QUANTITATIVE STELLAR SPECTRAL CLASSIFICATION. II. EARLY TYPE STARS

M. J. Stock¹,²,³, J. Stock², J. García¹ and N. Sánchez¹

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ABSTRACT

The method developed by Stock & Stock (1999) for stars of spectral types A to K to derive absolute magnitudes and intrinsic colors from the equivalent widths of absorption lines in stellar spectra is extended to B-type stars. Spectra of this type of stars for which the Hipparcos Catalogue gives parallaxes with an error of less than 20% were observed with the CIDA 1-meter reflector equipped with a Richardson spectrograph with a Thompson 576x384 CCD detector. The dispersion is 1.753 Å/pixel using a 600 lines/mm grating in the first order. In order to cover the spectral range 3850 Å to 5750 Å the grating had to be used in two different positions, with an overlap in the region from 4800 Å to 4900 Å. A total of 116 stars was observed, but not all with both grating positions. A total of 12 measurable absorption lines was identified in the spectra and their equivalent widths were measured. These were related to the absolute magnitudes derived from the Hipparcos Catalogue and to the intrinsic colors (deduced from the MK spectral types) using linear and second order polynomials and two or three lines as independent variables. The best solutions were obtained with polynomials of three lines, reproducing the absolute magnitudes with an average residual of about 0.40 magnitudes and the intrinsic colors with an average residual of 0.016 magnitudes.

Key Words: STARS: FUNDAMENTAL PARAMETERS
1. INTRODUCTION

In a previous work two of the authors (Stock & Stock, 1999) published a method for the derivation of stellar physical parameters such as the absolute magnitude, an intrinsic color, and a metallicity index from the equivalent widths or pseudo-equivalent widths of absorption lines in stellar spectra. Use was made of a library of stellar spectra made available by L. Jones (1999). Of these stars those were rejected for which the Hipparcos Parallax Catalogue gives parallax errors larger than 20% of the parallax itself. Due to this restriction the number of remaining O- and B-type spectra was too small to be included. To close this gap we decided to launch our own observing program dedicated exclusively to early type stars. A number of recent papers have been dedicated to the subject of a quantitative stellar classification. Malyuto & Schmidt-Kaler (1999) classify G-, K-, and M-type stars on the basis of spectral indices derived in the region from 6000 to 10000 Å. A similar approach is used by Malyuto, Oestreicher and Schmidt-Kaler (1997) for K- and M-type stars based on spectra in the region from 4800 to 7700 Å.

2. OBSERVATIONS

In view of the restriction just mentioned we started an observing program with the Richardson spectrograph of the CIDA observatory attached to the 1-meter reflector, concentrated on O- and B-type stars which fulfilled the same parallax error restriction used in the previous work. A grating of 600 lines/mm was used in the first order yielding a dispersion of 1.753 Å/pixel. The detector is a Thompson 576x384 CCD with a pixel size of 23 microns. The spectral range captured by a single exposure is about 1000 Å. Two grating positions were used, one yielding usable spectra from 3950 Å to 4900 Å, the other from 4800 Å to 5750 Å. In the following we distinguish these as the B- and V-spectra. The grating positioning mechanism was rather crude (it has now been improved) such that the different spectra are not always centered at exactly the same wavelength. For this reason some of the lines near the end of the spectra are not always covered.

The observing list was made up with the Bright Star Catalogue in combination with the Hipparcos Parallax Catalogue, selecting all O- and B-stars brighter than the 6th apparent V-magnitude. Of these 116 stars were observed, resulting in 72 stars with B-spectra only, 39 stars with B- and V-spectra, and 5 stars with V-spectra only. A typical example of a B- and a V-spectrum is shown in Figure 1. Table 1 contains a list of all observed stars with their HD-numbers and additional pertinent information. An intrinsic color-magnitude diagram of the observed stars is shown in Figure 2.

3. DATA REDUCTION

As in the previous paper the data analysis will be based on the equivalent widths of absorption lines. When the true continuum is resolved, and this is here the case, the determination of the equivalent width is a standard procedure and need not be described here. The signal/noise ratio naturally depends on the brightness of the star, the exposure time, and a series of other factors. In most cases the value of S/N is found near 50. A total of 11 measurable absorption lines was found in the B-spectra, and only 4 in the V-spectra. Three of these are common to both the B- and the V-spectra. Thus only one additional line was added by including the V-band in the observing program. Even so the inclusion of the V-band turned out to be quite fortunate as will be seen in the analysis. In the first place it gave us a convenient handle to determine the accuracy with which the equivalent widths are determined. Also it turned out that the line added by the V-band provides an important classification criterion.

