TWO DIMENSIONAL SPECTRAL CLASSIFICATION USING A COMPUTER

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ABSTRACT

A computer program for the automatic classification of stellar spectra is described. The aim of this program is to derive accurate absolute luminosities and spectral classes of individual stars for improved spectral parallaxes. Preliminary results are presented and future applications are discussed.

1. INTRODUCTION

As a result of the work of W. W. Morgan and his associates spectroscopic parallaxes are today one of the most important and most accurate methods of determining the distance of individual stars. Unfortunately our colleagues investiating the structure of the galaxy are still not content with this accuracy (c.f., e.g., Wielen 1975). Therefore, we have been studying the possibility of increasing the accuracy of two dimensional spectral classification by replacing visual inspection of classification spectrograms by an automatic computer analysis of suitably recorded stellar spectra. An advantage of this method is obviously that a microphotometer or a spectrum scanner (or any other modern photometric device which can be used to record stellar spectra in digital form) is at least potentially much more accurate in determining and comparing quantitatively line strengths (used as classification criteria) than even a well trained human eye. This advantage will probably become even

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more evident in the future when (perhaps within the next ten years) the photographic plate will be finally replaced by the more sensitive, more linear, and less noisy one- and two-dimensional photoelectric detectors which are presently being developed at various places. These detectors will produce their output in computer readable digital form. Thus, a computer analysis will also be the most direct, most convenient and most economic way to evaluate such data. Of course, today fairly accurate parallaxes can also be derived from multicolor filter photometry. However, using modern detectors, it often takes less time (and definitely less perfect weather conditions) to obtain a low or medium resolution spectrogram than to obtain a full set of filter photometry measurements. In addition, such spectrograms usually contain more physical information. We have to admit that computer classification also has certain obvious drawbacks: it will be very difficult to teach a computer to evaluate the many different types of peculiar stellar spectra. And spurious spectral features produced by detector defects (like the common defects in photographic emulsions) are much more difficult to detect for a computer than for the combination of trained human eye and human brain.

2. AN OUTLINE OF THE PROGRAM

The program has been designed to produce absolute luminosities and spectral types of normal (i.e. non-peculiar) stellar spectra of B to M stars. It is intended to apply this program in the future mainly in connection with linear photoelectric detectors like Digicons or Intensified Reticon systems. So far no operational detector of this kind is available to us. Therefore, for developing and testing the program we have been using a set of rather conventional prismatic classification spectrograms (115 Å mm^{-1} at Hγ, IIa-O plates) of MK standards which have been obtained (for different purposes) more than 10 years ago at the McDonald Observatory. The spectrograms were converted into digital form using a Grant measuring engine. Since the spectrograms were not calibrated, a rough conversion of the recorded density values into intensity was made using a standard mean characteristic curve of the IIa-O emulsion. A flow diagram of the program in its present form is given in Fig. 1.

The classification procedure starts by reading a spectrogram (i.e. 800 intensity values corresponding to 800 consecutive wavelength intervals) and some approximate information on the dispersion function and the wavelength limits of the spectrum (3800 Å - 5000 Å). In a first program step the computer looks for the strongest lines in the spectrum. For this purpose a running mean is calculated and subtracted from the spectrum. All narrow minima in the resulting

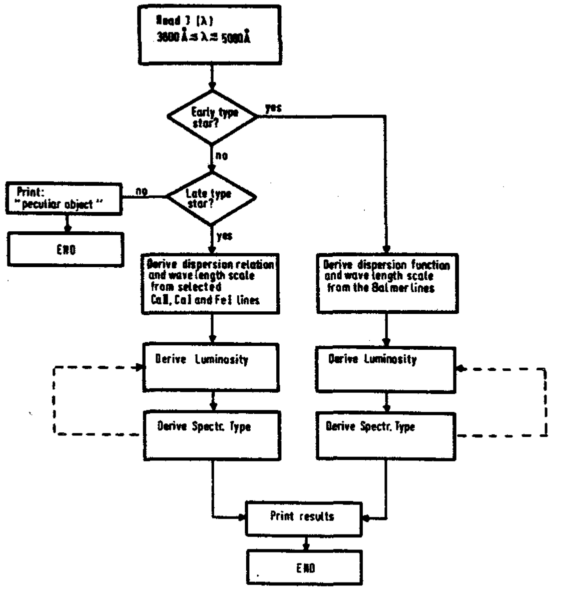

Fig. 1. The flow diagram of the program.

