LUMINOSITY CALIBRATION OF GIANTS AND SUPERGIANTS, G0–M5

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Abstract. Calibration curves giving M_v for stars of luminosity classes III, II, Ib, Iab and 0 are derived and shown graphically in the HR diagram. There are serious gaps in which the calibration needs to be improved.

The luminosity calibrations that I have to discuss here do not involve any new methods of estimating absolute magnitudes. They do, however, meet the condition that virtually all the stars included had their spectral classification checked or revised by intercomparison of a nearly uniform set of spectrograms. The two main reasons for imposing this requirement were:

(1) The need to come as close as we can to eliminating stars with spectral peculiarities, which can systematically affect both temperature types and luminosity classes. The resulting calibration is limited to stars of roughly solar composition.

(2) The desirability of reducing statistical corrections by making the variances within each group as small as possible.

The table of revised standard types for the stars is given in a review article on classification by Margon and Keenan (1973).

1. Class III – Giants

For the main giant branch the calibration of luminosity classes in terms of visual absolute magnitudes was based on mean trigonometric parallaxes, using the method of reduced parallaxes (Russell and Moore, 1938). As far as possible the class III stars were separated into the three subclasses IIIa, IIIb, IIIab, and the IIIa and IIIb stars were not used in the calibration. The stars that could be rejected as definitely brighter than the central giant branch, and, hence, classified as IIIa or IIIb were a minority of the giants, for all doubtfull cases were retained and classified as merely class III. This at least served to eliminate distortion of the means by such stars as β Gem, with its very bright apparent magnitude, which would dominate any weighted mean. From several good spectrograms β Gem could be classified as K0 IIIb, and the large trigonometric parallax of $+0\overset{''}{.}093$ gives the good value of $+1.0$ for M_v. By comparison with Figure 1 it is evident that with good spectrograms one can just detect a luminosity difference of about a half magnitude in K-type giants.

By using only stars brighter than the fifth visual magnitude it was possible to derive

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satisfactory values of $\langle M_v \rangle$ in spite of the small samples – averaging 12 or 13 stars for each group. Not all the eligible stars brighter than $V=5.0$ have been re-classified, particularly in the southern hemisphere, and the resulting imcompleteness factor so nearly balanced the Malmquist correction that the latter could be omitted except for the last group (M1–M2). Most of these M-stars were fainter than $V=4.5$, and a correction of $+0.2$ mag. was estimated and applied to this group. The general correction $\langle M \rangle - M\,(M_\pi\rangle) = 5(\langle \log \pi \rangle - \log \langle \pi \rangle)$ ranged from -0.2 to -0.7 mag.

Good arguments can be advanced for preferring either weighted or unweighted means. In the plots of group means in Figure 1 both solutions are given, and in the

