PART IV

ABSOLUTE MAGNITUDE DETERMINATIONS FROM HYDROGEN-LINE PHOTOMETRY

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ABSOLUTE MAGNITUDE DETERMINATIONS FROM HYDROGEN-LINE PHOTOMETRY

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Abstract. The history and status of Balmer hydrogen-line photometry are briefly reviewed, and problems associated with calibrations in general are commented on.

The calibration work at Kitt Peak is described in some detail for B, A, and F type stars. The data used, the determination of intrinsic colours and colour excesses, photometric classification, and the relation of our indices to other people's are reviewed. With this background, the procedure used in establishing the absolute magnitude — Hβ calibration is given, and the preliminary calibration is presented. Finally, the work remaining to be done before the calibration is final is noted, and a comparison is given to Blaauw's zero-age main sequence calibration.

1. History

The history of the use of Balmer-line strengths for the determination of stellar luminosities has been a rich one over the past 50 yr, and I cannot hope to review it all, or even mention it all, here today. I will content myself, and I hope you, by briefly noting some of the past work that I feel has been particularly influential, by summarizing the current status of Balmer hydrogen-line work, and by describing in some depth the work I am most acquainted with: my own calibration efforts with the β and *uvby* systems.

Pre-1950, the major work was by Lindblad (1922, 1925, 1926), Anger (1931, 1932), Öhman (1935), and Williams (1936), who measured Balmer lines on spectral plates and discussed the relation of the derived hydrogen-line strengths to stellar luminosities. Data for stars in clusters were especially useful in such discussions, as the relative luminosities of the stars were well known.

Later, Petrie and his collaborators at Victoria (Petrie, 1950, 1953, 1956, 1965; Petrie and Maunsell, 1950; Petrie and Moyls, 1956) developed and applied the photographic technique to determine hydrogen-line equivalent widths from spectral plates for B-type stars. The technique and calibrations are reviewed and discussed in depth by Petrie (1965) in a paper giving the revision to his earlier calibration. In a paper later today, Crampton will summarize the Victoria system as it now stands.

Others who lately have been in photographic hydrogen-line efforts are Hack (1953), Kopylov (1958), Sinnerstad (1954, 1961a, b), Beer (1961), and Furenlid (1971).

Soon after Petrie's extensive effort, photoelectric techniques to measure a parameter related to hydrogen-line strengths were developed and used by Strömgren (1951, 1952, 1956a, b, 1958), Crawford (1958), Hoag (1965), Bappu *et al.* (1962), Johnson and Iriarte (1958), Beer (1964), Andrews (1968), Graham (1967), and others.

Absolute magnitude calibrations of the β index, that we use, have been given

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by Hardie and Crawford (1961), Fernie (1965), and Crawford (1970), but were based on considerably less material than the calibration that I'll present later in this paper.

Strömgren (1963) gave an excellent summary of the Balmer line work to that time, and he (Strömgren, 1966) again reviewed the status of hydrogen-line spectral-classification work. Both these review papers also discussed other narrow-band photometric classifications and calibration work.

2. Some Problems

Calibration of anything observed vs anything more-or-less physical for B-type stars is not an easy task, as the authors above have clearly shown.

What we'd really like to have are observed parameters, easy to measure for bright and faint stars, internally accurate, free of systematic effects, that are closely (even linearly) related to a physical parameter of the stars, very sensitive to the physical parameter (that is, giving a large range of the observed parameter), and completely free of the influence of any other physical parameter. Nature has not allowed any such situation to exist, and the best we can do is try to obtain parameters that will do as good a job as possible, so that we can use them with some confidence in our astronomical research. Sometimes we can measure an extra parameter, which, while useful in itself, will also allow us to correct one of the main parameters for an undesirable side effect.

An obvious example: We measure a colour index such as $(B - V)$, which is well related to effective temperature. Side effects are interstellar reddening, abundance effects, and even rotation velocity, magnetic field, and binary star effects. Any extra parameter to help correct for these side effects, such as $(U - B)$, has side effects of its own. And so it goes. Quite difficult.

In many cases, theory can help us observers quite a lot. We would be lost, or at the least inefficient, without theory to guide us. However, we must be extremely careful (as Morgan has often pointed out) not to force-fit or to let pre-conceived ideas mess us up. We are measuring observed parameters, and these we relate, or calibrate, to physical parameters. In my opinion, this philosophy is one of the keys that has led to the success of the MK system. It is a network (or two observed 'parameters') that 'classifies' or describes a star's spectrum. It is, in principle, even independent of the spectral dispersion used, for it is defined by standard stars. The observed parameters are then calibrated in terms of temperature and absolute magnitude. In fact, they have been re-calibrated many times. Such methods and philosophy are certainly valid for the best and most useful photometric systems too, I believe.

Enough of philosophy, let me now list some of the specific problems we have to watch out for, or allow for, in hydrogen-line photometry:

(a) accurate and precise standard systems, equipment, and techniques are needed to insure an accurate parameter free of systematic error,

(b) interstellar reddening corrections,

(c) rotational velocity effects,

(d) peculiar stars (however peculiar is defined),
(e) binaries,
(f) cluster membership,
(g) emission line stars, and
(h) accurate and precise absolute magnitudes to calibrate the observed parameter against.

3. The Kitt Peak Work

With this brief background, let me now go on to a detailed description of the work at Kitt Peak. The final calibrations are not quite finished, but little yet remains to be done, and I hope to finish it by the end of this year. The preliminary results presented today should differ little from the final ones.

A. THE DATA

Most of the discussion to follow will be devoted to parameters of (a) the *uvby* system, defined by Crawford and Barnes (1970c), that was originated by Strömgren and developed by him and by us at Kitt Peak, and (b) the β system defined by Crawford and Mander (1966).

The parameters used are:

V – an apparent magnitude, on the same system as the V of the *UBV* system;
$(b-y)$ – a colour index, freer of line blanketing effects than $(B-V)$ of the *UBV* system;
$(u-b)$ – a colour index;
m_1 – a colour difference, related to blanketing in the 4100 Å region;
c_1 – a colour difference, related to the Balmer discontinuity;
β – the hydrogen line-strength parameter.

These parameters are discussed in the standard-system papers mentioned above, and by Strömgren (1963, 1966).

We also use *UBV* and MK data taken from the literature, especially for comparison purposes. Not all the *uvby* or β data are our own: some have been taken from the literature and some have been kindly given to me in advance of publication. I wish to thank very much those who have supplied their unpublished data to me.