For the lines in common to both bands we can carry out an analysis of the accuracy with which the equivalent widths are determined. Only three lines are available for the test. There is a pronounced dependence of the accuracy on the equivalent width itself. The relation found is best described by

\[ e = 0.035 + 0.088w \]  \hspace{1cm} (1)

where \( e \) is the average accuracy with which a line of equivalent width \( w \) is determined. Units are Angstroms. A complete list of the lines is given in Table 2, with their wavelength taken from the Multiplet Table by Ch. Moore (1972) as well as their identification. Furthermore, for each line, an inner region and two outer regions were selected. The two outer regions, one on each side of the line –each at least several Angstroms wide- were used to determine a ”continuum” or ”pseudo-continuum”, while the integration of the inner region yielded the equivalent width. Also it is indicated whether they were measured in the B- or in the V-spectra or in both. All this information is shown in Table 2. For two

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1 Laboratorio de Investigaciones Astronómicas, Universidad del Zulia, Venezuela
2 Centro de Investigaciones de Astronomía (CIDA), Venezuela
3 Postgrado de Física Fundamental, Facultad de Ciencias Universidad de Los Andes, Venezuela
lines the relation between the equivalent widths measured in the B- and the V-spectra is shown in Figure 3. Likewise the relation between the intrinsic colors \((B - V)_0\) and the equivalent widths for H-\(\delta\) and HeI(4143) is shown in Figure 4.  
In these plots the size of the symbol represents the luminosity of the star in the sense that the larger the symbol the more luminous the star. The plots demonstrate the known fact that the He-lines reach their maximum equivalent width around the spectral type B2, while the equivalent width of the hydrogen lines increases all the way through the B-class.

4. ANALYSIS

The principal purpose of this work is to find means by which physical parameters, namely the absolute magnitude \(M_V\) and the intrinsic color \((B - V)_0\), can be predicted from the equivalent widths of absorption lines. The external data used are the spectral types in the MK-system, the apparent V-magnitudes, and the observed \((B - V)\)- colors given in the Bright Star catalogue, and the parallaxes and parallax errors in the Hipparcos Catalogue. Intrinsich colors \((B - V)_0\) were deduced from the MK-types. The respective relations may be found for instance in tables given by Allen (1973). These colors can be compared with the observed colors and a reddening effect can be found. If interpreted as due to absorption by interstellar or circumstellar material the effect on the apparent V-magnitude can be estimated. For this purpose we use the usually adopted relation

\[
Av = 3.0E((B - V))
\]

where \(Av\) is the absorption in the V-band, and \(E((B - V))\) the reddening of the \((B - V)\)-color. This correction was applied when the color excess is greater than 0.03 magnitudes. Using the parallax given in the Hipparcos Parallax Catalogue the corrected magnitudes were converted into absolute magnitudes \(M_V\). For the relation between the physical parameters \(M_V\) or \((B - V)_0\) and the equivalent widths we adopt second order polynomials with two or three independent variables, the latter being the equivalent widths of two or three absorption lines. Thus the equation for the absolute magnitude with three lines has the form

\[
M_V = a_{000} + a_{100}w_1 + a_{010}w_2 + a_{001}w_3 + a_{200}w_1^2 + a_{110}w_1w_2 + a_{101}w_1w_3 + a_{020}w_2^2 + a_{011}w_2w_3 + a_{002}w_3^2
\]

where \(w_1, w_2, \) and \(w_3\) are the equivalent widths of the three respective absorption lines. The coefficients \(a_{ijk}\) have to be determined by least squares, forming equation (3) for all spectra in which values for the three different equivalent widths were obtained. With 3 lines out of 12 a total of 220 combinations can be made up. With two lines a total of 66 combinations can be made up. Equation (3) can also be used for the intrinsic colors, introducing these instead of the absolute magnitudes. For the three-line combinations 10 coefficients have to be determined by least squares. If only two lines are used (skipping in equation (3) all terms containing \(w_3\)) the number of unknowns is 6. Likewise omitting the square and mixed terms the expression for the linear dependence of \(M_V\) on two or three lines is obtained. Replacing in all equations \(M_V\) by \((B - V)_0\) expressions are found which relate the intrinsic colors to the equivalent widths. We have also tested solutions based on four absorption lines, without obtaining a significant improvement with respect to the previous solutions.

We should point out here that all spectra entered the solution with the same weight. It would be possible to assign weight according to the respective relative parallax errors, i.e. the parallax error divided by the parallax itself, which in our selection is limited to a maximum of 20%. This idea was discarded in view of the biased selection of stars in the Hipparcos Catalogue which may favor stars of certain absolute magnitudes, and of the fact that in general low luminosity stars have more accurate parallaxes due to their proximity.

5. RESULTS FOR THE ABSOLUTE MAGNITUDES

Two- and three-line solutions were calculated for all possible line combinations. For each combination the average residual \(r_{av}\) (Hipparcos absolute magnitude minus polynomial absolute magnitude) was calculated. Outliers with residuals larger than 2.5\(r_{av}\) were eliminated and the solution was repeated. For both the two-line and the three-line solution those with the smallest \(r_{av}\) were selected. The respective combinations for two and three lines and their \(r_{av}\)-value are given in Table 3 and Table 4. The full information with the corresponding coefficients is found in Table 3a and Table 4a available on our website (www.cida.vc/stock/paper2). We also tried the linear dependence of the absolute magnitude on the equivalent widths of two or three lines. The respective data are also given in Table 3, Table 4 Table 3a and Table 4a. As may be seen in these tables average residuals of 0.40 magnitudes can be obtained.
For the best combination of the lineal solutions with three lines we also give the respective coefficients in Table 5.