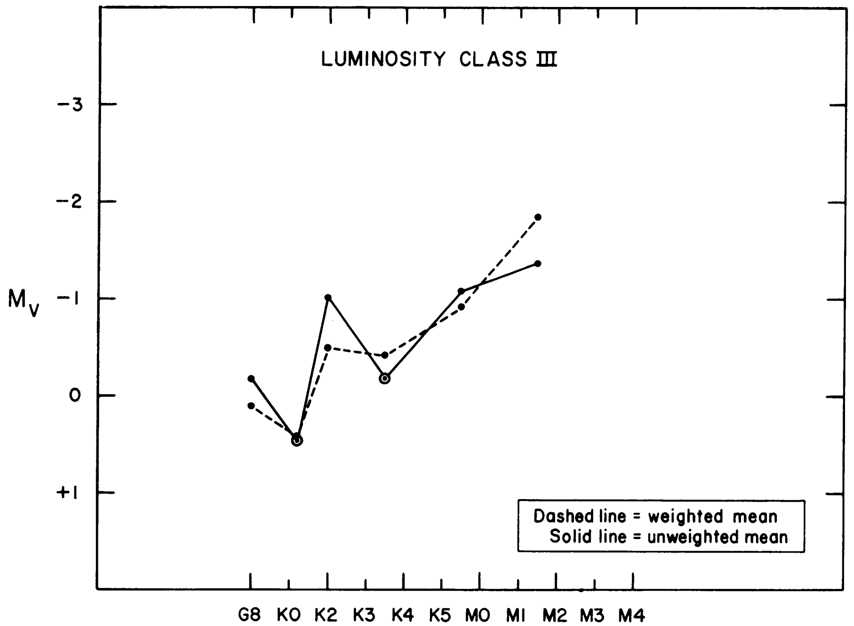

Fig. 1. Calibration of giants by mean trigonometric parallaxes. Stars with $V < 5.0$.

final calibration the two sets were averaged. The two encircled points represent direct unweighted means of the absolute magnitudes for the groups in which no negative parallaxes occurred. Although their almost exact agreement with the mean parallax solutions must be fortuitous, it seems evident that no serious systematic error was involved in the corrections applied to the latter.

The zigzag pattern in Figure 1 is due, of course, to the small size of the samples, and there seems to be no reason not to draw a smooth curve through the band of points. This was done to give the final calibration of class III in Figure 6. From the deviations of the group means from this curve the mean error of the smoothed relation is 0.27 mag. from the unweighted means and 0.17 mag. from the weighted ones.

The choice of trigonometric parallaxes to calibrate class III was not made to disparage the value of statistical parallaxes, but I felt it desirable to have this independent solution to permit comparison with the luminosities derived from radial velocities and proper motions. In Figure 2 the new luminosities are plotted against the values found by Jung (1970) for the stars in the *Yale Catalogue of Bright Stars*. The dashed line has a 45° slope. No marked systematic difference is present but Jung's final adopted values were not smoothed as much as mine, and his groups means show greater oscillations, particularly at K1, where he obtained a luminosity lower by 0.6 mag. Of course, neither the sample population nor the breadth of the band of giants averaged was the same in the two solutions. Nevertheless, the overall agreement appeared close enough to justify the use of Jung's values to extend our solution in Figure 6 by the dashed line as far as type G5.