Data for the following stars have been used:

(a) northern hemisphere O–B5 stars brighter than $V=6.5$, Crawford *et al.* (1971b);
(b) southern hemisphere O to G0 stars brighter than $V=5.0$, Crawford *et al.* (1970);
(c) southern hemisphere O–B5 stars $V=5.0$ to 6.5, Crawford *et al.* (1971a);
(d) northern hemisphere A2–G0 stars brighter than $V=6.5$, Strömgren and Perry (1965) and Crawford *et al.* (1966);
(e) northern hemisphere A0-type stars brighter than $V=6.5$, Crawford *et al.* (1972);
(f) northern hemisphere B8- and B9-type stars, Crawford *et al.* (unpublished);
(g) northern hemisphere O-type stars fainter than $V=6.5$, Crawford and Golson (unpublished);

and for the following clusters and associations:

(a) Hyades, Crawford and Perry (1966);
(b) Praesepe, Crawford and Barnes (1969b);
(c) Coma, Crawford and Barnes (1969a);
(d) NGC 752, Crawford and Barnes (1970a);
(e) IC 4665, Crawford and Barnes (1972);
(f) Pleiades, Crawford (unpublished);
(g) α Per, Crawford and Barnes (unpublished);
(h) h and χ Per, Crawford *et al.* (1970);
(i) NGC 6231, Crawford *et al.* (1971);
(j) IC 2602, Hill and Perry (1969);
(k) IC 2391, Perry and Hill (1969);
(l) Sco-Cen, Hardie and Crawford (1961), Glaspey (1971);
(m) Orion, Crawford (1958), Crawford and Barnes (1966);
(n) III Cep, Crawford and Barnes (1970b);
(o) NGC 2362, Perry (unpublished);
(p) II Per, Crawford (1958);
(q) NGC 6871, Cohen (1969);
(r) NGC 6910, Crawford and Barnes (unpublished);
(s) NGC 6913, Crawford and Barnes (unpublished);
(t) NGC 6611, Crawford and Barnes (unpublished);
(u) NGC 5460, Claria (1971);
(v) NGC 2264, Strom *et al.* (1971); and
(w) NGC 2244, Heiser (unpublished).

B. INTRINSIC COLOURS AND COLOUR EXCESSES

For the A- and F-type (those stars cooler than about A2, the location of maximum hydrogen absorption), we determine the intrinsic colour from the following equation:

$$(b-y)_0 = a - b\,\beta - c\,\delta c_1 - d\,\delta m_1 .$$

For A-type stars (β=2.890 to 2.720), the constants used are a=2.943, b=1.000, c=0.100, d=0.100. The resulting mean error, for one star, as determined from stars within 100 pc, is $\pm 0\overset{\mathrm{m}}{.}011$. This scatter includes effects of duplicity, rotation velocity, and so forth, as essentially no data were eliminated from the least squares solution. It can be seen that β is an effective parameter in predicting intrinsic colour, for c and d are small; i.e., little luminosity or abundance effects exist.

For F-type stars (β=2.720 to 2.600), the coefficient b increases as we go to later types (smaller β), as β begins to lose sensitivity to temperature near G0 while $(b-y)$ does not; the coefficient c is 0.1 or a bit smaller; and the coefficient d increases toward later spectral type, as blanketing effects become larger.

Details and limitations of the calibrations for A- and F-type stars will be discussed fully in a forthcoming paper; a summary has been given by Crawford (1970).

For the B-type stars, we have determined colour excesses, $E(U-B)$, and intrinsic

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colours $(U-B)_0$, for those stars with available *UBV* data, by a procedure described by Crawford (1958). A linear reddening slope has been assumed: $E(U-B)/E(B-V) = 0.72$. This use of a linear slope may not be justified in all cases, but should be adequate for the discussions to follow. I prefer the use of $(U-B)_0$ to $(B-V)_0$ for B-type stars, as the former has a considerably larger range (about 4 times larger than $(B-V)_0$). I also prefer it over the parameter Q (Johnson and Morgan, 1953) as it is a more natural parameter, i.e., the intrinsic colour, and is no more difficult to determine than is Q.

For an overall discussion of effects of interstellar reddening on the *UBV* parameters, I believe that the investigation by Fitzgerald (1970) is the most complete.

For investigation of reddening effects on the *uvby* system, I have used the data noted above. Figures 1, 2, and 3 show the relation between the observed $(u-b)$, m_1, and c_1 indices with respect to $(b-y)$ for O-type stars. Separate symbols are used in

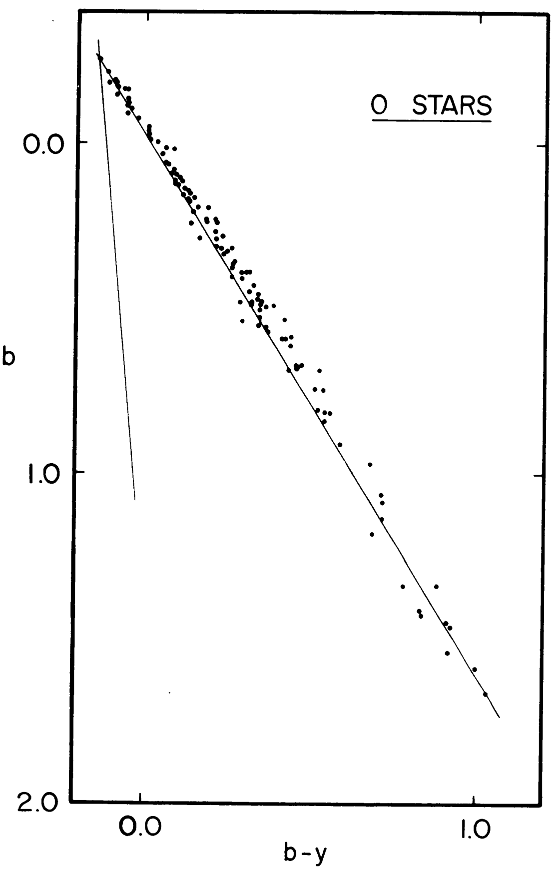

Fig. 1. The $(u-b)$ vs $(b-y)$ relation for a number of O-type stars observed from Kitt Peak. A linear line of slope 1.61 is shown through the data points. The line to the left traces the intrinsic colour line for B-type stars.

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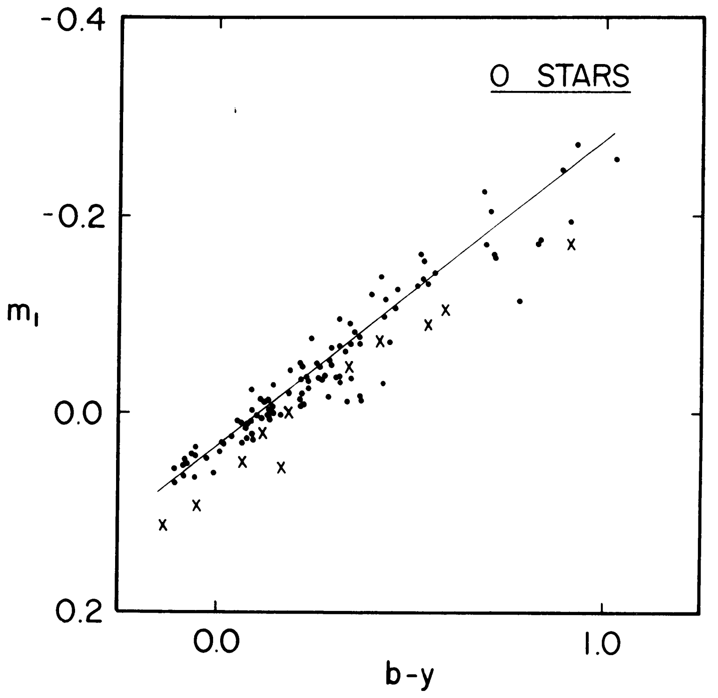

Fig. 2. The m_1 vs $(b-y)$ relation for a number of O-type stars. A reddening line, with slope near -0.3, is shown. Crosses denote Of-type stars.

