# H$\beta$ PHOTOMETRY FOR THE ASSOCIATION I LACERTAE*

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## ABSTRACT

Photoelectric observations have been made on sixty-nine stars in the I Lacertae association Narrow-band interference filters centered on the H$\beta$ absorption line weie used. A distance modulus of 8.9 was found from both a cluster main-sequence fit and from the available calibration of the index $\beta$ in terms of absolute magnitude Nine of eleven stars observed, that lie above the association main sequence, are probably non-member foreground objects, the other two possibly being contracting stars. The stars lying in the dispersed region of the association are shown to be systematically older than those in the concentrated part near the star 10 Lacertae.

## I. INTRODUCTION

A continuing program at the Dyer Observatory has been the detailed study of the nearby OB associations. The aim is to provide accurate distance moduli through the use of late B-type stars found from objective-prism spectrum plates taken with the Dyer Observatory 24-inch Baker-Schmidt telescope. Observations have so far been published on two associations: I Lacertae, by Hardie and Seyfert (1959); and on II Persei, by Seyfert, Hardie, and Grenchik (1960). In this work $U$, $B$, $V$ photometry was obtained with the 24-inch telescope and used to obtain corrections for interstellar absorption. Then a fit of the corrected color-magnitude diagram in the region of the late B-type stars (where evolutionary effects are not critical) to the so-called "zero-age" main sequence of Sandage (1957*b*) resulted in an accurate distance modulus and hence absolute magnitudes for the brighter members.

The region for which Hardie and Seyfert have spectral types is the area about 10 Lacertae, where the density of association stars is highest (Blaauw 1958). This does not include the dispersed area extending to the northeast from 10 Lacertae. In the denser area, however, the classifications should be complete for member stars as late as A0. There is a need yet for objective-prism plates to fainter limiting magnitudes, in order to decide on such questions as the existence of A-type members, the luminosity function, the presence of possible contracting stars, etc.

## II. THE OBSERVATIONS

The B-type stars in the list of Hardie and Seyfert have been observed for H$\beta$ intensities with the Dyer Observatory 24-inch reflector and with the 16-inch reflector at Kitt Peak. The observations were made with conventional photoelectric photometers but equipped with two interference filters centered at H$\beta$, one with a half-width of 30 A and the other of about 150 A. In addition, a few earlier measures obtained in other programs with the 36-inch reflector at the McDonald Observatory were used. All measures were transformed to the $\beta$ system as defined by Crawford (1958, 1960), i.e., $\beta = -2.5 \log (I_N/I_W) + C$, where $I_N$ and $I_W$ are the intensities through the narrow and wide filter, respectively, and $C$ is the transformation correction. The mean error of a single observa-

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tion as determined from standard stars was $\pm 0.007$ mag., and the average number of observations per program star was 2.1. The observations are listed in Table 1. The first three columns give the BD number, the HD number, and the star's name or HR number as given in the bright star catalogue (Schlesinger 1940). The fourth column gives the spectral type, MK types being taken from Blaauw and Morgan (1953); the others, without luminosity classes, are taken from Hardie and Seyfert (1959). Column five gives the $(U-B)$ color index corrected for interstellar reddening by the procedure for B stars as described by Crawford (1958). The $U$, $B$, $V$ photometry has been taken from Harris (1955) or from Hardie and Seyfert. A few new measures with the Kitt Peak 16-inch have

