# 17. THE HYDROGEN LINES AS LUMINOSITY CRITERIA IN EARLY-TYPE STARS

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In this short paper, the calibration procedure for the absolute magnitudes derived from the H$\beta$ indices will be discussed. These H$\beta$ indices have been measured for the distant OB-type stars in our studies of galactic structure and are discussed in the paper by Bok which is found elsewhere in this volume (Paper 36).

The intensity of the hydrogen lines in the spectra of early-type stars has long been recognized as an indicator of their absolute magnitudes. This quantity is mainly dependent on the electronic and ionic Stark broadening in the star's atmosphere which is, in turn, well correlated with the surface gravity and the luminosity of the star. It is also dependent to a smaller degree on the temperature in the star's atmosphere, and earlier workers have emphasized that corrections for this should be made if any calibration is to include stars for which the spectral types cover a wide range.

In the application of the method to problems of galactic structure, two factors should be kept in mind. Firstly, since apparently faint OB-type stars are likely to be very important in any study of distant galactic associations, it is essential that the equipment used should utilize the available light as efficiently as possible in order to obtain a measure of the intensity of one or more of the hydrogen lines. Secondly, in all programs of this nature, it is desirable to observe large numbers of stars and so the time of observation per star should be kept to a minimum.

For these reasons, a one-parameter luminosity classification using the equivalent width of the H$\beta$ line was employed in conjunction with three-colour, broad-band photometry on the *UBV* system which was used to determine the apparent magnitudes and the interstellar absorption corrections required to estimate distances.

A measure of the equivalent width was obtained by using the method initiated by Strömgren and developed further by Crawford (1958). This method uses two interference filters, one of 15 Å half-width and another of 150 Å half-width both being centred on the H$\beta$ line. These filters can be mounted in a conventional photometer and the ratio of the intensities measured with a photomultiplier. By the extensive measurement of his standard stars (Crawford 1960) on each night of observation, the observed ratios are converted directly into H$\beta$ indices on Crawford's system.

The general approach to the calibration problem is to compile a list of early-type stars for which reliable MK spectral classifications as well as H$\beta$ indices are available and to use the most recent MK luminosity calibration, that of Johnson and Iriarte (1958), to derive spectroscopic absolute magnitudes. Many of our calibrating stars are members of young galactic clusters and of associations similar to those that we have observed in our studies of galactic structure. The H$\beta$ index is then plotted against these absolute magnitudes, and curves of best fit are computed for the different luminosity classes. Although the internal luminosity dispersion in the MK classes is considerable, we can, by using a large number of stars in the calibration, effectively eliminate this scatter. Data for 165 stars were used in the calibration. In Figure 1 is shown the graph for a typical sample of about 25% of the calibrating stars. The different MK luminosity classes are divided into three groups: classes I and II, classes III and IV, and class V, and these are plotted with separate notations in the figure. Two features of Figure 1 should be noted. Firstly, the stars of classes I and II are grouped to the top left of the diagram with a relatively small dispersion in the Hβ index and in absolute visual magnitude, $M_V$. Secondly, the stars of classes III and IV tend to lie systematically to the left of the class V stars, particularly for the late-B spectral types.

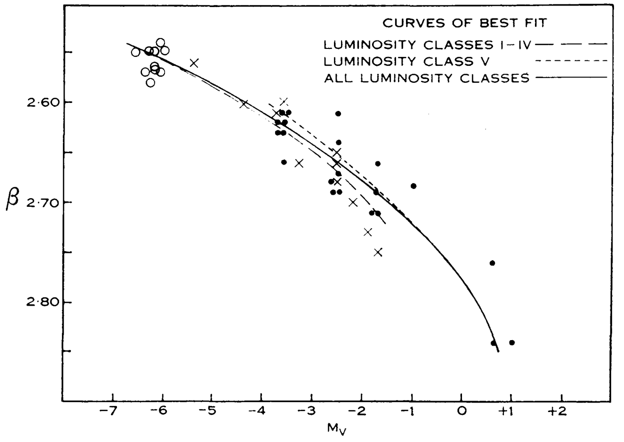


Fig. 1.—Hβ index (ordinate) plotted against spectroscopic absolute magnitude (abscissa) for different MK luminosity classes. Least-squares curves of best fit are also drawn for the three cases described in the text. Luminosity classes I and II, O; luminosity classes III and IV, ×; luminosity class V, ●.