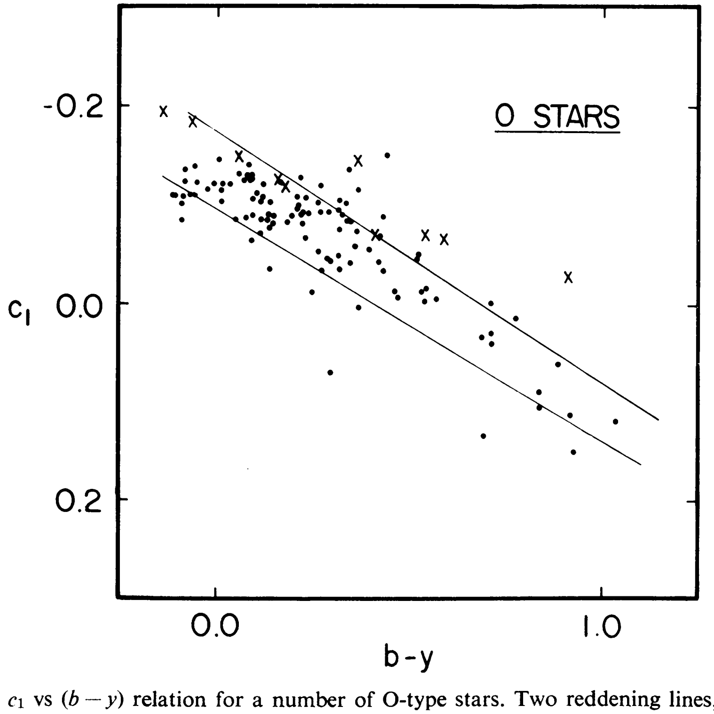

Fig. 3. The c_1 vs $(b-y)$ relation for a number of O-type stars. Two reddening lines, with slopes near 0.2, are shown. Crosses denote Of-type stars.

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Figures 2 and 3 for the known Of type stars. Allowing for some luminosity and spectral type effects, I have derived the following reddening relations:

$$E(u-b) = 1.6\,E(b-y),$$
$$E(m_1) = -0.3\,E(b-y), \quad \text{and}$$
$$E(c_1) = 0.2\,E(b-y).$$

One can also derive $E(b-y) = 0.73\,E(B-V)$ from a plot of $(b-y)$ vs $(B-V)$ for the same stars. I have used these four reddening relations in the work described below.

Figure 4 shows the relation between the observed c_1 and $(b-y)$ indices for the brighter O to B5-type field stars. A well defined, left-hand envelope is evident, and it

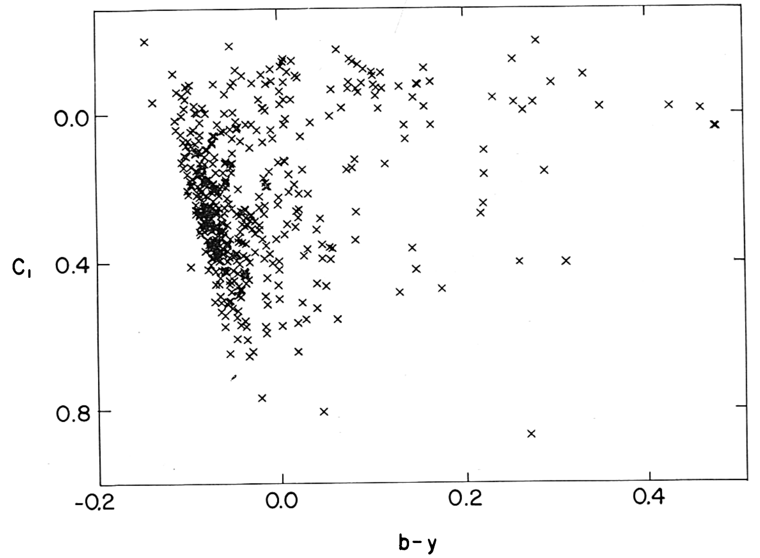

Fig. 4. The c_1 vs $(b-y)$ diagram for O-to-B5 type stars brighter than $V = 6.5$. Reddening lines are nearly horizontal in the diagram, with the intrinsic colour line as the left-hand envelope of the points.

may be defined as the intrinsic colour relation (at least to a first approximation). For the preliminary calibration, I have assumed $(b-y)_0 = -0.116 + 0.097c_0$, where c_0 is the unreddened c_1 index. The final calibration will allow for non-linearities and for small luminosity effects evident both in the observed data for bright stars and in theoretical model atmospheres. Checks have been made by calculating colour excesses for clusters in which the reddening is either zero or essentially uniform. (See, for example, Hill and Perry (1969) and Crawford *et al.* (1970).)

A comparison of the reddening values so obtained with values obtained from *UBV* data (the procedure described above) and from MK types and $(B-V)$ values shows that the agreement (where data are good) is excellent. For example, a detailed comparison of the three methods is given by Crawford *et al.* (1970) for the stars in the h and χ Per clusters.

In all the work to follow, we have assumed the ratio of total-to-selective absorption to be $A_V/E(B-V)=3.2$; i.e., $A_V/E(b-y)=4.3$.

C. HYDROGEN-LINE DATA, AND PHOTOMETRIC TWO-DIMENSIONAL CLASSIFICATION FOR B-TYPE STARS

In Figure 5, I show the relation between our observed β values and Petrie's Hγ values for B-type stars with data in common. The Hγ values have been taken from a recent compilation by Crampton, who has kindly sent me his data. Only a sampling of data

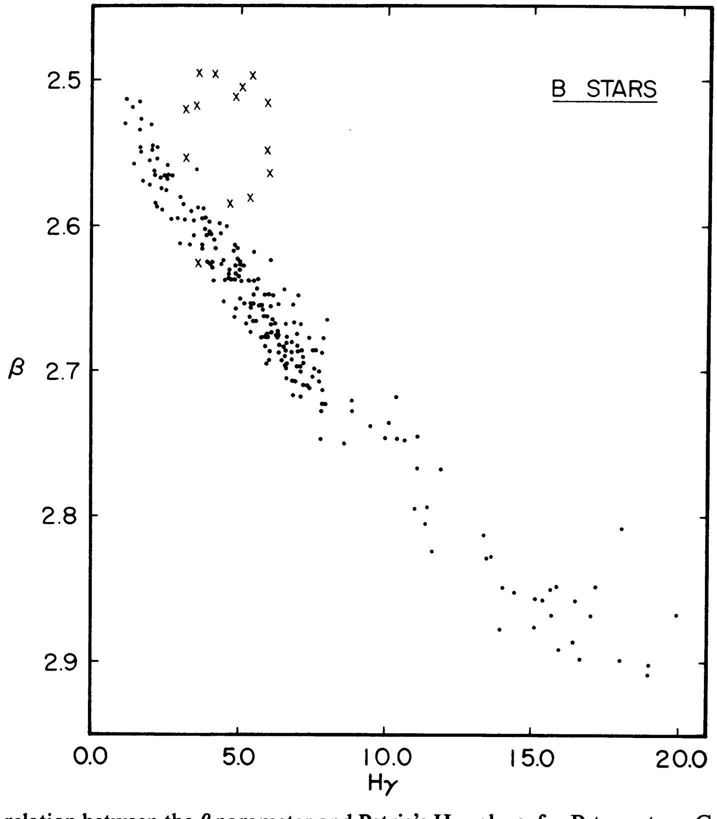

Fig. 5. The relation between the β parameter and Petrie's Hγ values, for B-type stars. Crosses denote known emission line objects; points for some such objects would lie off of the top of the figure. Only a sampling of points for late B-type stars are shown.

for the later B-type stars has been plotted, to show the trend. Emission line objects are generally well separated from the main relation. No scatter due to rotation velocity effects is apparent in the data, and the overall scatter in the relation is close to that expected from observational error alone.

