PART III

CALIBRATION OF SPECTROSCOPIC PARALLAXES

THE CALIBRATION OF LUMINOSITY CRITERIA

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Abstract. Attention is drawn to important systematic effects in the calibration procedure due to the accidental errors in the measured luminosity criteria. The present state of the luminosity calibrations in the MK system is reviewed with reference to recent work based on proper motions and radial velocities, and on trigonometric parallaxes, resulting in evidence for corrections of about -0.4 mag. for the K0–K5, III stars. Brief reference is made to the developments with regard to the M_v(K) system.

The present report summarizes the principal elements of the review presented at the symposium.

1. Avoidance of Using a 'Biassed' Calibration Curve

The problem of the calibration of luminosity criteria is essentially that of establishing the relation between the measured quantity I (say, an intensity ratio in the spectrum) and the absolute magnitude, M. It is complicated by (a) the observational errors in I; (b) the circumstance that for a given I, the luminosity may depend on still other factors such as unresolvable duplicity, or stellar rotation and the angle of orientation of the rotational axis, or chemical abundance. Factors like these may be described to cause a 'cosmic' scatter with respect to a standard relation between I and M. They will be discussed in more detail elsewhere during this symposium. For the present introduction I shall ignore these 'cosmic errors' in M and assume that for errorfree values of I a strict relation between I and M exists. Attention will be drawn here to the importance of the random errors in I as a cause of *systematic* errors in the derived M, if no proper precautions are taken in deriving the calibration relation. The matter has been discussed previously (Blaauw, 1963), but a re-presentation, with a somewhat simpler approach, seems useful.

The systematic effect referred to is a function of the frequency distribution of the absolute magnitudes, $\varphi(M)$; for reasons of simplicity we shall assume it to be gaussian with dispersion σ. We further, also for the sake of simplicity, shall assume the relation between M and true I to be linear, $M = \alpha I + \beta$, and the mean error of I to be μ_i. The frequency distribution of I, $F(I)$, is then also gaussian, with dispersion $\sigma/\alpha = \sigma_i$. Figures 1a, b, c show, respectively, a section of the distribution function $\varphi(M)$, the corresponding distribution $F(I)$, and the relationship between I and M.

Suppose we select from the sample a subgroup with observed values of I in the interval ΔI around I_0' (I_0' chosen arbitrarily). For these, a mean absolute magnitude is determined, either by trigonometric or by secular parallaxes: M'. We shall assume this value of M' to be error-free. The dashed relation in Figure 1c, is obtained by plotting the value M' obtained in this way for the selected subgroup at I_0' as well as the value M'' obtained similarly for a subgroup at I_0''. I_0'' is also arbitrarily chosen. Now, this dashed relation is *not* to be identified with the strict relation $M = \alpha I + \beta$, which ought to be used as a calibration curve for converting observed I into M.