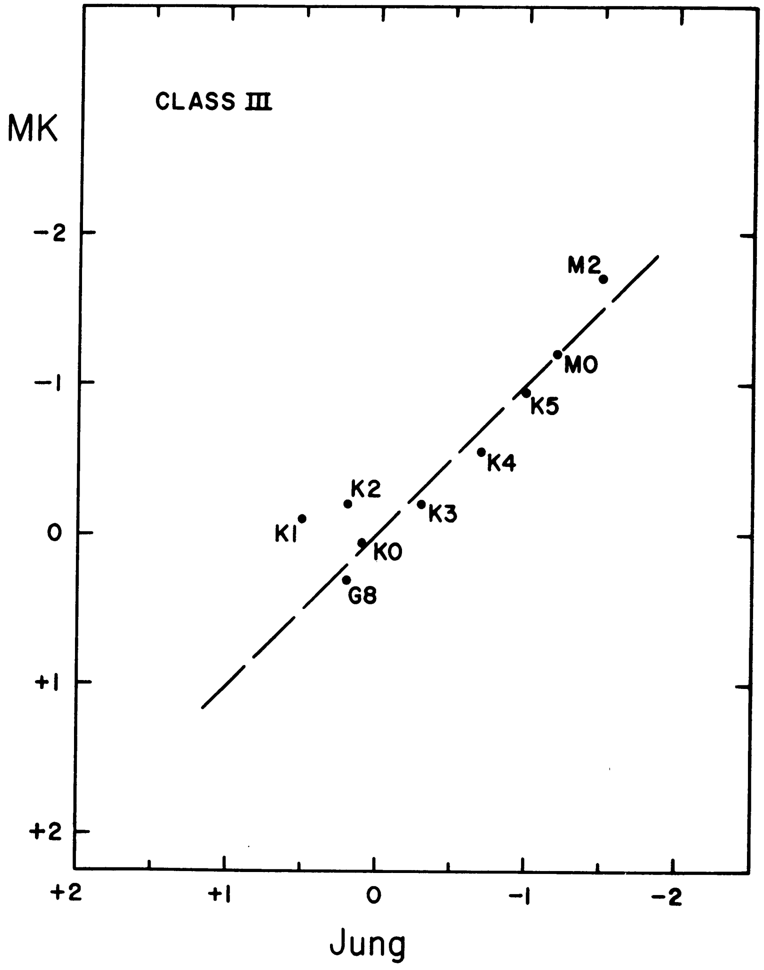

Fig. 2. Comparison of smoothed mean trigonometric values of M_v with Jung's values derived from statistical parallaxes. The dashed line has a slope of 45°.

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2. Class II – Bright Giants

When we go above the giant branch even the mean trigonometric parallaxes become too small to be meaningful. At the same time the number of well-classified stars is so small that one must lump a number of spectral classes together to have a large enough sample to give decent statistical parallaxes. There is an alternative means of calibration, however. The linear relation between K-line emission widths and absolute magnitudes that was found by Olin Wilson allows the values of M_v for class II stars to be derived by interpolation. Since his calibration (Wilson, 1970), was tied to the Sun, the Hyades main sequence and giants, and the Perseus cluster supergiants, it is independent of the class II stars, and can therefore be applied to them without any circularity in the argument. Dr Wilson is currently preparing a new catalogue of K-line luminosities and kindly provided me with the revised data for a number of stars having luminosity classes near II. His coudé spectrograms were limited for the most part of stars with $m_v \leqslant 7.0$, and since neither his sample nor mine was complete for this range, the elimination of stars classified IIa or IIb leaves only the few points plotted in Figure 3 for the center of the bright-giant group at the present time. The apparent dispersion in the diagram is too great to be accounted for by the uncertainty in classification alone.

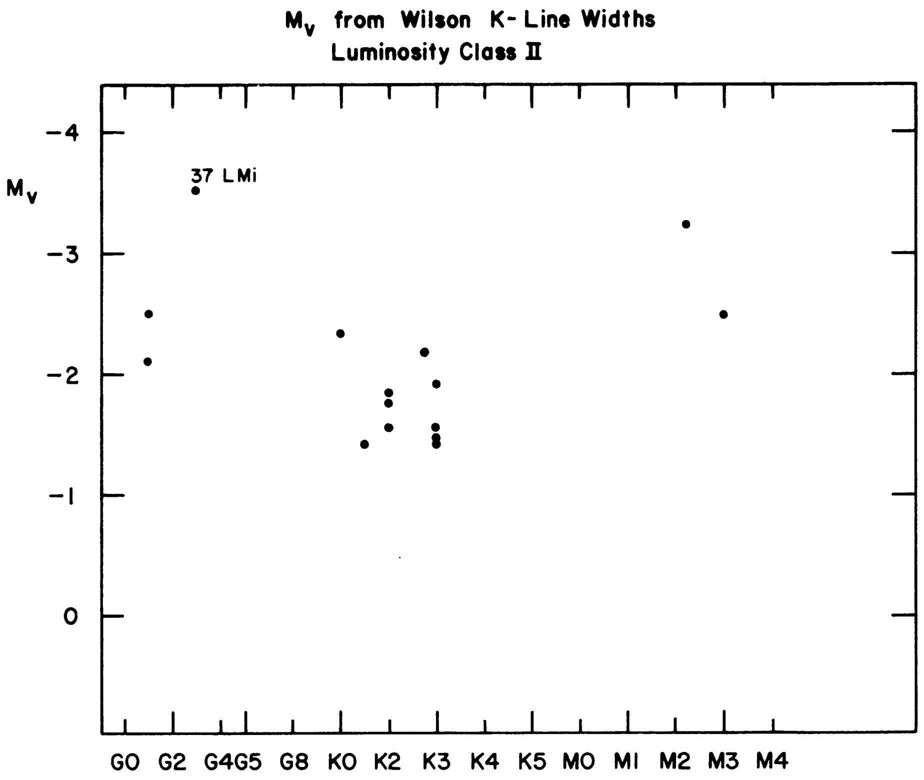

Fig. 3. Luminosities of class II stars given by K-line calibration of Wilson.