In Figure 6, we show the relation between two well-observed photoelectric parameters. The data plotted are for the β system standard stars, the β's taken from

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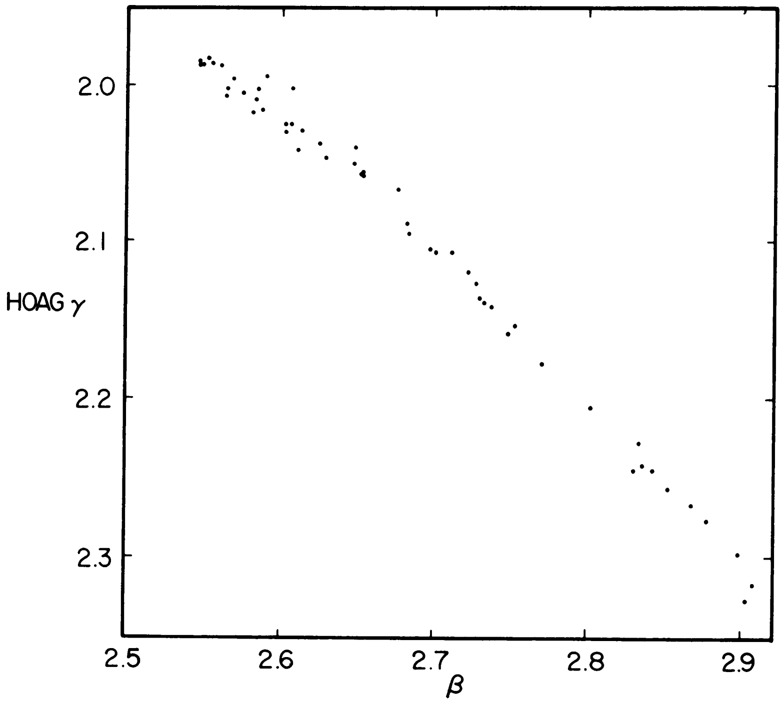

Fig. 6. The relation between the β parameter and Hoag's photoelectric Hγ parameter, for standard stars of the β system.

Crawford and Mander (1966) and the Hγ values from Hoag's unpublished γ values for the same stars. We wish to thank him for permission to show his data. As can be seen, the scatter is quite small.

In Figure 7, we show our β data plotted against Andrews' (1968) Hα data, for B-type stars. The points above the average relation are due to emission line stars. Again, as in the Hγ vs β plots, points for emission line stars are well separated from the main relation, and no rotational velocity effects are evident in the relation. Many supergiant stars have hydrogen emission, but the data for them lie along the main relation (upper left). The separation of such stars from main sequence emission line objects is rather easy. The turn-up for the brighter B-type stars is due to non-LTE effects, leading to emission (see Mihalas, 1972, and the references given there). The transition to emission is smooth, as theory predicts. An Hα parameter should thus be better than an Hβ parameter for absolute magnitude determinations for the brightest B-type stars. For later B-type stars, Hβ is probably better, and the two together can separate out 'emission-line stars'. Neither will work well if the emission is variable.

Photometric classification is possible with the parameters we have measured or derived above. The parameters measuring the Balmer discontinuity [$(U-B)_0$, c_0] relate to effective temperature, the hydrogen-line parameters [β, γ, or α] relate to luminosity, or absolute magnitude. A (β, c_0) diagram, therefore, is rather like an HR

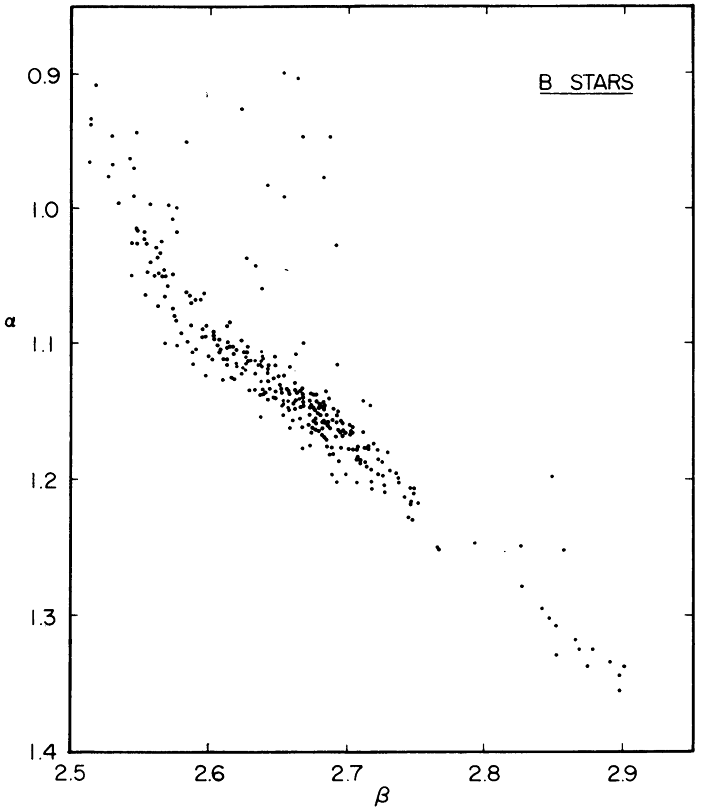

Fig. 7. The relation between the β parameter and Andrews' photoelectric Hα parameter. Emission line objects lie above the average relation. Points for B-type supergiants lie in the upper left of the diagram. Only a sampling of points for late B-type stars are shown.

diagram, or a colour-magnitude diagram. Furthermore, 'boxes' can be drawn in such a diagram relating to MK types. In fact, the relation of the photometry to the spectral types is very good; see, for example, Crawford (1958). Exceptions are usually 'peculiar' stars; for example, see Garrison (1967) and Cowley and Crawford (1971).

In Figure 8, we show the (β, c_0) data for the O–B5 stars brighter than V=6.5. A lower envelope is apparent. This lower boundary defines our 'zero-age main sequence' (ZAMS), and we interpret the scatter above it (except for that due to observational error!) to be due to the stars having evolved above the ZAMS and hence having greater luminosities for a given temperature. Such an interpretation is good only to a first approximation, of course, as the parameters are not ideal ones, as described in Section 2 above. In the final calibration, we will use a parameter $\delta\beta$ defined as

$$\delta\beta = \beta(\text{ZAMS}) - \beta(\text{observed}),$$

and relate this $\delta\beta$ to δM_V, where

$$\delta M_V = M_V(\text{ZAMS}) - M_V(\text{'observed'}).$$

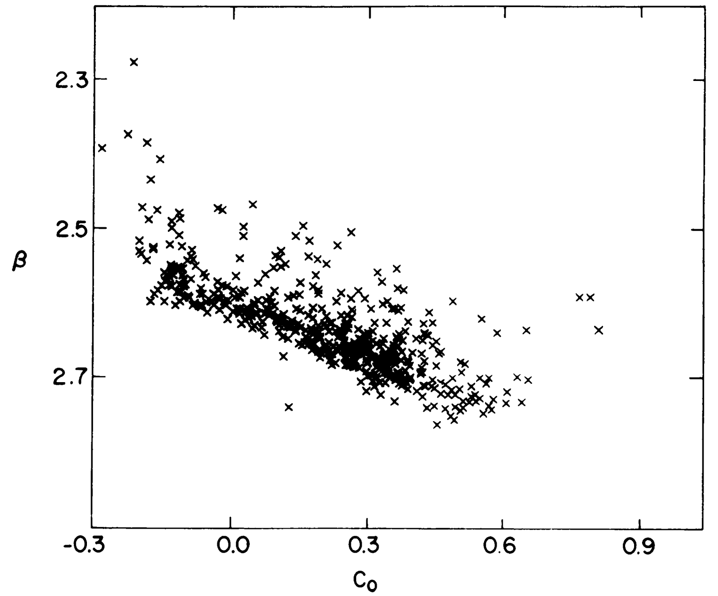

Fig. 8. The β vs c_0 diagram for O- to B5-type stars brighter than $V=6.5$. We define the lower envelope as the 'zero-age main sequence' (ZAMS).