TABLE 1

B STARS WITH Hβ PHOTOMETRY

| BD | HD | Name | Sp | $(U-B)_0$ | Sp(phot) | $A_V$ | $V_0$ | β |
|---|---|---|---|---|---|---|---|---|
| 35°4843.. | 214180 | ... .... | B9 | −0 01 | A0 | 0 18 | 9 2 | 2 920 |
| 36°4835*... | 212883 | HR 8549 | B2 V | −0 82 | B2 | 27 | 6 2 | 2 646 |
| 4868. .. | .. .. | . ..... | B9 | −0 02 | A0 | .30 | 10 2 | 2.926 |
| 4898*. | 214652 | .. . | B2: V | −0.82 | B2 | 33 | 6.5 | 2 657 |
| 4912... | . ... | . .. | A0 | −0 11 | B9 | 39 | 9 8 | 2 902 |
| 4922... | 215212 | . | B8 | −0 41 | B7 | .33 | 8 9 | 2.765 |
| 37°4598 . | ..... | . . | B7 | −0 30 | B8 | 21 | 10 0 | 2 838 |
| 4631. | 214263 | . .. | B2 V | −0 85 | B2 | 30 | 6 6 | 2 651 |
| 4632 . | ... | .. | A0 | −0 26 | B9 | .30 | 9 5 | 2 847 |
| 4636 . | . . | . | A0 | −0 08 | A0 | .30 | 9.8 | 2 898 |
| 4648. | .. . | .. . | B8 | −0 22 | B9 | .27 | 9.5 | 2 828 |
| 4659 . | ...... | ........ | B8 | −0.07 | A0 | .24 | 9 9 | 2 890 |
| 4670 . | 215191 | HR 8651 | B1 V | −0 92 | B1 | .48 | 6 0 | 2 619 |
| 38°4786. | ...... | .. . | A0 | −0 04 | A0 | 24 | 9.4 | 2 863 |
| 4797* | 213801 | .. . | B8 | −0 39 | B8 | .21 | 8 0 | 2.746 |
| 4801* . . | 213918 | . . .. | B7 | −0 62 | B5 | 60 | 8 1 | 2 740 |
| 4808B.. | 214167 | 8 Lac B | B2 V | −0.88 | B2 | 27 | 6 2 | 2 644 |
| 4808A*. | 214168 | 8 Lac A | B1 Ve | −0 98 | B1 | .33 | 5 4 | 2 613 |
| 4816 .. | 214433 | ... .. | B7 | −0 56 | B5 | .24 | 8.3 | 2.709 |
| 4817 .. | 214432 | . ..... | B3 V | −0 74 | B3 | 27 | 7.5 | 2 671 |
| 4826... | 214680 | 10 Lac | O9 V | −1 11 | O9 | 30 | 4 6 | 2 585 |
| 4831*.. . | 214783 | . | A0 | −0 18 | B9 | 27 | 8 3 | 2.775 |
| 4834. | ....... | . ... | B9 | −0 04 | A0 | 33 | 9 3 | 2 892 |
| 4849. . | 215211 | .. . | B7 | −0 51 | B7 | 33 | 8 3 | 2 764 |
| 4852*. | 215304 | ... . | B9 | −0 18 | B9 | 45 | 8 6 | 2 887 |
| 4859.. | .. .. . | ... ... | A0 | −0 09 | A0 | 39 | 9 2 | 2 896 |
| 4883..... | ......... | ... .... | B8 | −0 38 | B8 | .36 | 9 1 | 2 804 |
| 39°4841... | 212978 | HR 8553 | B2 V | −0 83 | B2 | .24 | 5 9 | 2 642 |
| 4862... | .. | . .. . | B9 | −0 06 | A0 | .30 | 9 5 | 2 908 |
| 4863. . | .. ... | .. | B9 | −0.13 | B9 | 27 | 10 1 | 2 846 |
| 4886 .. | 214022 | .. . .... | B7 | −0 56 | B5 | 30 | 8 2 | 2 747 |
| 4890... | . ..... .. | . .. . | B8 | −0 21 | B9 | .18 | 9 3 | 2.838 |
| 4892. .. | 214243 | .. | B7 | −0.65 | B5 | 18 | 8.1 | 2 711 |
| 4907.. | . ... | . .... | B9 | −0 10 | A0 | 18 | 9 9 | 2 887 |
| 4912*.. | 214993 | 12 Lac | B2 III | −0 95 | B1 | .36 | 4 9 | 2 615 |
| 4920. ... | . . | ... . | B8 | −0 14 | B9 | 27 | 9 6 | 2 894 |
| 4943. . | .. . | .. .. . | A1 | −0 03 | A0 | 21 | 9 8 | 2.878 |
| 40°4845.. | ...... . | .. . | B7 | −0 34 | B7 | 30 | 8.8 | 2 836 |
| 4854 .. . | 213976 | .. . | B2 V | −0 90 | B2 | 39 | 6 6 | 2 644 |
| 4862. . | .... | . ... . | B8 | −0 19 | B9 | .33 | 9 3 | 2 832 |
| 4882 .... | . . ... | .... .. | B7 | −0 50 | B7 | 0 48 | 8 9 | 2 748 |