"reduced" spectrum, which extend below a suitably chosen level, are now catalogued by the computer as "strong lines." In the next step the computer checks whether in the wavelength pattern formed by these strong lines (the Balmer series) can be recognized. For this purpose it is assumed that starting from the red limit of the spectrum the first strong line encountered is the Hβ line. Starting from this line the computer uses the approximate dispersion function to extrapolate to the approximate position of the Hγ line. If a strong line is found in the neighborhood of the extrapolated position, another extrapolation is made to the Hδ line. This procedure is repeated until the H_8 line is reached. If a consistent Balmer line pattern is found, the star is recognized as an "early type" star, a definite dispersion function (approximated by a third order polynomial) and wavelength scale are established from the Balmer lines and the preprogrammed classification criteria for B, A or early F stars are used in the following classification. If the computer does not find the Balmer series, it tries to detect a consistent wavelength pattern formed by the CaII H and K lines, the CaI 4227 line and several selected strong FeI lines. If these lines are found, again a wavelength scale is established and the classification criteria for late type stars are applied. If neither the Balmer series nor the late type characteristic lines are recognized among the strong lines, the computer capitulates and prints a message denoting the spectrum as peculiar.

3. CLASSIFICATION CRITERIA

A great number of different classification criteria have been tested during the past months. We thus obtained a list of those criteria which are useful for computer classification (see Fig. 2). For determining the luminosity of B0 to F0 stars the photographic -

"β-index" as defined by Furenlid (1971) applied to the Hγ and Hδ lines was found to be the most reliable and accurate criterion. Two different methods have been tested and used to derive a measure for the strength of the lines used as classification criteria. For the first method the spectrum in the neighborhood of the line is convolved with two normalized filter functions which are centered on the line. The filter functions are chosen in a way that one gives basically information on the line while the second gives basically information on the adjacent continuum. The ratio of the two resulting integrals then gives a measure for the line strength. For the second method the computer determines an approximate continuum level basically by connecting the first intensity maxima shortward and longward of the line center by a straight line. Using this approximate continuum level, an approximate equivalent width is then determined and used for the following analysis. Except for early type stars with few absorption lines the continuum derived in this way is usually quite different from the true stellar continuum level. However, since the same procedure is used for calibrating the criterion from standard stars, the poor approximation should have no influence on the accuracy of the automatic classification. During the actual classification procedure the computer searches the spectrum for the presence (i.e. significant equivalent width) of certain temperature or luminosity sensitive lines which are listed in the program. The strength or relative strength of these selected lines have been calibrated before from standard star spectra. From each usable criterion a separate luminosity value or spectral type is calculated. The printed output contains these individual results as well as an average luminosity and spectral type of each spectrum. A large scatter in the results obtained from the individual criteria indicates either poor input data or a more or less peculiar spectrum.

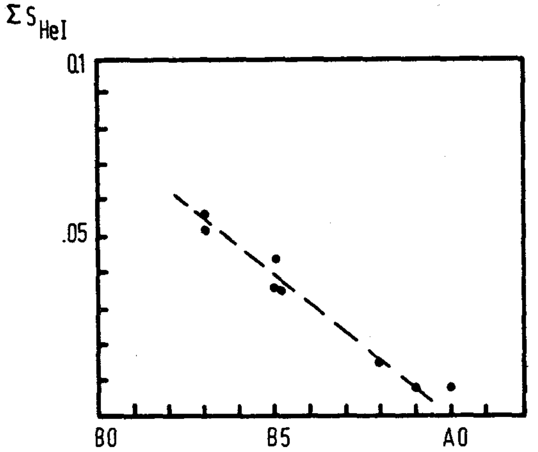

Fig. 2. The dependence of the summed line strength of the HeI lines 4026, 4144 and 4471 Å on spectral class.

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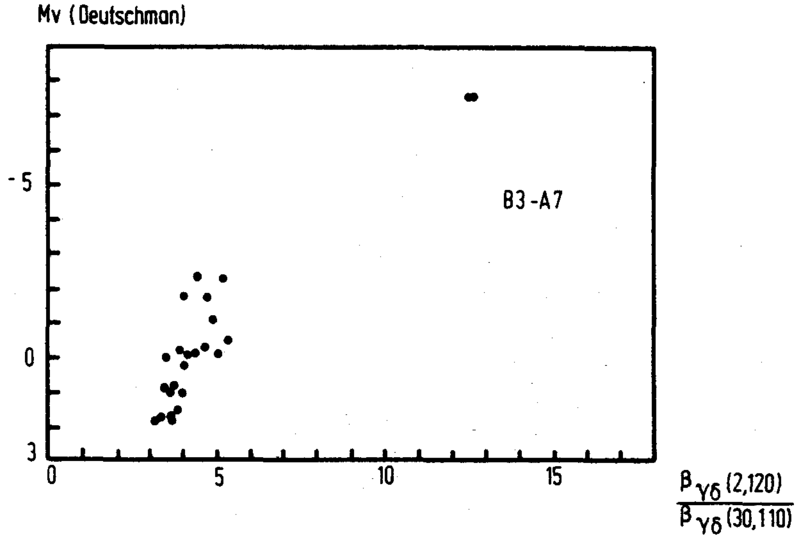

Fig. 3a. The dependence of the ratio of the photographic β-indices β (2,120)/ β (30,110) on the absolute luminosity for stars of spectral class B3 - A4. The luminosities are taken from Deutschman et al. (1976).