If we regard the K-line emission width as another luminosity criterion more or less independent of the usual criteria used on small-scale spectrograms, the scatter in Figure 2 suggests that the several criteria do not correlate perfectly – which is not surprising when we consider that the different spectroscopic features will not necessarily respond in exactly the same way to individual variations in such physical characteristics as chromospheric activity. One striking discrepancy is shown by the well-known bright giant ζ Cyg, which nearly all recent observers have assigned to luminosity class II. The K-line luminosity is +1.1, which would put it at the lower edge of the giant branch and entirely off the diagram. ζ Cyg does have a slight enhancement of Ba II, but is not a real barium star and this degree of peculiarity does not seem sufficient to explain the large discrepancy.

In order to take account of all the stars near luminosity class II, and the evidence from membership in open clusters and binary systems, the stars between types G8 and K4 have been grouped together in Figure 4. For the two binaries near Ib, ε Peg and

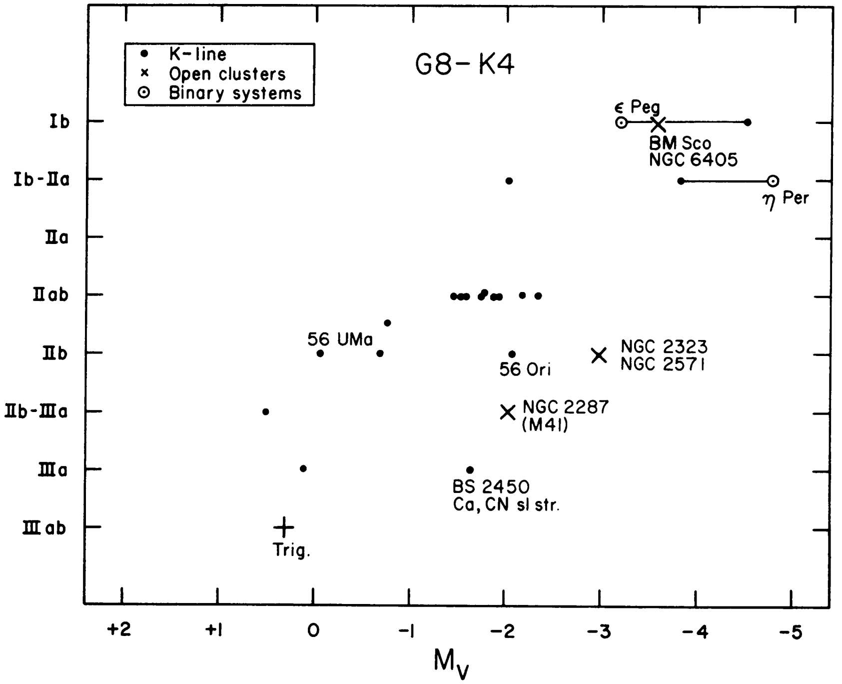

Fig. 4. Comparison of K-line absolute magnitudes with those derived from open clusters and binary systems. The + shows the mean trigonometric absolute magnitude for class III, types G8–K4.

η Per, the K-line luminosity and that derived from the spectral classification of the early-class companion have been jointed by a bar. For these two stars the differences between the two methods is in the opposite sense. The class IIb, IIab, and IIa stars in clusters, however, appear to have higher luminosities than those given by the K-line

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widths. The adopted mean curve in Figure 6 represents a compromise between the two sets of data. As soon as a sufficient body of accurate types is available for class II stars – perhaps down to $V=8$ – it will be especially desirable to derive statistical parallaxes for this luminosity range.