B. Hauck and B. E. Westerlund (eds.), Problems of Calibration of Absolute Magnitudes and Temperature of Stars, 47–56.

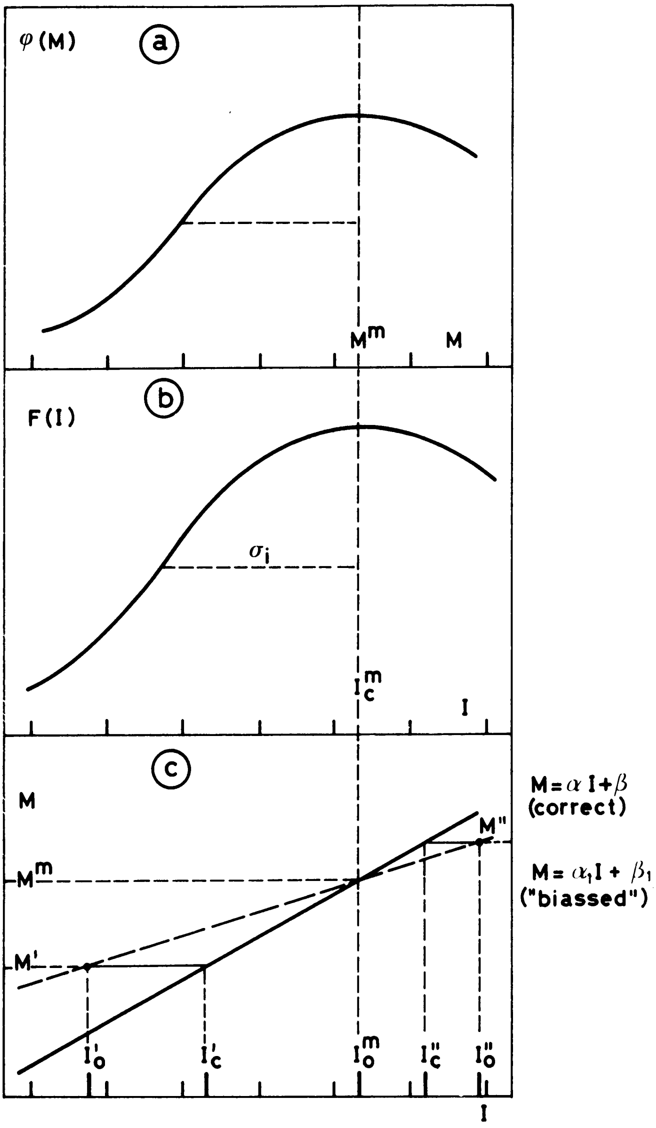

Fig. 1. (a) The frequency distribution of absolute magnitudes, assumed to be gaussian. (b) The corresponding frequency distribution for the luminosity criterion I, assuming a linear relation between M and I. (c) The biassed calibration relation $M=\alpha_1 I+\beta_1$ (dashed line) and the correct relation. $M=\alpha I+\beta$ (drawn line).

Use of this biassed (sometimes called 'partial') dashed line $M=\alpha_1 I+\beta_1$ has, in the past, led to spurious conclusions, as we shall mention below.

For determining the proper relation $M=\alpha I+\beta$, we proceed by selecting the values M' or M'' obtained before and asking: which are the proper values of I belonging to them? We shall denote these by I_c' and I_c'', sothat $M'=\alpha I_c'+\beta$ etc. I_c' differs from

I_0' because, in the subsample $\Delta I_0'$ we have collected error-affected values of I_0 which happen to have arrived in this interval as a result of the measuring errors in I. The essential point, then, is, that the mean of the true values of I in this subsample is normally *not* identical to I_0' but differs from it systematically. In the present case, more objects with true value $I > I_0'$ have crept in than objects with $I < I_0'$, due to the slope of the function $F(I)$. A positive correction therefore has to be applied to I_0' to obtain the true value of I corresponding to M'. Similarly a negative correction has to be applied to I_0''. No correction need be applied to the value I_0^m corresponding to M^m, the absolute magnitude for which $\varphi(M)$ is at maximum, for reasons of symmetry. We have, $M^m = \alpha I^m + \beta = \alpha I_0^m + \beta$. It can be shown easily that

$$\frac{I_c' - I_0^m}{I_0' - I_0^m} = \frac{I_c'' - I_0^m}{I_0'' - I_0^m} = \frac{\sigma_i^2 + \mu_i^2}{\sigma_i^2}.$$

The thus corrected points (M', I_c') and (M'', I_c'') define the correct calibration relation $M = \alpha I + \beta$; it contains the point $(M^m, I_c^m) \equiv (M^m, I_0^m)$.

Clearly, the change in slope from the true relation to the biassed one is such, that using the latter for converting observed values of I into M leads to an underestimate of the spread in the absolute magnitudes. Typical examples of this effect, which can be very serious, have been mentioned in the article quoted (Blaauw, 1963).

