same quality and exposure time give a difference in brightness of a magnitude or more. Possibly the nebula varies, but experience with photographic photometry in nebulous regions inspires caution in suggesting that the variability of 30 Doradus is certain.

The integrated apparent magnitude, on photographs that show the nebulous extensions well, is not fainter than 4.0, corresponding to an integrated absolute magnitude of approximately −14. The nebula is therefore some ten or eleven magnitudes brighter than the Orion Nebula.

The diameter of the brightest part of 30 Doradus is twenty parsecs. Extending out from this large nucleus are fainter wisps and loops of nebulosity, making the total diameter of the object about 40 parsecs in all position angles. Many faint stars are scattered through the nebulosity and the wisps are condensed in several places around stars.

If 30 Doradus were in the position of the Orion Nebula, it would extend over most of the constellation. It would have an integrated apparent magnitude of −7.5, and consequently would cast strong shadows on the surface of the Earth.

MARCH 15, 1925