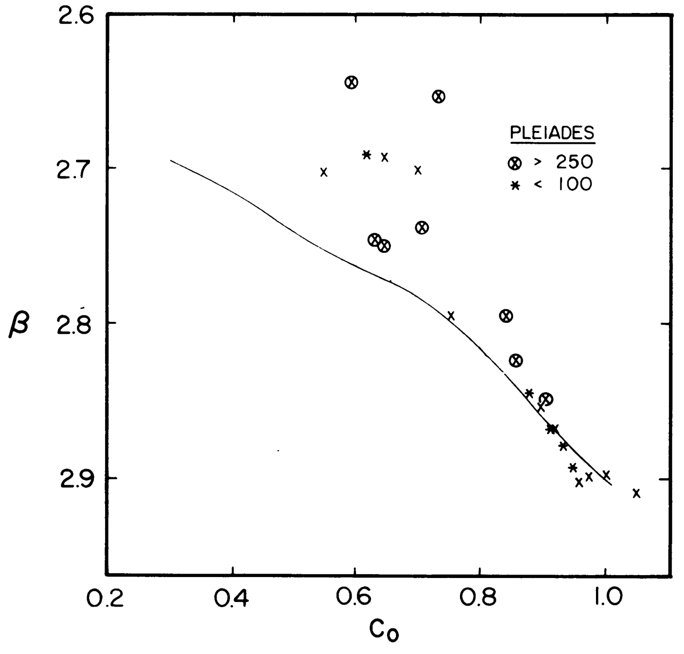

Fig. 9. The β vs c_0 relation for B-type stars that are members of the Pleiades cluster. Different symbols denote stars with large or small $V \sin i$ values (in km s^{-1}). The line drawn in the diagram is the ZAMS.

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In Figure 9, we show the (β, c_0) relation for the B-type stars in the Pleiades cluster. The separation of the brighter stars from the ZAMS line is evident. Little, if any, effect is noticeable due to $V \sin i$ differences.

D. THE ABSOLUTE MAGNITUDE CALIBRATION

We do the calibration by several distinct steps:

(1) Determine the shape of the ZAMS relation between M_V and β for the A and F stars, by observations in clusters. In three of the clusters used, Pleiades, α Per, and IC 4665, the A and F stars should be nearly unevolved; therefore, no correction for any δM_V above the ZAMS has been applied. For the other clusters, a correction has been applied to those stars with significant δc_1 (For discussion of these corrections, see Stromgren, 1966, and Crawford, 1970.). For A-type stars $8\ \delta c_1 = \delta V_0$ has been added to the individual V_0's; for F stars $11\ \delta c_1 = \delta V_0$ was used. The V_0 vs β relation for the stars in IC 4665 is shown in Figure 10, as an example. Diagrams for the separate clusters were overlayed, sliding the diagrams vertically along lines of equal β, and

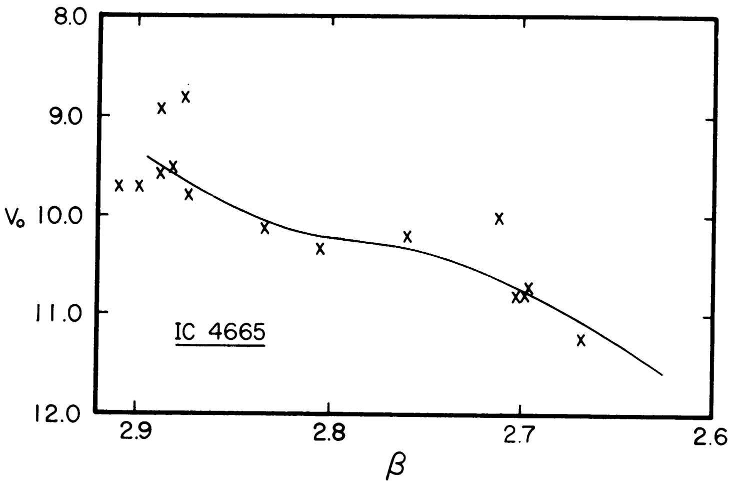

Fig. 10. The V_0 vs β relation for A, F-type members of the cluster IC 4665. A mean relation is drawn through the points.

a smooth mean relation best fitting the individual relations was drawn. The Hyades and Praesepe were *not* used in this determination.

(2) Determine the zero-point of the relation from a fit to trigonometric parallax stars. Absolute magnitudes were calculated for those stars with parallaxes greater than 0".100, in the *Yale Trigonometric Parallax Catalog* (Jenkins, 1963), and for those with parallaxes greater than 0".060 having large weight. The resultant absolute magnitudes were plotted in a (M_V, β) diagram, and the corrections for δM_V applied whenever δc_1 was not equal to zero. The mean slope determined above, in Step 1, was then fitted to the corrected points. The result is shown in Figure 11. It can be seen that the mean cluster slope fits the data for the parallax stars quite well.

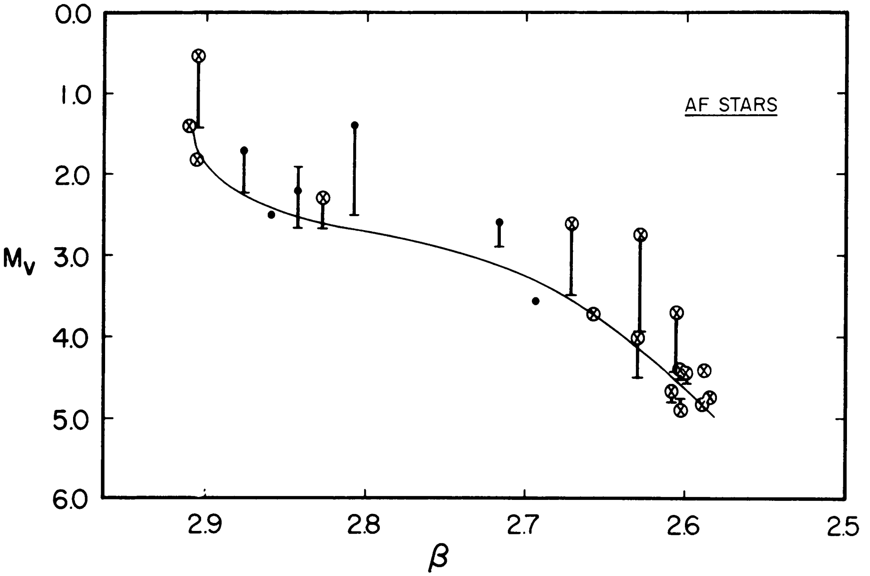

Fig. 11. The M_V vs β relation for A, F-type stars with large trigonometric parallaxes. The vertical line with the cross-bar shows the correction for evolutionary effects (see text). The mean relation from clusters is drawn in the figure, as best fitting the points for the parallax stars. The line, therefore, is the calibration valid for the ZAMS for the A- and F-type stars.