* These stars have the following characteristics:

36°4835: ADS 15942.
36°4898: Spectroscopic binary.
38°4797: Possible double star.
38°4801: ADS 16064.
38°4808 A, B: ADS 16095.
38°4831: Possible contracting star.
38°4852: Possible double star
39°4912: DD Lac, β CMa-type variable.

been included. The remaining columns give the photometric spectral type as determined from this color index, the interstellar visual absorption ($A_V = 3.0\ E_{(B-V)}$), the visual magnitude corrected for this absorption, and the measured value of $\beta$. An asterisk after the BD number refers to a remark at the end of the table.

In addition to the B stars, a few A stars in the association were measured as a possible test for membership. These were chosen from the stars lying above the main sequence in the HR diagram given by Hardie and Seyfert. These measures are given in Table 2. For these A stars the photometric spectral types were determined from the $(B - V)$ color index. The column headed $(B - V)_0$ was determined by assuming a uniform absorption over the association. This assumption is discussed later.

### III. DISCUSSION

The corrected color-magnitude diagram for the stars of Table 1 is shown in Figure 1. The curve drawn through the points is the mean relation for the northern part of the Scorpius-Centaurus association (Hardie and Crawford 1960). For this fit, a distance modulus of 8.9 was used for the Lacertae group, corresponding to a distance of 600 parsecs. This modulus was determined from the B stars later in type than B3, using both a cluster main-sequence fitting technique (e.g., Harris 1958; Johnson 1958) and the calibration of $M_V$ in terms of $\beta$ from the II Scorpii results of Hardie and Crawford. The mean color indices and mean $\beta$'s, for a given spectral type, are in good agreement for the two associations. One star was omitted from this determination, +38°4831. This star will be discussed in more detail later. No stars were excluded because of possible duplicity. From the position of the upper part of the main sequence in Figure 1 relative to the II Scorpii curve, it is probable that the I Lacertae association is slightly older.

TABLE 2

A STARS WITH H$\beta$ PHOTOMETRY

| BD | Sp | $(B-V)_0$ | Sp(phot.) | $V_0$ | $\beta$ |
|---|---|---|---|---|---|
| 36°4917 . . . | A5 | 0 15 | A5 | 9 5 | 2 848 |
| 4923 . | A2 | 21 | A7 | 7 9 | 2 810 |
| 4924. . . . . . . | A5 | .14 | A5 | 9 4 | 2 846 |
| 37°4594. . | A5 | .15 | A5 | 8 2 | 2 773 |
| 4681. . . | A4 | 05 | A1 | 8.2 | 2 888 |
| 4713. . . . . . | A3 | .08 | A3 | 8 0 | 2 875 |
| 38°4787. . . | A7 | .11 | A3 | 7 4 | 2.851 |
| 39°4856. . . . . | A1 | 03 | A1 | 7 9 | 2 908 |
| 4870. . . . . | A1 | 04 | A1 | 7 7 | 2 918 |
| 4926*. . . . . . | B8p | 0 03 | A1 | 9 0 | 2 736 |

* Possible contracting star.

Figure 2 shows the relation between $(U - B)_0$ and $\beta$. A mean relation for II Scorpii fits the plotted points to within the observational error. Any field stars would be expected to deviate upward and to the right. Differential spread of the member stars in distance and effects of duplicity should not cause much scatter in this type of diagram (Crawford 1958), but some scatter may be expected parallel to the $\beta$-axis if there is undetected emission in the hydrogen lines of some stars.