3. Classes Ib, Ia and O – Supergiants

Membership in groups of stars at known distances is recognized as the best means of calibrating the luminosities of late-type supergiants. Both the membership of individual red stars in clusters and associations, and the distances to these aggregates, have been

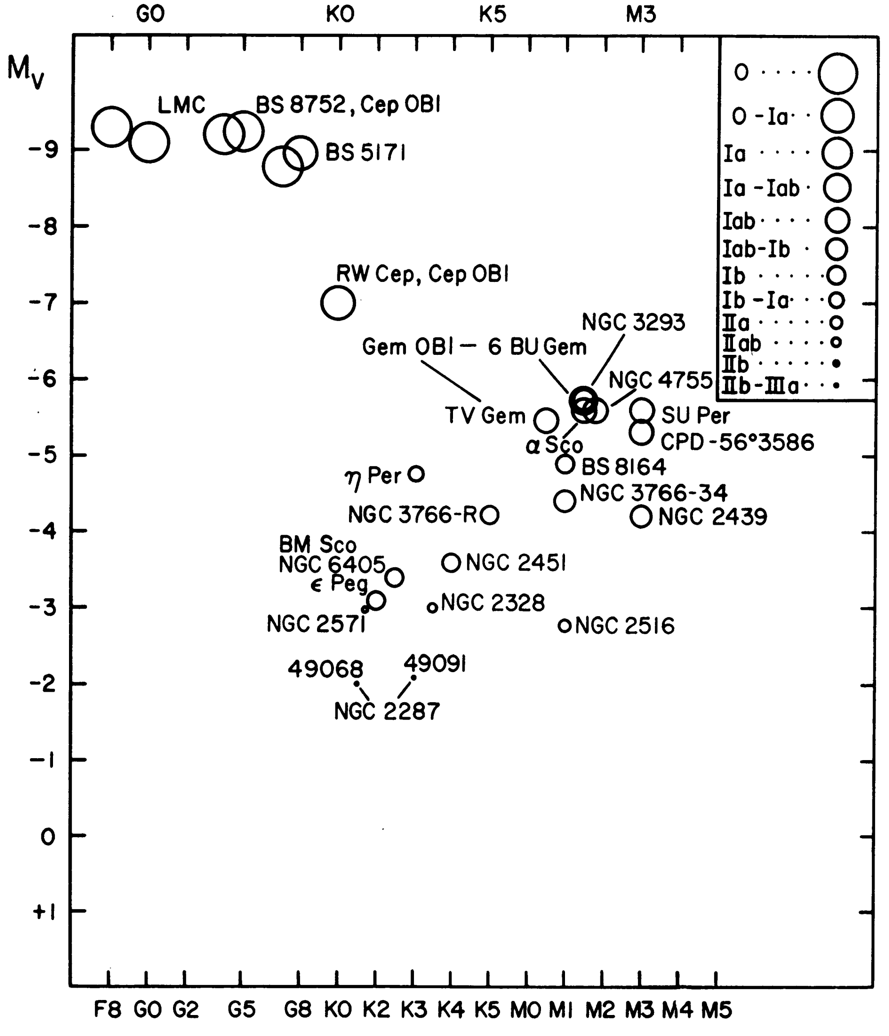

Fig. 5. Luminosities of supergiants given by their membership in binary systems, open clusters or associations.

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reviewed carefully by Schmidt-Kaler (1961), Hagen (1970), Humphreys (1970), Humphreys *et al.* (1971, 1972), Schild (1970), Stothers (1969, 1972), Stothers and Leung (1971), and others. These data, combined with our revised types, are summarized in Table I.

The only systematic changes that I have introduced followed naturally the recognition of the brightest supergiants of the LMC as defining luminosity class 0. For the distance modulus of 18.6 for the LMC (Wesselink, 1971), the visual absolute magnitudes of the four reddest 'super-supergiants' defined by Feast and Thackeray (1956) remain in the range −8.8 to −9.3 mag., very close to their original estimates. With the brighter M-type supergiants in h and χ Persei retained as defining class Iab, the other classes of supergiants can be assigned by interpolation.