The importance of the line 12 (HeI 5047.736) is evident. Since this line is present only in the V-spectra which are considerably less numerous than the B-spectra we have also calculated solutions based entirely on the 11 lines in the B-spectra. The respective results are also given in Table 3-4 and Table 3a-4a. Comparing the data for the solutions with 11 and with 12 lines the importance of the inclusion of the V-spectra is clearly demonstrated. For most of the stars on our list comments are given in the Bright Star Catalogue, some actually rather extensive. We have looked at the comments for the outliers eliminated in the calculation of the coefficients. They do have comments, but these are shared with other stars which were not found to be outliers. It appears that we would need more stars if we were to determine whether the "outlier" condition can be predicted on the basis of measurements of the equivalent widths of absorption lines only. We should point out here that only two supergiants are included in our sample of stars, one a B8.Ia, the other a O9.5Ib. Both turned out to be outliers. Consistently solutions based on three lines gave better results than those based on two lines. The differences between the linear and the second order solutions, however, indicate no clear advantage of one or the other.

6. RESULTS FOR THE INTRINSIC COLORS

We have already indicated that equation (3) can readily be modified to be applied to the intrinsic colors as function of the equivalent widths of two or three lines in a linear or second order polynomial. The data for the combinations which gave the smallest average residual are given in Table 6-7 and Table 6a-7a, the latter two available on our website (www.cida.ve/~stock/paper2). As may be seen in these tables, average residuals of 0.016 magnitudes can be obtained. Just as in the case of the absolute magnitudes a significant improvement is obtained with the three-line dependence as compared to the two-line dependence. On the other hand, linear or second order solutions do not consistently favor one or the other. The lines 10 (HeI 4921.929) and 12 (HeI 5047.736) occur most frequently among the ten best solutions.

7. CONCLUSIONS

For the recovery of the physical stellar parameters $M_v$ and $(B - V)_0$ from the equivalent widths of absorption lines we have tested linear and second order polynomials with two and with three lines as independent variables, making use of all possible line combinations. Significant improvement was obtained by switching from a two-line dependence to a three-line dependence, but no consistent improvement was found by switching from linear to second order polynomials for both the absolute magnitudes and the intrinsic colors. Table 8 shows how often the different lines were used in the best solutions for $M_v$ and for $(B - V)_0$ colors. Taking into account that line 12 only occurs in the V-spectra which are far less numerous than the B-spectra the lines 4, 9, 11, and 12 are the most important lines for the recovery of the absolute magnitudes. For intrinsic colors, again one has to allow for the fact that line 12 is far less observed than all the other lines. The lines 3, 8, 10, and 12 are the most important ones for the recovery of the intrinsic colors. The usefulness of the hydrogen lines H-$\beta$ (9) and H-$\gamma$ (4) has long been known. The sensitivity of the green helium lines 5015.7 (11) and 5047.7 (12) for classification purposes was not widely known because their are not available on spectra taken for MK classification.

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| HD number | V (B-V) | Parallax (mas) | Parallax error (mas) | Spectral type | B-sp | V-sp |
|-----------|---------|----------------|---------------------|---------------|------|------|
| 224990    | 5.04    | 6.40           | 0.87                | B4 V          |      |      |
| 886       | 2.83    | -0.19          | 9.79                | 0.81          | B2 IV|      |
| 3369      | 4.34    | -0.12          | 4.97                | 0.82          | B3 V |      |
| 5737      | 4.30    | -0.15          | 4.85                | 0.84          | B7 IIIp|      |
| 7374      | 5.97    | -0.08          | 6.52                | 0.79          | B8 III|      |
| 14951     | 5.48    | -0.10          | 5.41                | 1.04          | B7 IV|      |
| 16582     | 4.08    | -0.21          | 5.04                | 0.83          | B2 IV|      |
| 17081     | 4.24    | -0.12          | 7.40                | 0.85          | B7 IV|      |
| 18604     | 4.71    | -0.11          | 7.69                | 0.76          | B6 III|      |
| 19356     | 2.09    | 0.00           | 35.14               | 0.90          | B8 V |      |
| 22203     | 4.26    | -0.11          | 11.02               | 0.75          | B9 V |      |
| 23227     | 4.99    | -0.16          | 4.45                | 0.62          | B5 III|      |
| 23302     | 3.72    | -0.10          | 8.80                | 0.89          | B6 III|      |
| 23388     | 4.30    | -0.11          | 8.75                | 1.08          | B6 V |      |
| 23466     | 5.34    | -0.10          | 5.54                | 0.80          | B3 V |      |
| 23630     | 2.85    | -0.09          | 8.87                | 0.99          | B7 III|      |
| 23850     | 3.62    | -0.07          | 8.57                | 1.03          | B8 III|      |
| 23277     | 5.40    | 0.10           | 10.02               | 0.54          | A2 m |      |
| 24587     | 4.64    | -0.14          | 8.46                | 0.75          | B5 V |      |
| 24760     | 2.90    | -0.20          | 6.06                | 0.82          | B0.5 V|      |
| 25340     | 5.28    | -0.13          | 7.20                | 0.83          | B5 V |      |
| 25330     | 5.67    | 0.00           | 5.77                | 0.78          | B5 V |      |
| 26326     | 5.45    | -0.15          | 4.49                | 0.78          | B5 IV|      |
| 26912     | 4.27    | -0.05          | 7.50                | 1.13          | B3 IV|      |
| 28375     | 5.53    | -0.10          | 8.47                | 1.11          | B3 V |      |
| 29248     | 3.93    | -0.21          | 5.56                | 0.88          | B2 III sb|      |
| 29763     | 4.27    | -0.11          | 8.14                | 0.78          | B3 V |      |
| 30211     | 4.01    | -0.15          | 6.13                | 1.03          | B5 IV|      |
| 33802     | 4.45    | -0.10          | 13.53               | 0.69          | B8 V |      |
| 34085     | 0.18    | -0.03          | 4.22                | 0.81          | B8 Ia|      |
| 34503     | 3.59    | -0.12          | 5.88                | 0.77          | B5 III|      |
| 35468     | 1.64    | -0.22          | 13.42               | 0.98          | B2 III|      |
| 35497     | 1.65    | -0.13          | 24.89               | 0.88          | B7 III|      |
| 36267     | 4.20    | -0.14          | 11.30               | 1.01          | B5 V |      |
| 37742     | 1.74    | -0.20          | 3.99                | 0.79          | O9.5 I b sb|      |
| 41534     | 5.65    | -0.19          | 3.01                | 0.57          | B2 V |      |
| 41753     | 4.42    | -0.16          | 6.10                | 0.88          | B3 IV|      |
| 42560     | 4.45    | -0.18          | 5.14                | 0.78          | B3 IV|      |
| 43157     | 5.83    | -0.16          | 5.28                | 0.83          | B5 V |      |
| 43153     | 5.34    | -0.10          | 6.80                | 0.93          | B7 V |      |