Once the correct relation $(M = \alpha I + \beta)$ is used for calibrating a given set of values of I into M, the resulting distribution of M is, of course, affected by the random errors of I in such a way as to broaden the (gaussian) distribution of M. This effect must be considered quite separately from that described before. E.g. the determination of the proper calibration relation may be based on a quite different sample of stars than those for which the calibration is used, the latter for instance with mean error μ_j of I. The 'broadened' dispersion of M then is larger than the true one in the proportion $(\sigma_i^2 + \mu_j^2)^{1/2}/\sigma_i$. If $\mu_i \equiv \mu_j$, then the resulting effect of using the biassed calibration curve is still a narrowing, in the ratio $\sigma_i/(\sigma_i^2 + \mu_i^2)^{1/2}$. Neglecting the narrowing effect of the use of the biassed calibration curve may, for example, lead to a serious underestimate of the width of the giant branch in the HR diagram.

2. The Calibration of the MK Luminosity Classes

The MK spectral and luminosity classification system remains a most useful frame of reference for classification systems in general, although for certain domains of the array it is gradually being replaced by other, quantitative, systems. For the O, B and A stars this is the case with respect to the intermediate-band u, v, b, y system plus Hβ photometry, especially making use of the quantities $c_1 = (u - v) - (v - b)$ and $m_1 = (v - b) - (b - y)$ and thereby adding the third dimension: metal abundance. For the late type stars the luminosity estimates through the measures of the Ca$^+$ reversals gradually supersede the visual luminosity estimates. Several refined narrow and intermediate band systems, discussed elsewhere at this symposium, represent further improvements.

A. PRINCIPAL METHODS OF CALIBRATION

For a discussion of the status of the calibration of the MK system, reference to Figure 2 is useful. It indicates, by means of the differently hatched regions, the applicability of the three principal basic methods for the calibration: trigonometric parallaxes, secular parallaxes (more general: the use of proper motions plus radial velocities), and the zero-age main sequence fitting procedure.

The most fundamental method, trigonometric parallaxes, applies to the main sequence stars F5 through M, and also to a certain extent to the giants of classes

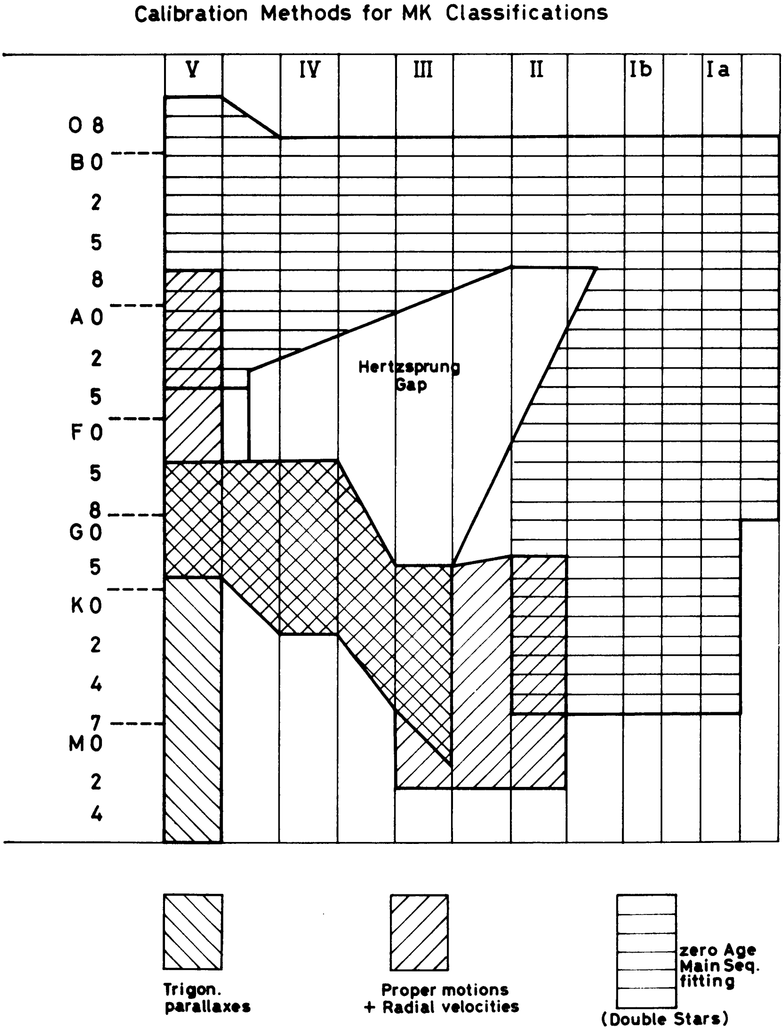

Fig. 2. The applicability of the three methods for luminosity calibration (trigonometric parallaxes, proper motions plus radial velocities, and fitting of the zero age main sequence) for the various domains of the HR diagram in the MK classification system.