With the aid of the I.B.M. 1620 computer of the Australian National University, least-squares polynomials of best fit have been computed for three cases: (1) luminosity classes I–IV, (2) luminosity class V, (3) all luminosity classes. The curves for the fourth degree polynomials of best fit are also plotted in Figure 1. A systematic displacement of the curve for classes I–IV with respect to the curve for class V is clearly indicated. If there are no systematic errors in the MK calibration, we conclude from Figure 1 that the absolute-magnitude calibration curve depends slightly on the luminosity class. In the absence of detailed information for a program star, the precision of this calibration is therefore limited. The curve for all classes combined, which lies between the curves for classes I–IV and class V, approaches the former at high absolute luminosities and the latter at low luminosities in an asymptotic manner. This curve reflects the choice of calibrating stars which was made largely from young associations and clusters. Since it is expected that the objects under study will be basically similar to the clusters and associations from which many of the calibrating stars were drawn, it is reasonable to suppose that the combined curve represents the best calibration for the Hβ indices in this particular application.

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Several other factors contribute to the scatter about the calibration curve. One cause of scatter arises from the multiplicity of many early-type stars. Stellar systems of two or more components which differ little in spectral type and luminosity are especially responsible for errors in the estimates of absolute magnitude. The measured H$\beta$ index of the stellar system is essentially a measure of an average atmospheric pressure in the stars. This value of the H$\beta$ index will correspond to an absolute magnitude on the calibration curve which will, in general, be fainter than the combined light of the stellar system.

The effects of emission lines are naturally very important in the application of this method. Known emission-line stars invariably give rise to such anomalous H$\beta$ indices that they can be immediately discarded. In other cases, however, there are similar anomalies of lesser degree and the decision as to whether emission is present or not can be difficult. It is certain that this effect contributes further scatter to the absolute magnitude calibration.

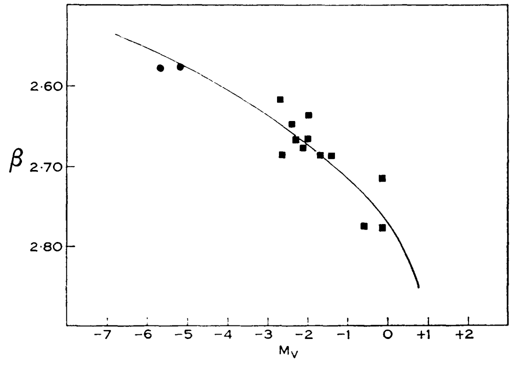


Fig. 2.—H$\beta$ index (ordinate) plotted against absolute magnitude (abscissa) for the B-type stars in the galactic clusters NGC 2264 and NGC 6383. Also plotted is the adopted calibration curve. Luminosity class V, ●; unclassified, ■.

These points can be illustrated with the results of some H$\beta$ photometry of the B-type stars in galactic clusters for which good photometric distances are available. With these distances, absolute magnitudes for the cluster members are computed and these can be plotted against the H$\beta$ indices. In Figure 2 such a diagram is plotted for the young clusters NGC 2264 and NGC 6383. For NGC 2264 a true distance modulus of $9\overset{m}{.}6$ was used which is the mean of the values published by Walker (1956) and by Johnson (1957). The true distance modulus of $10\overset{m}{.}5$ derived by Eggen (1961) was used in the calculation for NGC 6383. Also plotted is the adopted calibration curve. Keeping in mind the intrinsic uncertainties of all photometric distance moduli, it is clear that the general agreement is good over the whole range of absolute magnitude.