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| HD number | V (B-V) | Parallax (mas) | Parallax error (mas) | Spectral type | B-sp | V-sp |
|-----------|---------|----------------|---------------------|---------------|------|------|
| 43955     | 5.51    | -0.16          | 3.28                | 0.60          | B2/B3 V | *    |
| 44743     | 1.98    | -0.24          | 6.53                | 0.66          | B1 II/III | * *  |
| 45813     | 4.47    | -0.17          | 8.03                | 0.58          | B4 V | * *  |
| 45542     | 4.13    | -0.12          | 6.49                | 1.06          | B6 III | * *  |
| 46487     | 5.09    | -0.13          | 6.08                | 0.79          | B5 Vn | * *  |
| 46936     | 5.62    | -0.09          | 6.70                | 0.58          | B9 V | * *  |
| 47100     | 5.34    | -0.08          | 4.30                | 0.76          | B8 III | * * |
| 49643     | 5.75    | -0.10          | 5.84                | 0.77          | B8 III/IV | * * |
| 52089     | 1.50    | -0.21          | 7.57                | 0.57          | B2 II | * *  |
| 52670     | 5.64    | -0.17          | 3.17                | 0.59          | B2/B3 III/IV | * * |
| 53244     | 4.11    | -0.11          | 8.11                | 0.63          | B8 II | * *  |
| 56342     | 5.36    | -0.16          | 5.05                | 0.57          | B2 V | *    |
| 57821     | 4.94    | -0.04          | 6.31                | 0.69          | B5 II/III | * * |
| 58715     | 2.89    | -0.10          | 19.16               | 0.85          | B8 Vvar | * * |
| 59550     | 5.78    | -0.19          | 2.85                | 0.56          | B2 IV | *    |
| 60863     | 4.65    | -0.11          | 14.50               | 0.62          | B8 V | * *  |
| 61429     | 4.69    | -0.10          | 5.92                | 0.72          | B8 IV | * *  |
| 61555     | 3.80    | -0.16          | 7.18                | 1.06          | B5 IV | *    |
| 63975     | 5.12    | -0.12          | 7.76                | 1.02          | B8 II | * *  |
| 67797     | 4.40    | -0.16          | 6.90                | 0.69          | B5 V | * *  |
| 78316     | 5.23    | -0.09          | 6.74                | 0.91          | B8 III/IV | * * |
| 83754     | 5.07    | -0.15          | 6.33                | 0.91          | B4 IV/V | * * |
| 87901     | 1.36    | -0.09          | 42.09               | 0.79          | B7 V | * *  |
| 90994     | 5.08    | -0.14          | 9.46                | 1.16          | B6 V | * *  |
| 106625    | 2.58    | -0.11          | 19.78               | 0.81          | B8 III | * * |
| 107348    | 5.20    | -0.09          | 8.47                | 0.78          | B8 V | * *  |
| 116658    | 0.98    | -0.23          | 12.44               | 0.86          | B1 V | * *  |
| 120315    | 1.85    | -0.10          | 32.39               | 0.74          | B3 V sb | * * |
| 120709    | 4.32    | -0.15          | 10.96               | 0.88          | B5 | * *  |
| 120955    | 4.75    | -0.11          | 4.87                | 0.71          | B4 IV | * *  |
| 121847    | 5.20    | -0.09          | 9.61                | 0.69          | B8 V | * *  |
| 126769    | 4.97    | -0.07          | 7.85                | 0.80          | B7/B8 V | * * |
| 132955    | 5.45    | -0.13          | 9.32                | 0.84          | B3 V | * *  |
| 135742    | 2.61    | -0.07          | 20.38               | 0.87          | B8 V | * *  |
| 136298    | 3.22    | -0.23          | 6.39                | 0.86          | B1.5 IV | * * |
| 138485    | 5.53    | -0.15          | 4.24                | 0.84          | B3 V | * *  |
| 138749    | 4.14    | -0.13          | 10.49               | 0.66          | B6 Vn | * * |
| 138764    | 5.16    | -0.09          | 9.30                | 0.86          | B6 IV | * *  |
| 139365    | 3.66    | -0.18          | 7.33                | 1.01          | B2.5 V | * * |
| 142883    | 5.84    | 0.01           | 7.16                | 0.87          | B3 V | * *  |
| 143275    | 2.29    | -0.12          | 8.12                | 0.88          | B0.2 IV | * * |
| 147394    | 3.91    | -0.15          | 10.37               | 0.53          | B5 IV | * *  |