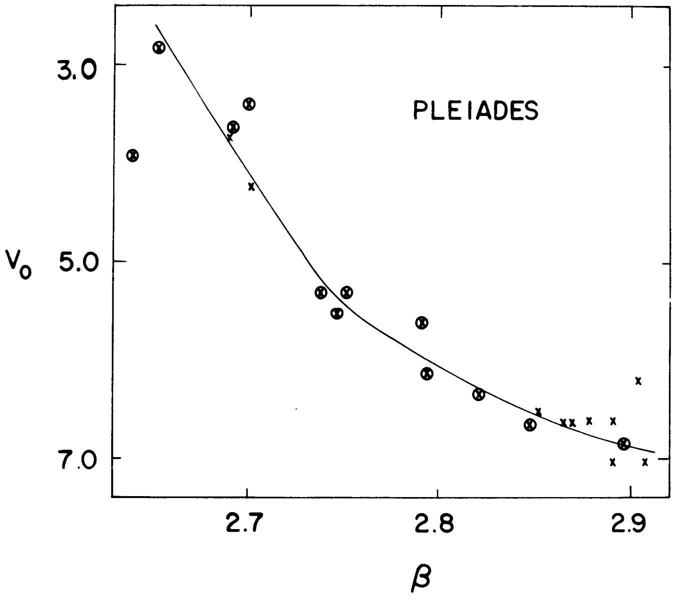

Fig. 12. The V_0 vs β relation for B-type members of the Pleiades cluster. The crosses with circles about them denote stars with $V \sin i$ greater than 200 km s^{-1}. The line is an eye estimate of the best fit to the points.

We therefore define this best fit as the ZAMS for A- and F-type stars, as a function of the parameter β. Furthermore, if the observed data for a given star, whether cluster member or field star, has a non-zero δc_1, we correct the ZAMS absolute magnitude for this 'evolutionary' effect. That is, $M_v = M_V\,(\mathrm{ZAMS}) - f\,\delta c_1$, where $f = 8$ for an A star and $f = 11$ for an F star.

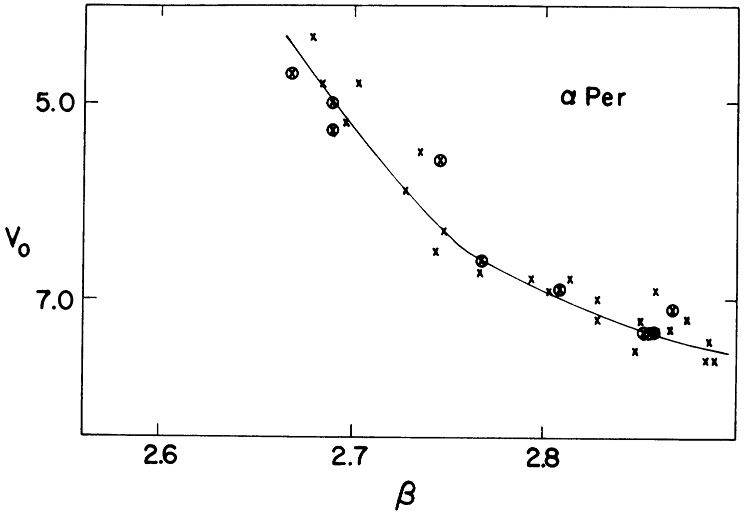

Fig. 13. As in Figure 12, but for members of the α Per cluster.

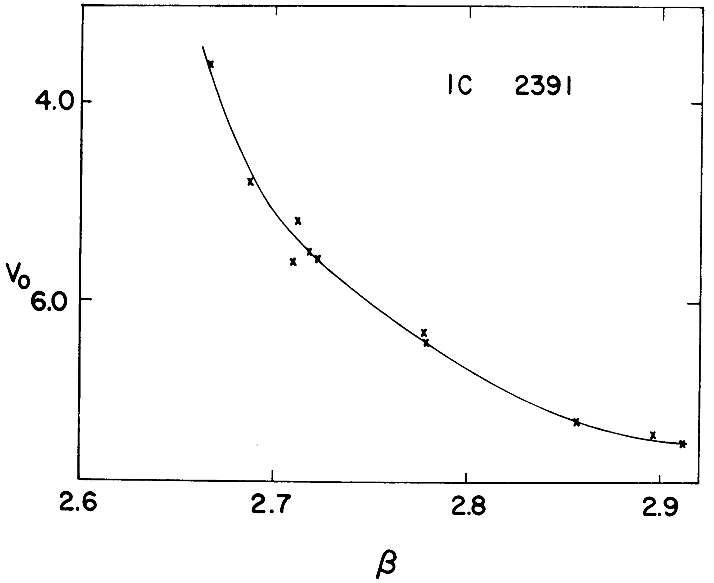

Fig. 14. The V_0 vs β relation for B-type members of the cluster IC 2391. Data from Perry and Hill (1969). The line is an eye estimate of the best fit to the points.

A 'by-product' of this preliminary calibration is the distance modulus to each of the clusters used in the fitting process. In particular, we find $5\overset{m}{.}5$ for the Pleiades, $6\overset{m}{.}2$ for the α Per cluster, and $7\overset{m}{.}5$ for IC 4665. We will use these values to fix the zero-point for the absolute magnitude calibration for the B-type stars.

(3) Determine the V_0 vs β relation for clusters containing B-type stars. Data for each of the clusters referenced above were used. We show in Figures 12 to 16 the relations for several of the clusters: the Pleiades, α Per, IC 2391, Orion, and NGC 6231.

(4) Overlay these V_0 vs β diagrams, sliding along lines of equal β, so as to determine the best fitting mean relation for all clusters. This procedure is quite similar to that used by Petrie for his Hγ calibration. He had considerably less data to use, however. In doing this overlay, I was impressed that little evolutionary or $V \sin i$ effects appear to be present.

(5) Determine the zero-point for the resultant mean relation (that is, change the V_0 scale to M_V by forcing the distance moduli of the three clusters of Step 2 to agree with the calibration). The resulting, preliminary, calibration is shown in Figure 17, as a smooth line. The symbols show Fernie's (1965) calibration, based on earlier, less complete, data.

The calibration also fits well the points for Sirius and Vega (from trigonometric parallaxes) and for Spica (from the interferometric work of Herbison-Evans *et al.* (1971)).

(6) Check the preliminary calibration for systematic errors to due age differences,

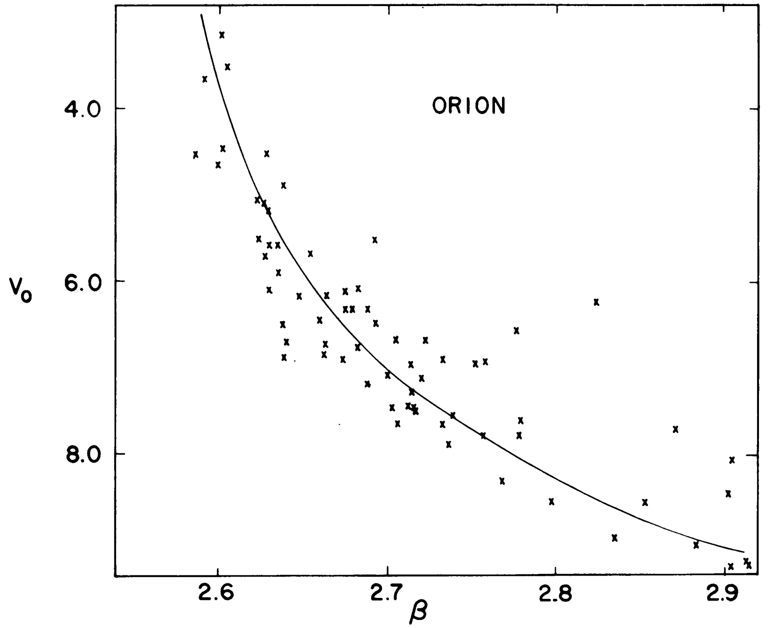

Fig. 15. The V_0 vs β relation for B-type stars in the Orion association. The line is an eye estimate of the best fit to the points.