The relation between $\beta$ and $V_0$ is shown in Figure 3. The dispersion of the points about a mean curve is $\pm 0.36$ mag. This number includes all such effects as duplicity, inclusion of possible non-member stars, spread in distance within the association, stars having incipient emission at H$\beta$, etc. The corresponding dispersion found for II Scorpii by Hardie and Crawford (1960) was $\pm 0.51$ mag.

There are no obvious field stars present among the stars of Table 1. Two stars, $+38°4797$ and $+38°4852$, which lie high on Figures 1 and 3, but close to the mean line in Figure 2, might be expected to be unknown double stars. For such stars the position in Figure 2 would only be shifted slightly from that of a single star of a weighted mean spectral type, but the observed visual magnitude would appear too bright in Figures 1 and 3.

The star $+38°4831$ lies above the mean relation in Figures 1 and 2, but fits the $\beta$, $V_0$ relation rather well. This behavior could possibly occur for a star in the process of gravitational contraction. It is hoped to obtain a classification spectrogram of this star shortly with the Kitt Peak 36-inch reflector.

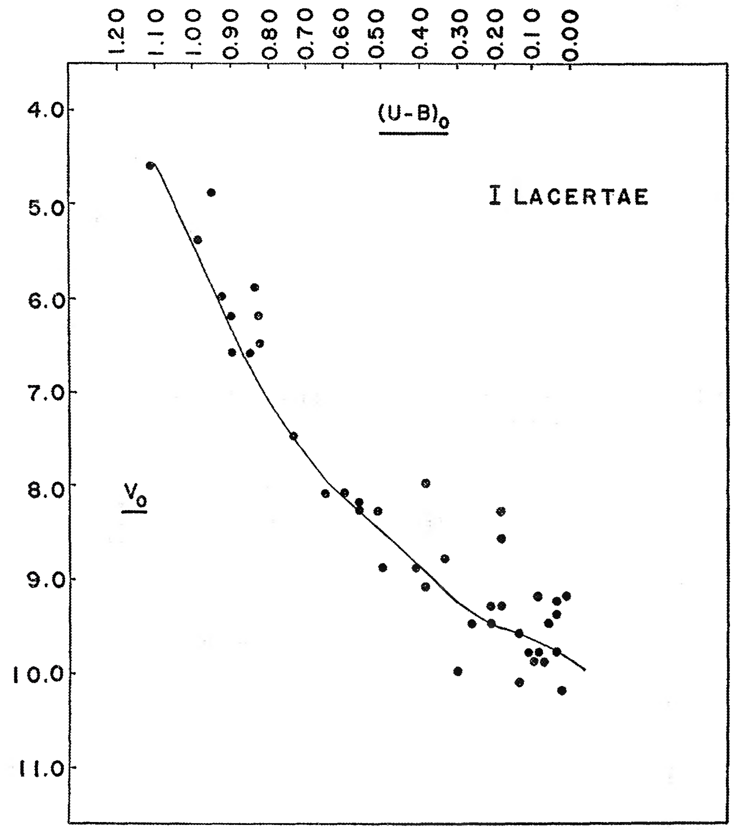


FIG. 1.—The corrected color-magnitude diagram for I Lacertae. The line corresponds to the mean relation for the northern part of the Scorpius-Centaurus association.

Figure 4 shows the final HR diagram for all stars observed by Hardie and Seyfert and by Harris. The filled circles refer to the stars of Table 1, where the visual absorptions were determined from the photometry alone. For all the other stars, a mean absorption of 0.31 mag. was assumed. The 41 stars of Table 1 yield a mean visual absorption of 0.31 mag. with a dispersion (r.m.s.) of $\pm 0.09$ mag.; therefore, the error in the photometric spectral type and in $V_0$ as tabulated should be quite small (of the order of $\pm 0.1$ mag.). The observed $(B - V)$ color indices were corrected for this uniform color excess and they used to determine a photometric spectral type for the stars later than A0. This procedure differs from that used by Hardie and Seyfert for the same stars. They used the objective-prism spectral types to determine the color excess for the stars later than A0 and to average this type excess with the photometrically determined excesses for the