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| HD number | V (B-V) | Parallax (mas) | Parallax error (mas) | Spectral type | B-sp | V-sp |
|-----------|---------|----------------|---------------------|---------------|------|------|
| 148605    | 4.79    | 8.30           | 0.84                | B3 V          |      |      |
| 148703    | 4.24    | 4.37           | 0.80                | B2 III-IV     |      |      |
| 149438    | 2.82    | 7.59           | 0.78                | B0 V          |      |      |
| 149757    | 2.54    | 7.12           | 0.71                | O9.5 V        |      |      |
| 154204    | 6.29    | 8.21           | 0.76                | B7 IV/V       |      |      |
| 158408    | 2.70    | 6.29           | 0.81                | B2 IV         |      |      |
| 158926    | 1.62    | 4.64           | 0.90                | B1.5 IV+...   |      |      |
| 160762    | 3.82    | 6.58           | 0.56                | B3 V sb       |      |      |
| 160578    | 2.39    | 7.03           | 0.73                | B1.5 III      |      |      |
| 172910    | 4.86    | 7.23           | 1.09                | B2 V          |      |      |
| 173300    | 3.17    | 14.14          | 0.88                | B8.5 III      |      |      |
| 175191    | 2.05    | 14.54          | 0.88                | B2.5 V        |      |      |
| 176162    | 5.51    | 6.34           | 0.80                | B4 V          |      |      |
| 180163    | 4.43    | 3.13           | 0.51                | B2.5 IV       |      |      |
| 180554    | 4.76    | 3.58           | 0.60                | B4 IV         |      |      |
| 182255    | 5.22    | 8.10           | 0.68                | B6 III        |      |      |
| 182568    | 4.99    | 4.21           | 0.58                | B3 IV         |      |      |
| 184171    | 4.74    | 5.20           | 0.55                | B3 IV         |      |      |
| 184930    | 4.36    | 10.61          | 0.94                | B5 III        |      |      |
| 186500    | 5.51    | 5.98           | 1.00                | B8 III        |      |      |
| 189103    | 4.37    | 5.28           | 0.90                | B2.5 IV       |      |      |
| 189944    | 5.88    | 4.85           | 0.66                | B4 V          |      |      |
| 190993    | 5.08    | 6.68           | 0.71                | B3 V          |      |      |
| 196740    | 5.06    | 6.61           | 0.66                | B5 IV         |      |      |
| 202671    | 5.40    | 5.63           | 0.95                | B5 II/III     |      |      |
| 207330    | 4.23    | 2.82           | 0.52                | B3 III        |      |      |
| 207971    | 3.00    | 16.07          | 0.77                | B8 III        |      |      |
| 209409    | 4.74    | 8.56           | 0.81                | B7 IVe        |      |      |
| 210424    | 5.43    | 5.81           | 0.75                | B5 III        |      |      |
| 210934    | 5.45    | 6.42           | 0.85                | B7 V          |      |      |
| 214748    | 4.18    | 4.38           | 0.87                | B8 V          |      |      |
| 214923    | 3.41    | 15.64          | 0.75                | B8.5 V        |      |      |
| 216831    | 5.73    | 3.90           | 0.70                | B7 III        |      |      |
| 219688    | 4.41    | 10.13          | 1.04                | B5 Vn         |      |      |
TABLE 2
LIST OF SELECTED LINES

| Line | Cont1(Å) | Line(Å) | Cont2(Å) | λ (Å) | Id. |
|------|----------|---------|----------|-------|-----|
| 1 B  | 4006.2   | 4020.3  | 4022.1   | 4032.7| 4036.2| 4050.3| 4026.4| HeI   |
| 2 B  | 4067.9   | 4082.1  | 4085.6   | 4119.1| 4124.4| 4142.0| 4101.7| Hδ    |
| 3 B  | 4122.6   | 4140.2  | 4142.0   | 4156.1| 4157.9| 4168.4| 4143.8| HeI   |
| 4 B  | 4298.9   | 4313.0  | 4316.5   | 4357.1| 4362.4| 4374.7| 4340.5| Hγ    |
| 5 B  | 4364.1   | 4378.2  | 4381.8   | 4392.3| 4397.6| 4410.0| 4387.9| HeI   |
| 6 B  | 4439.9   | 4462.9  | 4454.0   | 4477.0| 4478.7| 4487.5| 4471.7| HeI   |
| 7 B  | 4475.2   | 4477.0  | 4478.7   | 4482.3| 4485.8| 4494.6| 4481.0| MgII  |
| 8 B  | 4686.8   | 4702.6  | 4709.7   | 4716.7| 4720.3| 4729.1| 4713.4| HeI   |
| 9 B-V| 4820.8   | 4833.1  | 4836.6   | 4868.0| 4889.5| 4905.4| 4861.3| Hβ    |
| 10 B-V| 4900.1  | 4912.4  | 4916.0   | 4926.5| 4931.8| 4945.9| 4921.3| HeI   |
| 11 B-V| 5005.9  | 5011.2  | 5014.7   | 5020.0| 5023.5| 5032.3| 5015.7| HeI   |
| 12 V  | 5101.1  | 5112.4  | 5116.9   | 5129.3| 5136.3| 5148.7| 5047.7| HeI   |