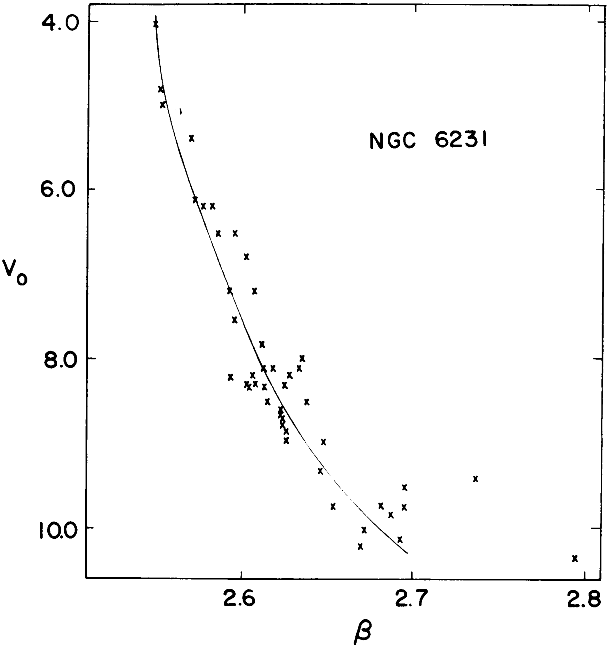

Fig. 16. As in Figure 15, but for members of the cluster NGC 6231.

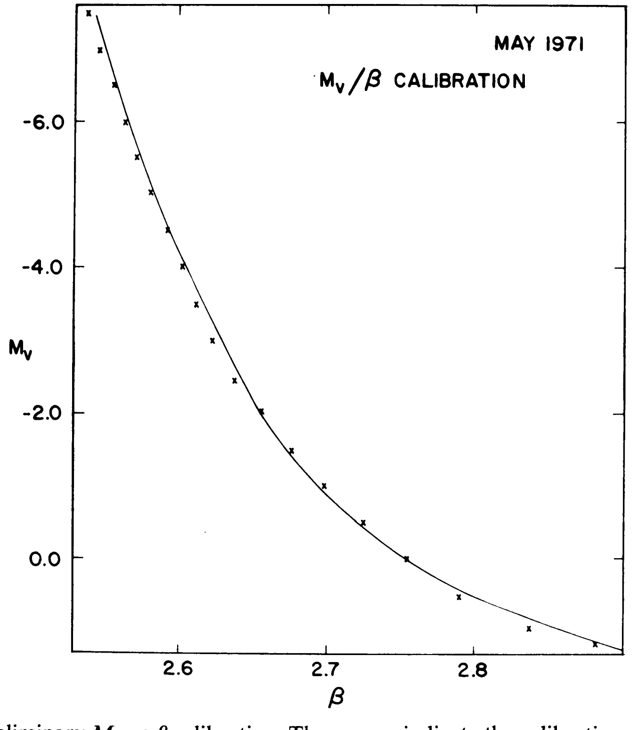

Fig. 17. The preliminary M_V vs β calibration. The crosses indicate the calibrations of Fernie (1965). The preliminary calibration is valid for stars on or near the ZAMS, but should be useful for evolved stars as well (see the text).

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rotational velocity effects, frequency-of-binary differences from cluster to cluster, spectral type effects, emission line stars, etc.

In general, we find few significant effects. In particular, there appear to be no systematic effects due to differences in $V \sin i$ from star to star, as Petrie (1965) also concluded from his photographic Hγ work.

Small age effects, or spectral type effects, depending on your point of view, do exist, but they are less than in the cluster fitting techniques previously used, for example, by Johnson (1957) or Blaauw (1963).

The last two figures are propaganda for the hydrogen-line technique and calibration. Figure 18 shows the $(V_0 - M_V)$ vs V_0 relation for the Pleiades, where evolutionary effects are certainly present. In the top part of the diagram, M_V's were determined using Blaauw's M_V (ZAMS) vs $(U-B)_0$ calibration. In the bottom half, the M_V's were determined using the M_V vs β calibration of Figure 17. Figure 19 shows the equivalent diagram for the α Per cluster. Clearly the latter technique is to be preferred (at least, I think so!), especially for field stars.

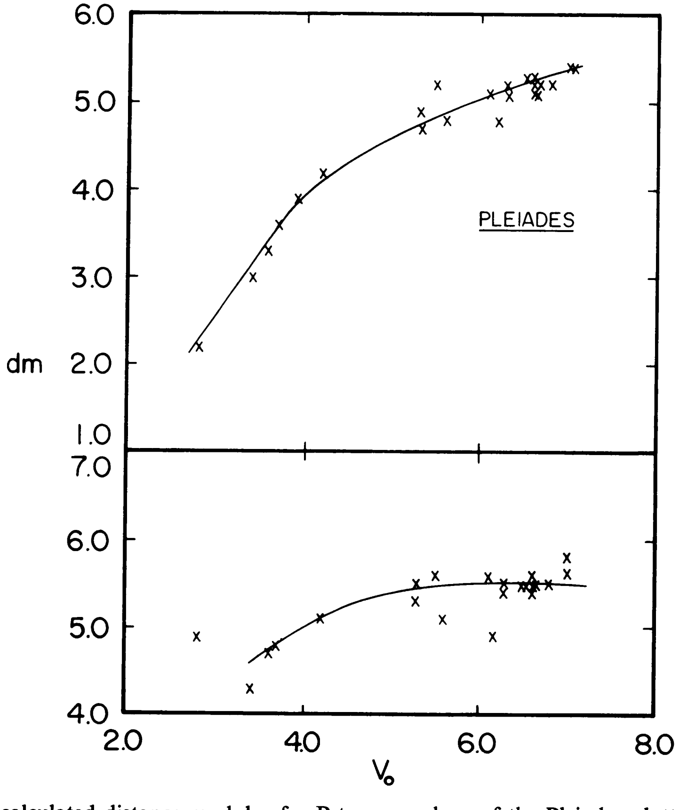

Fig. 18. The calculated distance modulus for B-type members of the Pleiades plotted versus their V_0 magnitude. Points on the top diagram were calculated using Blaauw's (1963) calibrations of M_V (ZAMS) vs $(U-B)_0$; points in the bottom diagram using the calibrations shown in Figure 17. Curvature indicates 'evolutionary effects'. (see text).

The final calibrations, nearly completed, will allow for these evolutionary effects via a δM_V correction, in terms of a $\delta\beta$ above the ZAMS in the β vs c_0 diagram. Things remaining to be done before I am willing to label the calibration as final are:

(a) remaining checks for systematic effects,

(b) averages for each MK spectral type,

(c) final determination of the $\delta\beta$ factor as a function of spectral type, and

(d) comparisons to other absolute magnitude calibrations.