G5 III to late K III, and to the intermediate classes IV. The secular parallax method overlaps with it for main sequence classes F5 through G5, for classes F5 IV through K0 IV, and for G5 III to late K III, but extends further along the main sequence upwards to class B8 V and along the giants down to the M III types, and to the giants G5 through K of class II. The zero age main sequence fitting procedure overlaps with the secular parallaxes upward from main sequence types A5, and somewhat in the domain of the G, K II stars.

Obviously this description is rather schematic, but it helps telling which method(s) will be most useful for the improvement of the present calibrations. In all methods, the region of the Hertzsprung gap (see Figure 2), due to its very scarce population, remains poorly calibrated, but due to this very scarcity the need for this calibration remains limited.

In the following paragraphs we review some recent improvements of the calibrations as compared to about ten years ago (Blaauw, 1963). See also Schmidt-Kaler (1965). We do not include in this discussion certain differential, though very interesting effects, like stellar rotation and abundance effects.

For a discussion of the accuracies within the classification system MK itself we refer to analysis by Jaschek and Jaschek (1971); It appears that the average uncertainty of a single classification (due to a variety of sources of error) is less than 0.6 luminosity class, and 0.6 or more in the spectral type.

B. RECENT IMPROVEMENTS THROUGH THE USE OF SECULAR PARALLAXES

The most comprehensive recent discussion is by Jung (1970). The procedure using proper motions and radial velocities, and referred to as a maximum likelihood method, aims at finding such a distribution of distances of stars of a given sample (spectral and luminosity type, apparent magnitude) as to give the 'best' fitting of proper motions (converted to tangential velocities) to radial velocities. It is essentially identical to the method applied long ago to more limited material and with more restricted computational facilities (for instance, Strömberg, 1933, 1936); however, the use of modern computers allows more diversified solutions. The method obviously is of greatest importance where trigonometric parallaxes fail or are of limited use: i.e. for stars of types A, F V and G, K, M III.

Basic material in Jung's analysis are the stars in the Bright Stars Catalogue (Hoffleit, 1964) for which proper motions and radial velocities are almost complete. This choice implies that the results apply virtually only to Population I and Disc population, the percentage of low metal abundance stars being very low.

The principal results by Jung are summarized in Tables I and II for classes V and III, respectively, in the columns headed 'P.M. + Rad. Veloc.'. The column BAD (1963) reproduces results given by the author (Blaauw, 1963) in *Basic Astronomical Data*. The numbers of stars used by Jung are indicated under *n*.

For classes V, B8–G8, the new results are systematically about 0.2 mag. brighter – but this is also the uncertainty inherent to the system due to the imperfections of the method. For classes III, G5–M4, the improvements are more striking: for K0–M

TABLE I

MK Class V; M_v per apparent mag.

		P.M. + Rad. veloc.			Trigon. parall.		
	B.A.D. (1963)	Jung (1970)	J − B	*n*	Jung (1971)	J − B	*n*
B 8	−0.5	−0.7	−0.2	140			
9	0.0	0.0	0.0				
A 0	+0.5	+0.5	0.0	134	+0.2	−0.4	34
1	+0.8	+0.6	−0.2				
2	+1.2	+0.7	−0.5	106	+0.6	−0.6	24
3	+1.5	+0.8	−0.7	81	+1.4	−0.1	22
5	+1.8:	+1.5	−0.3:	52	+1.2	−0.7:	17
7	+2.0:	+1.6	−0.4:				
F 0	+2.4:	+2.3	−0.1:	60	+2.5	−0.1:	26
2	+2.8:	+2.5	−0.3:				
5	+3.2	+3.0	−0.2	80	+3.3	+0.1	40
6	+3.5	+3.2	−0.3				
8	+4.0	+3.5	−0.5	60	+3.4	−0.6	35
G 0	+4.4	+4.1	−0.3	57	+4.3	−0.2	29
2	+4.7	+4.3	−0.4				
5	+5.1	+4.9	−0.2	29	+4.8	−0.5	32
8	+5.5	+5.5	0.0				

TABLE II

MK Class III; M_v per apparent mag.