Fig. 1. B- and V-type observed spectra of HD14951
| Linear Solutions | B-spectra |  | B- and V-spectra |  |
|------------------|-----------|---|-----------------|---|
| L1   | L2   | \(r_{av}\) | \(N_u\) | \(N_e\) | L1   | L2   | \(r_{av}\) | \(N_u\) | \(N_e\) |
| 2    | 4    | 0.517  | 54   | 5   | 2    | 4    | 0.517  | 54   | 5   |
| 2    | 9    | 0.504  | 54   | 5   | 2    | 9    | 0.504  | 54   | 5   |
| 3    | 9    | 0.529  | 91   | 9   | 3    | 9    | 0.529  | 91   | 9   |
| 4    | 7    | 0.553  | 102  | 9   | 4    | 7    | 0.553  | 102  | 9   |
| 4    | 11   | 0.496  | 74   | 7   | 4    | 11   | 0.496  | 74   | 7   |
| 5    | 9    | 0.588  | 103  | 8   | 4    | 12   | 0.381  | 34   | 5   |
| 6    | 9    | 0.581  | 102  | 9   | 7    | 9    | 0.556  | 102  | 9   |
| 7    | 9    | 0.556  | 102  | 9   | 9    | 10   | 0.568  | 106  | 10  |
| 9    | 10   | 0.568  | 106  | 10  | 9    | 11   | 0.563  | 82   | 4   |
| 9    | 11   | 0.563  | 82   | 4   | 9    | 12   | 0.482  | 41   | 3   |

| Quadratic Solutions | B-spectra |  | B- and V-spectra |  |
|---------------------|-----------|---|-----------------|---|
| L1   | L2   | \(r_{av}\) | \(N_u\) | \(N_e\) | L1   | L2   | \(r_{av}\) | \(N_u\) | \(N_e\) |
| 2    | 9    | 0.460  | 54   | 5   | 2    | 9    | 0.460  | 54   | 5   |
| 3    | 9    | 0.550  | 93   | 7   | 3    | 9    | 0.550  | 93   | 7   |
| 4    | 7    | 0.604  | 104  | 7   | 4    | 8    | 0.578  | 102  | 9   |
| 4    | 8    | 0.578  | 102  | 9   | 4    | 9    | 0.561  | 103  | 8   |
| 4    | 9    | 0.561  | 103  | 8   | 4    | 11   | 0.513  | 74   | 7   |
| 4    | 11   | 0.513  | 74   | 7   | 7    | 9    | 0.572  | 104  | 7   |
| 7    | 9    | 0.572  | 104  | 7   | 8    | 9    | 0.536  | 102  | 9   |
| 8    | 9    | 0.536  | 102  | 9   | 9    | 10   | 0.567  | 108  | 8   |
| 9    | 10   | 0.567  | 108  | 8   | 9    | 11   | 0.586  | 84   | 2   |
| 9    | 11   | 0.586  | 84   | 2   | 9    | 12   | 0.412  | 41   | 3   |

*\(N_u\): used stars, \(N_e\): eliminated stars*
TABLE 4

BEST COMBINATIONS FOR THE DETERMINATION OF ABSOLUTE MAGNITUDES BASED IN THREE LINES

| Linear Solutions | B-spectra | B- and V-spectra |
|------------------|-----------|------------------|
|                  | L1 | L2 | L3 | \( r_{av} \) | \( N_u \) | \( N_e \) | L1 | L2 | L3 | \( r_{av} \) | \( N_u \) | \( N_e \) |
| 1 2 9 | 0.482 | 53 | 5 | 1 4 11 | 0.421 | 26 | 2 |
| 1 4 11 | 0.421 | 26 | 2 | 1 4 12 | 0.387 | 26 | 2 |
| 1 9 11 | 0.333 | 26 | 2 | 1 9 11 | 0.333 | 26 | 2 |
| 2 4 11 | 0.451 | 28 | 1 | 1 9 12 | 0.326 | 26 | 2 |
| 2 9 10 | 0.498 | 54 | 5 | 2 4 11 | 0.451 | 28 | 1 |
| 3 4 11 | 0.464 | 64 | 6 | 2 4 12 | 0.440 | 27 | 1 |
| 3 9 11 | 0.475 | 65 | 5 | 2 9 12 | 0.384 | 27 | 1 |
| 4 5 11 | 0.500 | 74 | 7 | 3 4 11 | 0.464 | 64 | 6 |
| 4 8 11 | 0.499 | 74 | 7 | 4 8 12 | 0.424 | 35 | 4 |
| 4 10 11 | 0.486 | 74 | 7 | 4 10 12 | 0.387 | 34 | 5 |