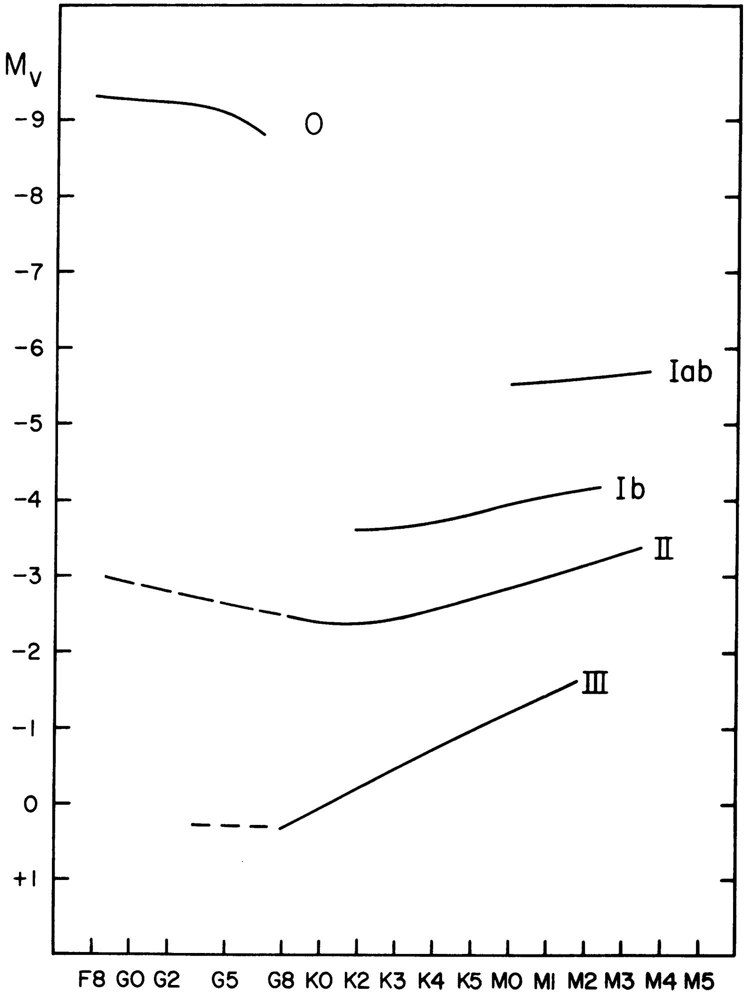

Fig. 6. Adopted luminosity mean absolute magnitudes for several luminosity classes. The dashed lines indicate extensions of lower weight.

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TABLE I

Adopted luminosities of late-type stars in clusters or binary systems

Star	System	Type	$(m-M)_0$	M_v	Sources	Remarks
SU Per	h & χ Per	M3–4 Iab	11.5	−5.6	Crawford *et al* (1969)	
η Per	Binary	K3–Ib–II	8.5	−4.7		Companion classified B8 V by Dr Slettebak
CPD −31°1790	NGC 2439	M3 Iab–Ib	11.7	−4.2	Becker (1963)	1
HD 52938	NGC 2323	K3.5 IIb		−3.0		
BS 3153	NGC 2516	M1 IIa	8.3	−2.8	Morgan and Abt (1969)	*Astron. J.* **74**, 813
CoD −29°5941	NGC 2571	K1.5 IIb	11.4	−3.0	Lindoff (1967) Hagen (1971)	*Arkiv. Astron.* **4**, 587.
CPD −57°3502	NGC 3293	M1.5 Iab–Ib	11.5	−5.7	Feast (1958)	*Monthly Notices Roy. Astron. Soc.* **118**, 618
CPD −60°3621	NGC 3766	M1–Iab–Ib	11.1	−4.4	Kraus (1967)	*Astron. Nachr.* **289**, 285
CPD −60°3636	NGC 3766	M0 Ib		−4.2:		2
CPD −59°4459	NGC 4755	M2–Iab	11.8	−5.7	Feast (1961)	*IAU Symp.* **20**, 22
α Sco	Binary	M1–M2 Iab	8.0	−5.6	Stone and Struve (1954)	3
BM Sco	NGC 6405	K2.5 Ib CN+1	8.5	−3.4	Talbert (1965)	4
ε Peg	Binary	K2 Ib	5.5	−3.1	Keenan	