		P.M. + Rad. veloc.			Trigon. parall.		
	B.A.D. (1963)	Jung (1970)	J − B	*n*	Jung (1971)	J − B	*n*
G 5	+0.4:	+0.3	−0.1:	51	+0.2	−0.2	70
8	+0.4	+0.2	−0.2	170			
K 0	+0.8	+0.1	−0.7	176	+0.4	−0.4	48
1	+0.8	+0.5	−0.3	98	+0.4	−0.4	19
2	+0.8	+0.2	−0.6	95	+0.6	−0.2	54
3	+0.1	−0.3	−0.4	88	−0.2	−0.3	48
4	−0.1	−0.8	−0.7	133	−0.3	−0.1	41
5	−0.3	−1.0	−0.7				
M0	−0.4:	−1.2	−0.8:	66			
2	−0.4:	−1.5	−1.1:	28			
4	−0.5:	−1.7:	−1.2:				

the visual luminosities are about 0.5 mag. brighter, which should be a significant improvement in view of the uncertainty of ±0.2 mag.

Ljunggren and Oja (1965, 1966) arrived at similar corrections for G8–K5, III stars (see Table III), from an analysis of proper motions and radial velocities in the context of a calibration study of the Uppsala photometric system (see also below).

C. RECENT IMPROVEMENTS THROUGH THE USE OF TRIGONOMETRIC PARALLAXES

Results of a recent comprehensive study of the use of trigonometric parallaxes by Jung (1971) are also given in Tables I and II, last columns. Again, the stars in the ***Bright Stars Catalogue*** are used, with parallaxes from the catalogue of Jenkins (1954). A special effort was made to take into account the systematic effects possibly entering into the results as a consequence of the random errors in the parallaxes in combination with the special choice of the sample: objects with (observed) parallaxes exceeding a certain numerical limit. Also investigated was the influence of systematic corrections to the Jenkins parallaxes.

For classes V, F2–G8, the new results are systematically about 0.3 mag. brighter than the 1963 'BAD' values: the differences probably are significant. For the A V stars (Table I) a similar correction is indicated. Here the numbers of stars in the sample are necessarily very limited. For classes III, G8–K5 (Table II), again a systematic negative correction of several tenths of a magnitude is found which appears significant. It depends somewhat on whether the Jenkins parallaxes are systematically corrected or not by $-0''.035$ as proposed by Schilt (1954). For these spectral classes Ljunggren and Oja (1966) arrive at a somewhat larger negative correction, about −0.6 mag. or the average (Table III).

Summarizing the results from secular and trigonometric parallaxes, we conclude that for luminosity class V, types A through G, the earlier calibrations were about 0.25 mag. too faint; that for luminosity class III types K0–K5 these early results were about 0.4 mag. too faint; and that for the G III stars and the M III starss maller, respectively larger negative corrections are indicated.

TABLE III

MK Class III; M_v per apparent mag.

			Ljunggren + Oja (1966)		
	B.A.D. (1963)	p.m. + rad.-vel.	LO − B	trig. parall.	t.p. − B
G 8	+0.4	+1.0	+0.6	+0.6	+0.2
K 0	+0.8	+0.2	−0.6	+0.1	−0.7
1	+0.8			+0.8	0.0
2	+0.8	+0.3	−0.5	−0.1	−0.9
3	+0.1			−0.2	−0.3
4	−0.1	−0.5	−0.4	−0.9	−0.8
5	−0.3			−1.4	−1.1

All values in Tables I to III refer to a selection of stars 'per apparent magnitude', i.e. containing the bias of intrinsically brighter stars of a certain subtype having been selected over a larger volume of space than the intrinsically faint stars. As has been pointed out before (Blaauw, 1963) these values are about half a magnitude brighter than values referring to a selection per volume of space.