A similar diagram for the older clusters NGC 6087 and IC 4725 (Messier 25) is presented in Figure 3. A distance modulus of $9\overset{m}{.}6$ was used for NGC 6087, derived from corrections made by the author to the photometry of Fernie (1961), who obtained a distance modulus of $9\overset{m}{.}4$. The distance modulus of IC 4725 was taken to be $9\overset{m}{.}1$, as proposed by Wampler *et al.* (1961) in their very thorough discussion of all the available observational data for the cluster. Some spectral classifications in NGC 6087 carried out by Feast (1957) have also been used. In Figure 3, the tendency of the points representing the stars of classes III–IV in the clusters to lie to the left of the calibration curve is apparent. Also prominent are several points which lie very much above the calibration curve. Two such deviating points, underlined in the figure, are known emission-line stars, and it is probable that many of the stars similarly positioned are affected by Hβ in emission which has not yet been detected by conventional spectroscopic techniques.

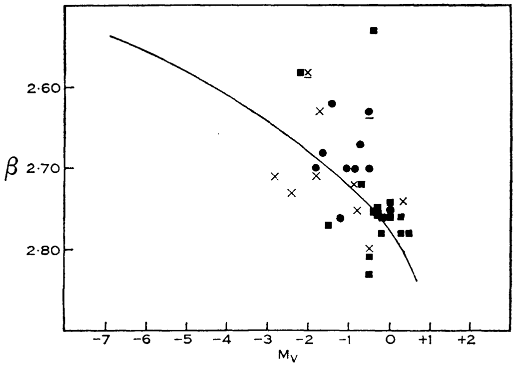


Fig. 3.—Hβ index (ordinate) plotted against absolute magnitude (abscissa) for the B-type stars in the galactic clusters NGC 6087 and IC 4725. Also plotted is the adopted calibration curve. Luminosity classes III and IV, × ; luminosity class V, ●; unclassified ■.

A recent paper by Sinnerstad (1961) on the quantitative luminosity determination for early-type stars yields a useful comparison with our work. From his measurements of the equivalent widths of Hγ and Hδ, Sinnerstad finds similar effects with luminosity class to those already discussed. He also compares the relative accuracy of a one-parameter classification similar to our own with that of a two-parameter classification using spectral type as the second "temperature" parameter. He finds that an additional mean error of $+0\overset{m}{.}23$ is introduced when the spectral type is neglected.

The Hβ index can easily be converted into the more conventional measure of equivalent width. With the use of a number of tracings made with the spectral scanner on loan to Mount Stromlo Observatory from the University of Michigan, the equivalent width of Hβ has been measured for a number of stars. Reference has also been made to the Edinburgh work of Butler and others (1955–1961), who measured equivalent widths from high-dispersion spectrograms. Hβ indices are also available for many of these stars. The derived relation between Hβ index and equivalent width is shown in Figure 4.

As an illustration of the use of the Hβ method, we shall summarize the results of Hβ and *UBV* observations made on 30 stars in the I Scorpii association. For these stars, a mean distance modulus of $11\overset{m}{.}4$ is found on the basis of the adopted calibration curve. This corresponds to a distance of 1900 pc. Although the standard deviation of the distance modulus for each star is found to be $\pm 0\overset{m}{.}55$, the large number of stars used reduces this scatter in the mean to a value of the order of the uncertainty in the derived calibration curve, which amounts to about $\pm 0\overset{m}{.}2$.

To summarize, the calibration curve for the early-type stars seems well defined and it is unlikely that systematic errors greater than $\pm 0\overset{m}{.}2$ are present. With the 50-inch telescope on Mount Stromlo, it is possible to use this method to estimate the absolute magnitudes of OB-type stars as faint as apparent magnitude 15. The