| Quadratic Solutions | B-spectra | B- and V-spectra |
|---------------------|-----------|------------------|
|                    | L1 | L2 | L3 | \( r_{av} \) | \( N_u \) | \( N_e \) | L1 | L2 | L3 | \( r_{av} \) | \( N_u \) | \( N_e \) |
| 2 4 9 | 0.465 | 56 | 3 | 1 9 12 | 0.395 | 27 | 1 |
| 2 5 9 | 0.489 | 55 | 4 | 2 6 9 | 0.443 | 54 | 5 |
| 2 6 9 | 0.443 | 54 | 5 | 3 9 11 | 0.447 | 66 | 4 |
| 2 7 9 | 0.484 | 55 | 4 | 3 9 12 | 0.334 | 35 | 4 |
| 2 9 10 | 0.483 | 55 | 4 | 4 6 11 | 0.456 | 75 | 6 |
| 3 9 11 | 0.447 | 66 | 4 | 4 8 12 | 0.457 | 38 | 1 |
| 4 6 11 | 0.456 | 75 | 6 | 4 9 12 | 0.417 | 37 | 2 |
| 4 8 11 | 0.473 | 75 | 6 | 7 9 12 | 0.454 | 38 | 1 |
| 4 9 11 | 0.471 | 76 | 5 | 8 9 12 | 0.440 | 38 | 1 |
| 9 10 11 | 0.480 | 81 | 5 | 9 10 12 | 0.342 | 40 | 4 |

\( N_u \): used stars, \( N_e \): eliminated stars
TABLE 5
COEFFICIENTS FOR THE BEST LINEAR COMBINATIONS OF ABSOLUTE MAGNITUDES BASED IN THREE LINES

| L1 | L2 | L3 | $a_{000}$ | $a_{100}$ | $a_{010}$ | $a_{001}$ |
|----|----|----|-----------|-----------|-----------|-----------|
| 1  | 2  | 9  | -5.1881   | 0.1720    | -0.3517   | 0.9100    |
| 1  | 4  | 11 | -6.1041   | -1.1267   | 0.8186    | 4.2092    |
| 1  | 9  | 11 | -5.3635   | -0.2788   | 0.6886    | 0.0740    |
| 2  | 4  | 11 | -6.2617   | -0.5080   | 1.2510    | 1.1302    |
| 2  | 9  | 10 | -4.5249   | -0.3179   | 0.8207    | -0.5408   |
| 3  | 4  | 11 | -5.4876   | 0.5196    | 0.7536    | -1.4535   |
| 3  | 9  | 11 | -5.0903   | 0.5743    | 0.6669    | -1.4267   |
| 4  | 5  | 11 | -5.0534   | 0.6887    | 0.0973    | -1.8178   |
| 4  | 8  | 11 | -4.9882   | 0.6807    | -0.3788   | -1.4161   |
| 4  | 10 | 11 | -5.4992   | 0.7414    | 0.8885    | -2.7578   |

| L1 | L2 | L3 | $a_{000}$ | $a_{100}$ | $a_{010}$ | $a_{001}$ |
|----|----|----|-----------|-----------|-----------|-----------|
| 1  | 4  | 11 | -6.1041   | -1.1267   | 0.8186    | 4.2092    |
| 1  | 4  | 12 | -5.6824   | -0.1997   | 0.7742    | 5.1345    |
| 1  | 9  | 11 | -5.3635   | -0.2788   | 0.6886    | 0.0740    |
| 1  | 9  | 12 | -5.3137   | -0.2258   | 0.6787    | 1.6170    |
| 2  | 4  | 11 | -6.2617   | -0.5080   | 1.2510    | 1.1302    |
| 2  | 4  | 12 | -5.8773   | -0.2922   | 1.0317    | 4.0268    |
| 2  | 9  | 12 | -5.4125   | -0.1425   | 0.7869    | 0.9973    |
| 3  | 4  | 11 | -5.4876   | 0.5196    | 0.7536    | -1.4535   |
| 4  | 8  | 12 | -5.4024   | 0.7490    | -1.1068   | 5.4555    |
| 4  | 10 | 12 | -5.9997   | 0.8121    | 0.1954    | 5.1382    |
TABLE 6
BEST COMBINATIONS FOR THE DETERMINATION OF (B − V)_0 COLORS BASED IN TWO LINES

Linear Solutions

| B-spectra | B- and V-spectra |
|-----------|------------------|
| L1 L2     | r_{av} N_u N_e | L1 L2     | r_{av} N_u N_e |
|-----------|------------------|
| 1 10      | 0.020 55 3       | 1 10      | 0.020 55 3       |
| 3 5       | 0.018 87 13      | 3 5       | 0.018 87 13      |
| 3 6       | 0.019 91 9       | 3 6       | 0.019 91 9       |
| 3 10      | 0.017 88 12      | 3 10      | 0.017 88 12      |
| 4 10      | 0.020 102 9      | 5 10      | 0.020 99 12      |
| 5 10      | 0.020 99 12      | 5 12      | 0.018 36 3       |
| 6 10      | 0.021 101 10     | 7 10      | 0.020 98 13      |
| 7 10      | 0.020 98 13      | 8 12      | 0.019 37 2       |
| 9 10      | 0.020 108 8      | 10 11     | 0.019 74 12      |
| 10 11     | 0.019 74 12      | 10 12     | 0.017 41 3       |