Corrections to the upper part of the calibration table in the 'BAD' volume are not studied here; these would be due largely to the application of the zero age main sequence fitting procedure. In this domain of the spectral and luminosity classes (O, B, A) the practical value of the luminosities in the MK system is now rapidly being superseded by the quantitative photometric methods (see the contribution of Crawford at this symposium).

3. The $M_v(K)$ System

No detailed discussion of this system, introduced by Wilson and Bappu (1957) will be presented here. It clearly is going to be a most important source for absolute magnitudes in the range of spectral types G5 and later for all luminosity classes, and thereby also an important basis for calibrations of the various visual (MK) and photometric luminosity criteria. See, for instance, work by Häggkvist and Oja (1970) on the calibration of narrow band photometric criteria for F8–M4 stars, especially of luminosity class III. This, however, will require further evaluation of the influence of chemical abundance effects on which the results so far are not unambiguous. For a recent review we refer to Wilson (1970); more recent papers dealing with the sensitivity of the method to chemical abundance are by Kjaergaard (1970) and Hansen (1972), and by Yoss and Lutz (1971), whereas Wilson and Woolley (1970) discussed the relation with stellar ages.

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DISCUSSION

Schmidt-Kaler: Before opening these papers for discussion I would like to make two remarks on some work done at Bochum concerning problems of intrinsic colours and absolute visual magnitudes of early type stars and supergiants.

1. The Upper Part of the Zero Age Main Sequence

Blaauw (1963) has constructed the upper ZAMS by fitting successively four open clusters and one association to the unevolved Hyades main sequence. It seems desirable (1) to bridge the gap by fitting an early-type cluster directly to the Pleiades or even to the Hyades, and (2) to do so for several clusters in order to check on possible systematic differences. In his doctoral thesis Vogt (1971) did this for the double cluster in Perseus. All stars in the 36′ × 60′ field were measured down to $V = 18\overset{\mathrm{m}}{.}0$ (altogether 6742 stars) as well as 4717 stars in eight symmetrically placed comparison fields of equal total area. The large numbers of stars and a careful study of the reddening and its variations in the field made it possible to determine the ridge line of the main sequence by statistical substraction down to $M_v = +3.6$ resp. $+4.0$. The result is that h Per gives a perfect fit within $\pm 0\overset{\mathrm{m}}{.}1$ maximal deviation to Blaauw's ZAMS in the interval $M_v = +3.4 \ldots -1.3$ (corresponding to $(B-V)_o = +0.38 \ldots -0.21$) while the unevolved main sequence of χ Per in the interval $M_v = +2 \ldots -2.5$ resp. $(B-V)_o = +0.10 \ldots -0.27$ displays systematic deviations from Blaauw's ZAMS up to $0\overset{\mathrm{m}}{.}3$. The cluster χ Per appears to be considerably younger than h Per; the distributions of the dwarf emission B-stars and of the supergiants are centered on it, the only O-star in the area belongs to it. A revised discussion of Vogt's photometry is in preparation.

2. The Absolute Magnitudes of OB-Stars and Supergiants

Recently, Stothers (1972) and Walborn (1972) presented recalibrations of the absolute magnitudes of supergiants and OB-stars, respectively. Although, of course, some improvement is possible we wish to point out that – with the present material – no significant differences between the new and the old calibrations (Blaauw, 1963; Schmidt-Kaler, 1965) are evident.

It is well known that the scatter of the absolute visual magnitudes for a given MK-type in this region of the Hertzsprung-Russell-diagram is about $\sigma_M = \pm 0\overset{\mathrm{m}}{.}6$. For example, the mean standard deviation for supergiants from Stothers' (1972) work is $\pm 0\overset{\mathrm{m}}{.}54$; a large part of this scatter is due to the fact that the MK-system puts the stars in discrete boxes.