I would like to conclude by showing one of the comparisons; Table I summarizes the comparison. For stars of a given MK spectral type, I have determined the average

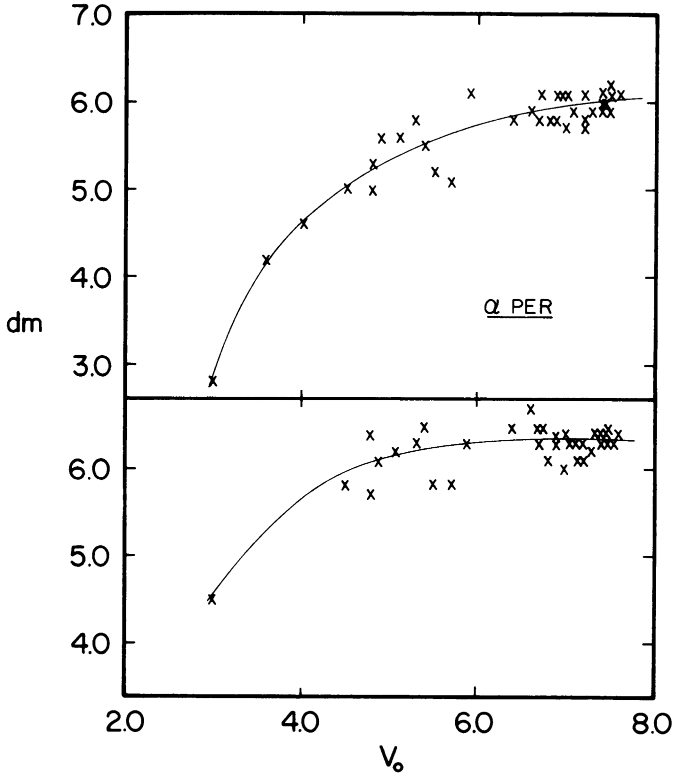

Fig. 19. As in Figure 18, but for members of the α Per cluster.

c_0 (there were about 20 stars in each sub-type). I then read off plots of c_0 vs $(U-B)_0$ the equivalent $(U-B)_0$ for each type. The resultant values agree closely with other author's average values for each sub-type, for example, Schmidt Kaler's (1965). I also read off the ZAMS line in the c_0 vs β diagrams the value of β equivalent to each average c_0. This β then gives us a M_V value from the calibration, valid for the ZAMS. From Blaauw's M_V (ZAMS) vs $(U-B)_0$ calibrations, I also obtained an M_V value valid for the ZAMS. Each of these values is given in Table I, and the agreement is excellent, better than I would have expected, perhaps. In any case, I think one can

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TABLE I

Comparison of the β, M_V calibration with Blaauw's $(U-B)_0$, M_V calibration, both valid for the ZAMS

MK type	c_0	$(U-B)_0$	β(ZAMS)	$M_V(\beta)$	$M_V(U-B)_0$
O9	$-0^{m}.12$	$-1^{m}.10$	$2^{m}.590$	$-4^{m}.6$	$-4^{m}.5$
B0	-0.07	-1.05	2.608	-3.9	-3.9
B1	$+0.02$	-0.96	2.629	-2.9	-2.8
B2	$+0.15$	-0.84	2.658	-1.9	-1.8
B3	$+0.33$	-0.67	2.701	-1.0	-0.9
B4	$+0.37$	-0.63	2.709	-0.8	-0.8
B5	$+0.42$	-0.59	2.720	-0.6	-0.6
B6	$+0.48$	-0.55	2.735	-0.3	-0.3

confidently use the (β, M_V) calibration, especially for stars near the ZAMS, and, with care, even for evolved stars.

I hope to have the final calibration done and in press shortly (particularly if the 4-m telescope program goes smoothly this fall and winter!). I would be most happy to receive constructive criticisms both now and after the meeting, before I get the final calibration finished.

Acknowledgments

I wish to thank very much those who have allowed me to use their data in advance of publication. I also wish to thank Dr Bengt Strömgren for his encouragement and advice throughout all phases of the work, Mrs Jeannette Barnes, and Mr John Golson, without whom my research would have withered more than it has during my large telescope adventures, and those many astronomers with whom I have had many enjoyable and profitable discussions about photometry and calibrations.

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DISCUSSION

Crampton: In the case of known binary stars did you make correction for duplicity?

Crawford: We did not make any correction for duplicity. The binaries are generally included in the discussion.

Blaauw: How large would you estimate the probable error of the main sequence fit to the trigonometric parallax stars, i.e., the p.e. of the zero point of the newly derived M_V system?

Crawford: Something like $0^m.1$ or $0^m.2$.

Wesselink: Could you use your M_V vs β technique to the non emission (apparently fainter) B stars in the Magellanic Clouds with consequent result for the distance modulus?

Crawford: Yes, we are observing just such stars at the present time.

Schmidt-Kaler: You showed a diagram Hα vs Hβ with quite a few emission B stars, and a diagram Hβ vs Hγ with very few. Did you put the same stars in both diagrams? Or does this mean that you find a discontinuous Balmer jump?

Crawford: Most of the stars are the same. Many more stars show emission at Hα than at Hβ or Hγ.

Jaschek: Did you observe in Orion stars which show helium line anomalies? Did you exclude B-type peculiar stars or, in general, peculiar stars?

Crawford: We observed a few of the stars in Orion that you refer to. Some look odd in our photometry, some do not. In general, we include peculiar stars in our work. The Am stars fit the calibrations for the A stars quite well. Most Ap stars look like B stars to me.

Maeder: With regard to the position of the Of stars in some of your diagrams one should note than, according to Walborn, the f-characteristics may be identified with a luminosity effect. One may show that the different position of the Of stars in $(U-B)$ vs $(B-V)$ diagram is in complete agreement with the luminosity effect predicted by the recent non-LTE models of Auer and Mihalas. This may be considered as a supplementary support to the hypothesis that the Of stars are intrinsically brighter that the so-called normal O-type stars. The observed difference is not due to the contribution of the emission lines in the filters ($< 0^m.003$) but to a change produced by the luminosity effect in the energy distribution.

Blaauw: Do stars in the Taurus stream, which is associated with the Hyades, behave similar to the Hyades proper in the c_1 vs β diagram?

Crawford: Yes, most of them look like stars in the Hyades cluster, according to Eggen.

Jones: I find that a back-warming correction is required in β when comparing stars of very different metal abundance. It amounts to roughly $0^m.05$ between stars of 0.01 the solar abundance and those of solar abundance.

Murray: Could the Hyades discrepancy be accounted for by slight differences in the proper motion system depending on apparent magnitude, leading to systematic differences in the absolute magnitudes, also depending on apparent magnitude?

Crawford: I don't think so; if anything, the photometry would indicate that there are no such difficulties.

Garrison: Isn't it disturbing that the two clusters which you find do not fit are the only old, rich clusters?

Crawford: Yes, however, the statistics of small numbers allow all sorts of puzzles.

Hauck: I just want to mention that all published measurements in the *uvby* β system have been compiled here by Lindemann and myself. It is possible to obtain the tape at the Centre de Données Stellaires in Strasbourg. Now we have 6000 stars and we hope to publish as soon as possible a general catalogue with homogeneous data.