Quadratic Solutions

| B-spectra | B- and V-spectra |
|-----------|------------------|
| L1 L2     | r_{av} N_u N_e | L1 L2     | r_{av} N_u N_e |
|-----------|------------------|
| 1 10      | 0.021 55 3       | 1 10      | 0.021 55 3       |
| 2 6       | 0.022 58 1       | 2 6       | 0.022 58 1       |
| 2 10      | 0.022 58 1       | 3 10      | 0.021 92 8       |
| 3 10      | 0.021 92 8       | 4 6       | 0.021 103 8      |
| 4 5       | 0.023 103 8      | 4 10      | 0.021 102 9      |
| 4 6       | 0.021 103 8      | 6 9       | 0.022 105 6      |
| 4 10      | 0.021 102 9      | 8 10      | 0.021 99 12      |
| 6 9       | 0.022 105 6      | 8 12      | 0.020 38 1       |
| 8 10      | 0.021 99 12      | 9 10      | 0.020 109 7      |
| 9 10      | 0.020 109 7      | 10 12     | 0.019 41 3       |

N_u: used stars, N_e: eliminated stars
**TABLE 7**

BEST COMBINATIONS FOR THE DETERMINATION OF \((B - V)_0\) COLORS BASED IN THREE LINES

| Linear Solutions | B-spectra | B- and V-spectra |
|------------------|-----------|------------------|
|                  | L1 L2 L3  | \(r_{av}\) Nu Ne | L1 L2 L3  | \(r_{av}\) Nu Ne |
| 1 3 6            | 0.018    | 53 5             | 1 8 12   | 0.017 27 1 |
| 1 3 10           | 0.018    | 54 4             | 2 8 11   | 0.014 27 2 |
| 1 8 11           | 0.017    | 27 1             | 2 8 12   | 0.016 27 1 |
| 2 8 11           | 0.014    | 27 2             | 3 5 12   | 0.016 36 3 |
| 3 5 7            | 0.018    | 87 13            | 3 6 12   | 0.016 36 3 |
| 3 5 10           | 0.019    | 91 9             | 3 10 12  | 0.016 37 2 |
| 3 6 10           | 0.019    | 92 8             | 4 8 12   | 0.013 35 4 |
| 3 6 11           | 0.019    | 63 7             | 6 10 12  | 0.016 36 3 |
| 3 7 10           | 0.018    | 89 11            | 8 9 12   | 0.015 36 3 |
| 7 10 11          | 0.018    | 69 12            | 9 10 12  | 0.017 42 2 |

| Quadratic Solutions | B-spectra | B- and V-spectra |
|---------------------|-----------|------------------|
|                     | L1 L2 L3  | \(r_{av}\) Nu Ne | L1 L2 L3  | \(r_{av}\) Nu Ne |
| 1 4 6               | 0.018    | 56 2             | 1 8 11   | 0.012 27 1 |
| 1 8 11              | 0.012    | 27 1             | 1 8 12   | 0.015 27 1 |
| 3 4 10              | 0.017    | 91 9             | 3 7 10   | 0.017 89 11 |
| 3 5 11              | 0.018    | 63 7             | 3 10 12  | 0.016 37 2 |
| 3 7 10              | 0.017    | 89 11            | 4 10 12  | 0.014 38 1 |
| 3 8 10              | 0.018    | 92 8             | 5 8 12   | 0.016 38 1 |
| 3 9 10              | 0.017    | 92 8             | 6 8 12   | 0.015 38 1 |
| 5 8 11              | 0.018    | 71 10            | 6 10 12  | 0.017 38 1 |
| 6 9 10              | 0.019    | 105 6            | 7 8 12   | 0.014 38 1 |
| 9 10 11             | 0.017    | 82 4             | 8 10 12  | 0.013 38 1 |

\(N_u:\) used stars, \(N_e:\) eliminated stars
TABLE 8
FREQUENCY N WITH WHICH LINES L WERE USED FOR THE BEST MV-SOLUTIONS

| Mv-solutions | (B − V)_o-solutions |
|--------------|---------------------|
| L  | N  | L  | N  |
| 1  | 8  | 1  | 8  |
| 2  | 13 | 2  | 3  |
| 3  | 7  | 3  | 18 |
| 4  | 23 | 4  | 5  |
| 5  | 2  | 5  | 6  |
| 6  | 4  | 6  | 9  |
| 7  | 4  | 7  | 6  |
| 8  | 6  | 8  | 16 |
| 9  | 26 | 9  | 5  |
| 10 | 6  | 10 | 20 |
| 11 | 22 | 11 | 10 |
| 12 | 14 | 12 | 17 |

Fig. 2. H-R Diagram of observed stars
Fig. 3. Relation between the equivalent widths Ew measured in the B- and V-spectra.
Fig. 4. Relation between the intrinsic colors $(B - V)_0$ and the equivalent widths $E_w$ for H-$\delta$ and HeI(4143).