

RED SUPER-SUPERGIANTS IN THE LARGE MAGELLANIC CLOUD

M. W. Feast and A. D. Thackeray

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Summary

Five members of the Large Cloud have been discovered with absolute visual magnitudes about -9.0 , spectral types from F8 to G5: and with colours between $+0.37$ and $+1.45$. Four of these stars are among the 30 brightest known members of the Cloud. The census of the brightest blue stars must be regarded as complete, but owing to the difficulty of distinction of foreground stars more red super-supergiants probably remain to be discovered.

The Magellanic Clouds offer a unique opportunity to study individually the brightest stars in an external system. The high degree of resolution guarantees in most cases that the slit of a spectrograph will isolate the light from single stars. In apparent magnitude there is a gain of 5 magnitudes over corresponding objects in M31. Consequently the number of objects which can be reached spectroscopically with existing equipment is very large. If one adopts 13.6 mag. as a practical working limit for spectra at 86 A/mm with the Radcliffe reflector, Shapley's luminosity function for the Large Cloud suggests that there are between 2000 and 3000 members within range of this equipment.

The Henry Draper Extension covering the region of the Large Cloud contains some 200 objects classified as O, B or Con, mostly brighter than 12.0 mag. From a sample of 25 such objects observed spectroscopically with the Radcliffe reflector (1) we can be sure that the great majority, if not all, are members of the Cloud. The HDE "B" or "Con" stars prove to be mostly late B or early A types with very narrow hydrogen lines. The presence of a true absorption O star still remains to be established. It is probable that the HDE "O" objects (some of which are as faint as 15 mag.) are mostly Wolf-Rayet type.

The HDE Catalogue also contains over 3000 stars classified as A or later. Most of these are foreground stars. But it is of the utmost importance to disentangle the minority of true members of type later than A. One such star was included in the previous tabulation (1), and as a result of further investigations the following bright stars have been found to be Cloud members from velocity shifts and supergiant characteristics.

Red Super-supergiants in the Large Cloud

Star	HDE		MK Type	SP _g	SP _v	SCI	M _v	Remarks
	Sp	m						
268757	M0	10.5	G5: Ia	11.8	10.3	+1.45	-8.9	near NGC 1743
269723	K5	11.4	G0 Ia	10.8	9.9	+0.92	-9.3	near NGC 2014
269953	K0	12.0	F8 Ia	10.7	10.0	+0.74	-9.2	near NGC 2085
271182	K0	9.7	F8 Ia	10.2	9.8	+0.37	-9.4	
30 Dor	F8-Go Ia	

No. 50

The magnitudes and colours in the fifth to seventh columns have been determined photoelectrically by Dr A. J. Wesselink on the Cape system using the Radcliffe 74-inch reflector and Cassegrain photometer. These results are to be regarded as provisional and in any case, in view of the large discrepancies from the HDE (photographic) magnitudes given in the third column, it appears likely that these objects of exceptionally high luminosity are variable in light.

The absolute visual magnitudes listed in the eighth column are based on an assumed distance modulus of 19.2 for the Large Cloud (2). It seems to be undesirable to apply the term "supergiant" to objects covering a range of some 7 magnitudes, and we would suggest the term "super-supergiant" to be appropriate to objects with M_V brighter than -7.0 .

With the exception of 271 182, which is in a loose grouping of stars containing some known Cloud members, all the above stars are near nebulae and clusters. 30 Dor No. 50 is not in the HDE and its precise position will be defined in a later paper devoted to the 30 Dor complex. Its magnitude has not been measured but it is estimated as between $10^{m.5}$ and $11^{m.0}$ pg so that its absolute magnitude is of the same order as that of the other stars.

Spectral classification.—The MK types in the fourth column have been obtained from Radcliffe spectra with dispersions of 86 and 49 Å/mm at H γ . The MK standards δ C Ma (F8 Ia) and HR 2974 (G0 Ia) match well the last four stars, except that in 30 Dor No. 50 the H lines cannot be used owing to the superposition of strong nebular H emission; also in this star all lines appear to be somewhat weakened, perhaps due to their being partly filled in by a nebular continuum.

Judging by the strength of the G band and the weakness of H, 268757 is clearly somewhat later in type than HR 2974 (G0 Ia), but certainly not as late as M (HDE). It is understood that the star has been classified as K from an ADH objective prism spectrum (3). Accurate classification is difficult on account of the fact that there are no MK Ia standards between G0 and M1. No good match is found with G0 Ib, G5 Ib, K2 Ib or K3 Iab. A fairly good match is provided by α Aqr (G2 Ib), but Sr II 4215 and some other lines are stronger in 268757. The classification as G5: Ia is subject to considerable doubt.