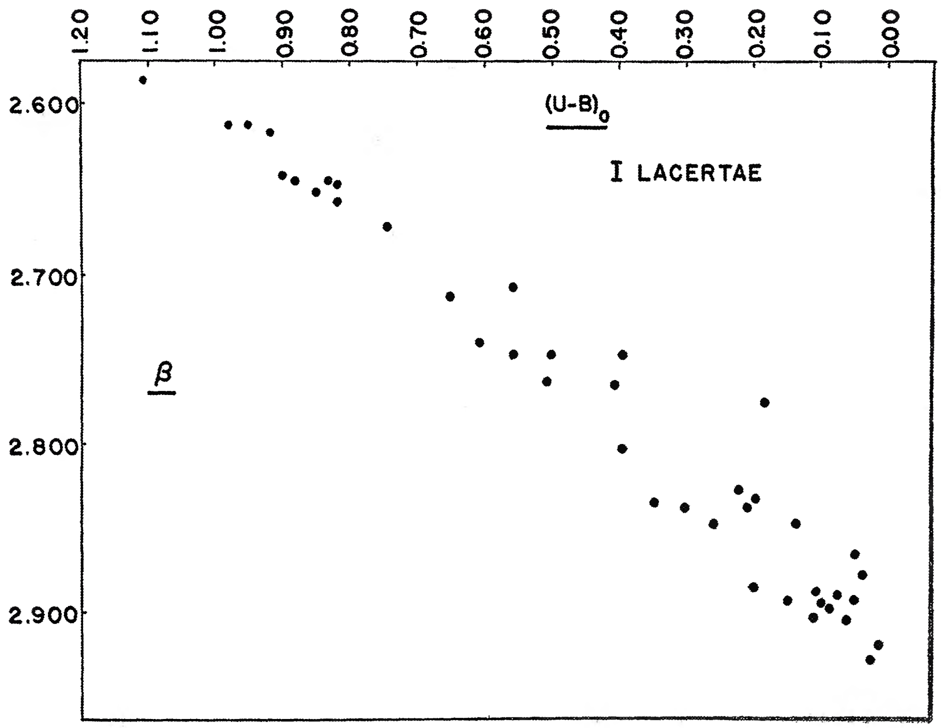


FIG. 2.—The relation between the corrected color index, $(U - B)_0$, and the H$\beta$ line strength index, $\beta$, for the I Lacertae association.

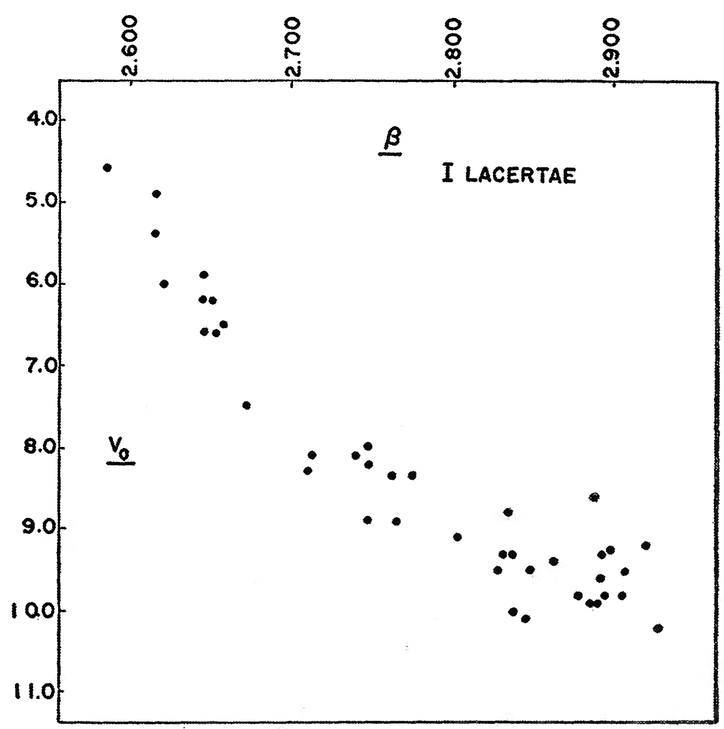


FIG. 3.—The relation between the corrected apparent visual magnitude, $V_0$, and the H$\beta$ intensity index, $\beta$, for the I Lacertae stars.

stars earlier than A0. However, because of the uniformity of the absorption over the association area, the accuracy in the use of such uniform corrections to the observed colors probably exceeds that of depending on the objective-prism spectral types. These types, indeed, do not agree with the observed colors in all cases. They are systematically correct, but the accidental error is large enough to make a significant difference in the determination of the visual absorptions.