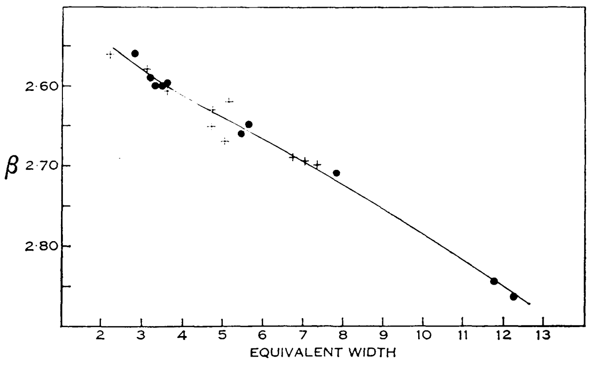


Fig. 4.—Comparison between Hβ index (ordinate) and the equivalent width of the Hβ line in Ångstrom units (abscissa). Stromlo (scanner with grating), ●; Edinburgh (high-dispersion spectrograms), +.

standard deviation of each estimated absolute magnitude is close to $\pm 0\overset{m}{.}6$, according to our studies of several groups of early-type stars. Observation of even a small group of faint OB-stars can reduce this scatter considerably in the mean, and it is in such applications that the method is seen to best advantage.

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## *Discussion*

*Aller:* A particular merit of this Hβ index method is that H line profiles constitute the one absolute magnitude criterion that has a sound theoretical basis. For luminosity class IV and V stars of a specified effective temperature and surface gravity one can compute, by methods of model atmospheres and Kolb-Griem theory, line profiles that appear to fit the observations very well.

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*Lindblad:* Sinnerstad, whose work was referred to, obtained from the line profiles two equivalents, line width and line depth. Thus two series could be obtained, and the dispersion in the inferred absolute magnitudes reduced. The line depth as a parameter can be effectively replaced by the intensity of the Balmer continuum. Sinnerstad is continuing his work by applying the H$\beta$ index measured photoelectrically to his analysis.

*Haro:* Can the H$\beta$ index method be used to determine the luminosity of early type stars in the halo? Some of these stars show very faint and narrow H lines similar to the ones that characterize the Morgan OB natural group.

*Graham:* This would be rather risky on the basis of H$\beta$ studies alone because the stars might be of differing compositions. Perhaps it could be reinforced by multicolour observations.

*Bok:* Now that we know how to measure the H$\beta$ indices in stars down to $15^{m}$, the big problem is how to locate the OB stars in the low-latitude regions observed in the fields of the southern hemisphere, as many are reddened by absorption in this region.

## 18. THE REGION OF NGC 6522

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The field of NGC 6522 is of especial importance because Baade considered that the cluster-type variable stars found in this field were located in a stellar concentration at the centre of the Galaxy. This particular field is a few degrees away from the actual centre, but is a region of comparatively small absorption, so that stars at considerable distances from the Sun can be seen and studied. Baade found a marked maximum in the frequency of these variables between $17^{m}$ and $18^{m}$ apparent photographic magnitude on plates which were exposed down to a limit of $20^{m}$. He supposed that this maximum was due to an actual concentration of cluster-type variables round the centre of the Galaxy. Assuming $0\overset{m}{.}0$ for the absolute magnitude, and allowing 3 magnitudes for absorption, Baade found a value of $8 \cdot 2$ kpc for $R_0$, the distance to the centre of the Galaxy. The absorption was computed from a rather high value for the reddening of the cluster NGC 6522 itself, which was given by Stebbins and Whitford.

During a visit to Pretoria, Mr. J. B. Alexander secured a number of direct photographs of this region at the Newtonian focus of the 74-inch Radcliffe reflector (stopped to 44 in.). Despite the low altitude of NGC 6522, Arp has secured a photoelectric sequence in the field, with the 200-inch telescope, and at Pretoria, where NGC 6522 passes near the zenith, Eggen tied this sequence in to suitable standards. Dr. Eggen communicated these results to us and we have calibrated Alexander's plates and constructed an HR diagram for NGC 6522; but as the cluster is in a very crowded region there are of course many field stars which cannot be distinguished easily from cluster stars. Indeed in the colour-magnitude array shown it requires the eye of faith to see at all the familiar HR pattern of a globular cluster showing amongst the field stars.

To meet this situation we determined the values of $B$ and $V$ for a number of stars in an annulus centered on this cluster but so far out that we were confident that there were few cluster stars in it. The next slide shows the HR diagram of this

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