Radcliffe spectra of long period cepheids in the Clouds taken at 86 Å/mm have been classified at F7 Ia to G2 I (4). At this dispersion, the super-supergiants reported in this paper show no certain differences spectroscopically from the cepheids which are about 2 magnitudes fainter. We must conclude that the MK criteria are insensitive to luminosity among the very brightest stars.

Colours.—Detailed discussion of the colours and magnitudes of these stars is postponed to a later communication when it may be hoped that further instances of such red super-supergiants will have been discovered. But it will be noticed that the colours, for the first three stars at least, do appear to be redder than for normal F to G giants, although they accord well with the colours of the cepheids (4). This fact probably accounts for the HDE classifications as K or M.

A comparison of the colours and spectral types suggests a rather abrupt increase in the colour index setting in at about F8 to G0. A similar effect is also shown by the cepheids as will be seen by comparing the colour-period (5) and spectrum-period (4) relations.

As is well known, G to K dwarfs are bluer than giants of the same spectral type, the same degree of ionization being produced by the lower pressures and lower surface temperatures of giant atmospheres. In the super-supergiants of

this paper one may expect even lower surface temperatures to be required to reproduce a G0 spectral type.

Owing to doubts concerning the temperatures and bolometric corrections appropriate to these objects calculations of radii are most unreliable, but for 268757 a radius of the same order as that of the red component of VV Cep ($2400 \odot$) is suggested.

The possibility of interstellar reddening has to be borne in mind particularly for stars involved in nebulosity, but the absorption cannot be put high without having to assign unacceptably high intrinsic luminosities. Moreover, in the case of 271182 near the northern border of the Cloud, there is no associated nebulosity and no appreciable absorption can be expected in this region.

Frequency of red super-supergiants in the Large Cloud.—Mrs Nail and Shapley (6) have found that star counts in the Large Cloud indicate the presence of red supergiants brighter than 14 mag. The five member stars reported here indicate that even in the brightest range of magnitudes ($M = -9$ and brighter) red super-supergiants can exist in appreciable numbers. Among stars of apparent magnitude 10.4 or brighter, there are some 18 known blue Cloud members (excluding a few cases of clusters formerly regarded as individual stars) and *at least* 4 red Cloud members with types F8 or later. We can be reasonably sure that the census of the brightest blue members is complete, but we are very far from being able to claim the same for red members; in fact the probability of finding more instances seems to be fairly high. We can conclude that among the 30 brightest members of the Large Cloud not less than 20 per cent are likely to be red F8 and later types, few are earlier than B5 and none earlier than B0. The conclusion is rather surprising since the brightest Population I stars are normally regarded as blue.

A detailed list of proved members and foreground stars will be published at a later stage. But as a guide to the extent of the search for bright members of types later than B we give below the frequency distribution of HDE magnitudes of stars that to date have proved to be foreground objects.

<i>Number of proved foreground stars (LMC)</i>									
Range of m.	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	≥ 12.0
Number	2	6	8	4	12	5	3	3	4

The investigated stars brighter than 10.0 mag. included many type A stars from the HD catalogue because it was hoped that objects like HD 33579 (1) might be found. But it now seems reasonably certain that any such object would have been marked out by the peculiarity of exceptionally narrow lines and that no cases have been missed.

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Note added 1957 February 8.—A star (HDE 269810, $12^m.1$, Sp. G0) near the nebula NGC 2032 has been proved to be the first instance of a true absorption O member of the Cloud. It is more than 1 mag fainter than the limit for inclusion among the 30 brightest members.

References

- (1) M. W. Feast, A. D. Thackeray and A. J. Wesselink, *Obs.*, **75**, 216, 1955.
- (2) A. D. Thackeray and A. J. Wesselink, *Obs.*, **75**, 33, 1955.
- (3) Bart J. Bok and D. Hoffleit, private communication.
- (4) M. W. Feast, *M.N.*, **116**, 583, 1956.
- (5) W. Buscombe, G. de Vaucouleurs and S. C. B. Gascoigne, *Austr. Journ. Sci.*, **17**, 30, 1954 (Fig. 15).
- (6) V. McK. Nail and H. Shapley, *P.N.A.S.*, **39**, 358, 1953 (Harv. Repr. 373).