As a check on this assumption of uniform absorption, an inspection of the Palomar Atlas prints of this region shows no obvious dust lanes, except in the neighborhood of HD 213976. This star, along with +39°4886 and +40°4845 in its vicinity, however, has an observed color excess close to the mean value adopted.

The open circles in Figure 4 refer to the stars later than A0 having observed $\beta$'s; they are listed in Table 2. Nine of these ten stars are probably foreground field stars. Their observed $\beta$'s are equivalent to those of ordinary main-sequence A stars. Table 3 gives

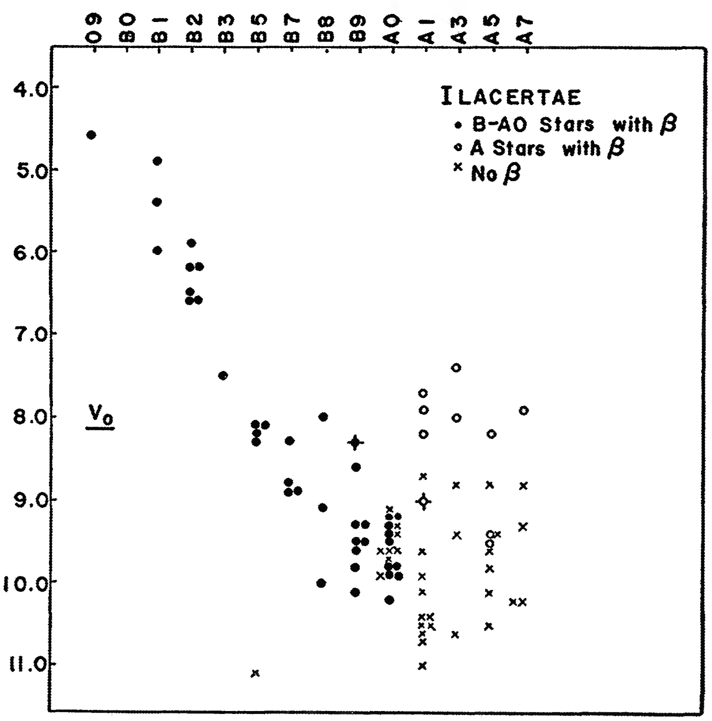


FIG. 4.—The spectral type, corrected apparent magnitude diagram for all stars observed by Hardie and Seyfert. Filled circles refer to B- and A0-type stars with observed $\beta$; open circles refer to A-type stars with observed $\beta$; and crosses to all stars with no observed $\beta$. The two stars with attached bars are possible contracting stars and are discussed in the text.

TABLE 3

MEAN $\beta$ FOR MAIN-SEQUENCE A STARS

| | SPECTRAL TYPE | | | | | |
|---|---|---|---|---|---|---|
| | A0 | A2 | A3 | A5 | A7 | F0 |
| $\beta$ ........ | 2.880 | 2 939 | 2.898 | 2 844 | 2.799 | 2.754 |

the mean $\beta$ for main-sequence A stars as found in other current programs of H$\beta$ photometry. The $(U - B)_0$ color indices appear normal for these stars. The remaining star, $+39°4926$, not only has a weaker H$\beta$ intensity for its spectral type but also was noted by Hardie and Seyfert as having a peculiar spectrum. It may be that this star is also a member in the process of contracting onto the main sequence.