Assuming that the distance determinations for the recalibrations and the first approximations of the absolute magnitudes as given in the Landolt-Börnstein Tables are free of errors we will certainly underestimate the variance of the differences of the calibrations. Applying Student's test to the differences ΔM_v (Stothers minus Schmidt-Kaler) only one difference significant on the 2% error-level (for the A Ia stars $+0.5 \pm 0.4$), and one just marginally significant difference (for the OB Ib stars -0.2 ± 0.2 on the 5% error-level) is found. The selection of A Ia stars is, however, for the most part taken from associations with uncertainties in distance modulus. Even the well-studied association Per OB1 gives rise to doubt: Stothers' discussion led him to assume $(m-M)_o = 11.5$ while Walborn's ends up with 11.65 which would lead to $\Delta M_v = +0.4$. At the level of $0\overset{\mathrm{m}}{.}2$, of course, systematic errors of various origin come into play.

Applying Student's test on the same assumptions to the differences ΔM_v (Walborn minus Schmidt-Kaler) only two just marginally significant differences are found: for the O–B3 Ia stars $\Delta M_v = -0.5 \pm 0.4$, for the B0–2.5 V stars $+0.5 \pm 0.4$, both on the 5% error-level, is observed. Walborn's revised MK classification appears more accurate and may lead to somewhat smaller scatter. But even with $\sigma_M = \pm 0.3$ no other even marginally significant differences are noted. On the other hand Walborn's selection of main sequence B stars contains a large proportion of almost unevolved stars, the ZAMS being just about $0\overset{\mathrm{m}}{.}5$ fainter than the average class V B star.

From the present discussion it is evident that the basic need in recalibrating the high luminosity areas of the MK-system is for more calibration stars. These should be members of many different groups and clusters in order to minimize possible systematic errors in individual cases. One and the same procedure should be used to find reddenings and distances; the colours should be evaluated simultaneously. Finally, a homogeneous distribution of calibrating stars over the areas considered should be aimed at. In the last three years Drs Moffat, Vogt and myself observed photoelectrically (in *UBV*) at the Bochum Southern Station 80 southern open clusters which had thus far never been studied, and photographically 12 northern open clusters thus far unstudied. They contain quite a few OB- and Be-stars and supergiants of all spectral classes. Work on their MK classification has just begun.

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Eggen: Calibration of MK luminosity classification – Why? Even for the bright stars classifiers have difficulty in agreeing on the classifications and since the use on faint stars is the real end product, it would appear to be dangerous to apply any calibrations – at least at the present time.

Blaauw: I see the following use of the MK-luminosity classifications – and hence of their calibration in these fields:

(a) For individual stars a MK spectrum may give more easily the luminosity estimate than photometry, especially if one thinks of the reddening problem.

(b) For bright stars, the MK system provides a frame of reference for newly developing classification systems. E.g., a narrow band photometry system, as long as it has been applied to a limited number of stars, can better be calibrated with respect to MK than by analysis of trigonometric parallaxes and proper motions. This latter, more fundamental way of calibrating has to be used of course, once the sample in the photometric system has become large enough.

(c) For faint stars, objective prism plates (as we may now be getting with the new large Schmidt telescopes equipped with objective prisms, on sites of superior seeing) give wholesale MK classification possibilities. Whereas their follow up with photometry will frequently be desirable, the MK types already allow: 1, selection of the objects; 2, identification of luminosities and check on later to be obtained photometric luminosities. A control of spectral features in addition to the information from photometry seems as a rule very useful.

Jaschek: Partially the answer was given already by Prof. Blaauw but I would like to add that spectral classification – and therefore its calibration – must go on because of the impossibility of several photometric systems to distinguish between reddened and unreddened objects of spectroscopically different appearance. Of course one cannot do spectroscopy or photometry alone, but must do both and use them together.

Keenan: Is it not historically true that the systematic correction to the original MW calibration of spectroscopic parallaxes was made first by Öpik, whose earliest Tartu paper preceeded (I think) the work of Russell and Moore?

Blaauw: I am not very familiar with the early historical developments; Dr Keenan probably is right.