[1] NGC 2439. In this field, and close to the M3 supergiant, is found R Pup, for which the revised type is G2 O from its close match with HDE 269953 in the LMC. Accordingly, a luminosity of $M_v \approx -9$ should be expected, which would place R Pup at about twice the distance of the cluster. Hence, although the radial velocities of the two supergiants appear to be comparable on the basis of visual inspection of the low-dispersion spectrograms, I regard the membership of R Pup in NGC 2439 as very doubtful.

[2] NGC 3766. The distances found by Sher (1962), Ahmed (1962) and Kraus (1967) have been averaged.

[3] α Sco. From membership in the association OB2 Stothers and Leung (1971) derive the slightly lower luminosity, $M_v = -5.2$. The star varies appreciably in light and temperature type.

[4] NGC 6405. The moduli of Rohlfs *et al.* (1959), Eggen (1961) and Talbert (1965) have been averaged. BM Sco appears to have unusually strong CN bands. The apparent brightness has varied considerably at a slow rate.

Most of the best calibrated objects from Table I are plotted as an HR diagram in Figure 5. Two VV Cep-class close pairs are CPD $-56°3586$ and BS 8164, and their absolute magnitudes are found from their B-type secondaries (Keenan, 1970). The point for α Sco (M1–M2, Iab) also is based upon the spectral types of its companion (Stone and Struve, 1954; Garrison, 1967). The star BS 5171, shown in the midst of the LMC stars, is the G-type supergiant to which attention was directed by Humphreys *et al.* (1971), who derived an absolute magnitude of -8.9 from their classification of B0 Ibp for its visual companion, using Blaauw's luminosity calibration for that type. My type for the primary component, G8 0–Ia, agrees essentially with theirs and is based on a spectrogram kindly loaned by Dr Humphreys. Since a value of $M_v = -9.0$ is obtained if one uses the calibration of Weaver and Ebert (1964) for B-stars, it is possible that my luminosity class is too low.

For nearly all the late-type supergiants both the temperature type and the luminosity vary appreciably, and the points plotted in Figure 5 are averages. The most accordant results are given by the five points for Iab stars, which cluster close to $M_v = -5.6$ over the observed range from M0 to M3 in type. This agrees with the result of Stothers (1972). Additional points for several luminosity classes could be added by including stars in other associations, besides 0B1 and Gem 1, but the evidence for both membership and distance for objects assigned to associations is so much less definite than for stars in clusters that the latter should be given much higher weight in calibrations.

The calibrations adopted on the basis of the discussions in this paper are shown graphically by the curves in Figure 6. The lines extend only as far as we have reasonably good absolute magnitudes at the present time. The gaps are serious, but there is hope of filling them – at least in part.

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DISCUSSION

Van den Bergh: Stars of luminosity class III represent a mixture of objects of differing age and composition. The absolute magnitude calibration for giants is therefore function of the data selected for the calibration. A good example is provided by the M giants in the nuclear bulge of the Galaxy for which $\langle M_v \rangle \simeq 0$ compared to $\langle M_v \rangle \simeq -1.5$ for the M giants near the Sun.

Schmidt-Kaler: I would say that perhaps the greatest merit of the MK-system is that it represents a reference system for about 95% of the stars. So it may serve as a guide to all subsequent work.