Table 4 gives the observed luminosity function for this concentrated part of I Lacertae. The observed stars have been considered in two groups—only the B stars, and the B stars plus the A0 stars. From Figure 4, there appears to be a real lack of stars later than A0 on the main sequence. Whether this is just observational selection or is real, and no main-sequence stars exist later than A0 or A1, is a problem that will have to await objective-prism plates to fainter limiting magnitudes. The last two columns of

TABLE 4

LUMINOSITY FUNCTION FOR I LACERTAE

| $M_V$ | Observed | | Initial (Sandage) | | |
|---|---|---|---|---|---|
| | B Stars | B+A0 | $f$ | $33f$ | $49f$ |
| −4.0 | 2 | 2 | 0 04 | 1 | 2 |
| −3.0 | 5 | 5 | 07 | 2 | 3 |
| −2.0 | 3 | 3 | 12 | 4 | 6 |
| −1.0 | 5 | 5 | 18 | 6 | 9 |
| 0.0 | 8 | 11 | .26 | 9 | 13 |
| +1.0 | 10 | 23 | 0 33 | 11 | 16 |
| Total | 33 | 49 | 1 00 | 33 | 49 |

TABLE 5

STARS IN DISPERSED AREA

| HD | Name | Sp | $(U-B)_0$ | $A_V$ | $V_0$ | $\beta$ |
|---|---|---|---|---|---|---|
| 209961 | HR 8427 | B2 V | −0 83 | 0 48 | 5 8 | 2 642 |
| 211835 | ........ | B3 Ve | .99 | ..... | ...... | 2 519 |
| 213420 | 6 Lac | B2 IV | .83 | .42 | 4.1 | 2 618 |
| 214240* | HR 8606 | B3 V | 61 | .36 | 5.9 | 2 682 |
| 216092 | ........ | B1: V | 80 | 45 | 7 4 | 2 614 |
| 216200* | 14 Lac | B3 IV: | .70 | 81 | 5 1 | 2 654 |
| 216534 | ........ | B3 V | .71 | .54 | 8 0 | 2 648 |
| 216684 | ........ | B3 V | .72 | .51 | 7.2 | 2 682 |
| 216851* | ........ | B3 V:n | 65 | .66 | 7.4 | 2 691 |
| 216916* | 16 Lac | B2 IV | 90 | 30 | 5 3 | 2 605 |
| 217101 | HR 8733 | B2 IV–V | .86 | 24 | 5 9 | 2 656 |
| 217227 | ........ | B2: V | .70 | .39 | 6 7 | 2 688 |
| 217543 | HR 8758 | B3e | .70 | .24 | 6.3 | 2 618 |
| 217811* | HR 8768 | B2 V | .72 | .57 | 5 8 | 2.678 |
| 218325* | ........ | B3 V | .80 | 84 | 6 9 | 2 585 |
| 218344 | ........ | B2 V | .80 | .33 | 7 2 | 2 657 |
| 218407* | HR 8800 | B2 V | 80 | 51 | 6 2 | 2.648 |
| 218674* | ........ | B3 IV | −0 69 | 0.54 | 6 2 | 2 622 |

* These stars have the following characteristics:

214240: Spectroscopic binary.
216200: Variable ?
216851: H$\beta$ absorption weak.
216916: $\beta$ CMa-type variable star.
217811: ADS 16472.
218325: H$\beta$ absorption weak
218407: Spectroscopic binary
218674: Spectroscopic binary ?

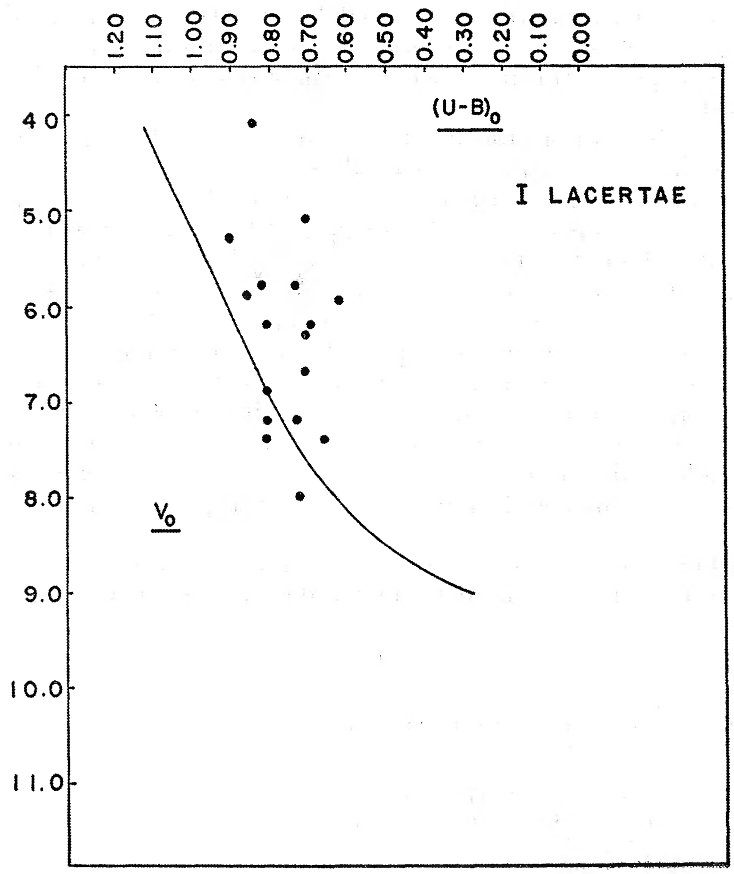


FIG. 5.—The corrected color-magnitude diagram for the stars in the dispersed area of I Lacertae. The line is the mean relation for the stars in the concentrated part of the association.

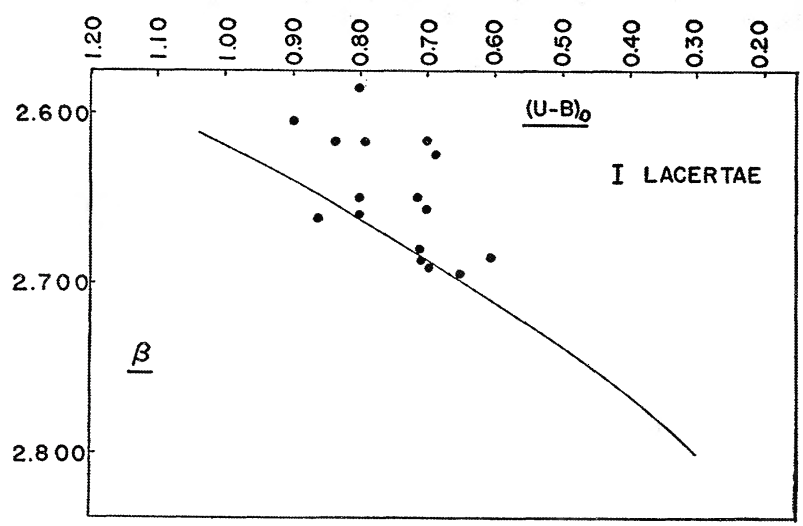


FIG 6.—The $(U - B)_0$, $\beta$ relation for the stars in the dispersed area of I Lacertae. The line is the mean relation for the concentrated part of the association.

the table show a comparison with the initial luminosity function used by Sandage (1957*a*, 1958). The numbers have been normalized to the same totals as the observed groups. As may be expected for an association, the number of observed stars compares well with this initial luminosity function.

Table 5 gives the observations for the bright stars observed by Harris in the dispersed part of the association. These stars are plotted in Figures 5 and 6. The curves in these two figures represent the mean relations for the stars in the 10 Lacertae area, as shown in Figures 1 and 2. As has been noted by Blaauw (1958), these dispersed stars appear to be systematically older. It can be seen that the earliest spectral types occur in the concentrated part of the association. In addition, there is an obvious turnoff of the points from the curve in both figures, such as would be expected for an older group. It seems inescapable that the stars in the dispersed part of I Lacterae are, on the average, older, under current theories of stellar evolution, than those in the concentrated part. From the larger scatter within the dispersed group, it is probable also that there is a larger differential range in ages among these stars than in the younger group. There are a number of possible field stars in this dispersed group as well. A complete discussion of this part of the association should await objective-prism plates of the region.

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