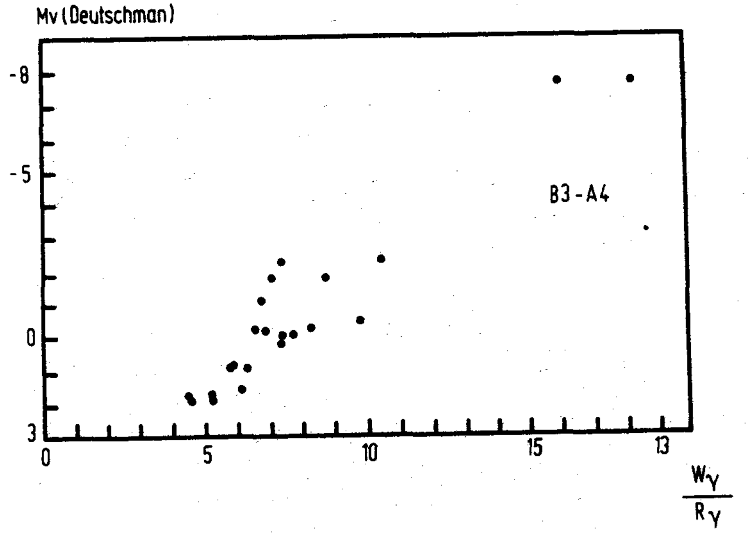

Fig. 3b. The dependence of the ratio of the equivalent width and relative line depth of Hβ on the absolute luminosity for stars of spectral type B3 - A7. The luminosities are taken from Deutschman et al. (1976).

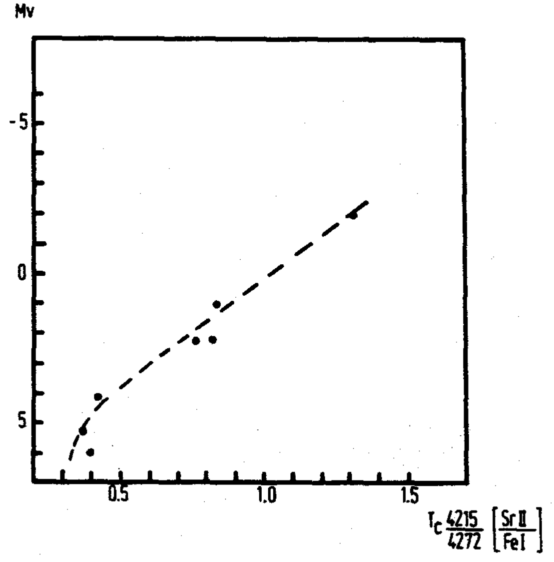

Fig. 4a. The dependence of the ratio of the relative line strength of the lines 4215 Å and 4274 Å on the absolute luminosity for G-stars.

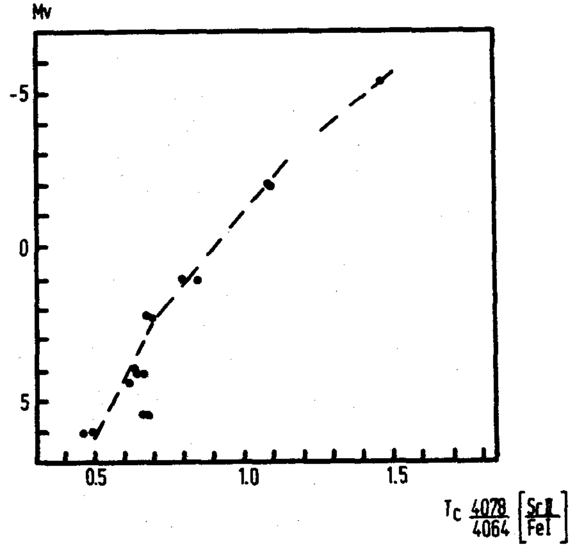

Fig. 4b. The dependence of the ratio of the relative line strength of the lines 4078 Å and 4064 Å on the absolute luminosity for G-stars.

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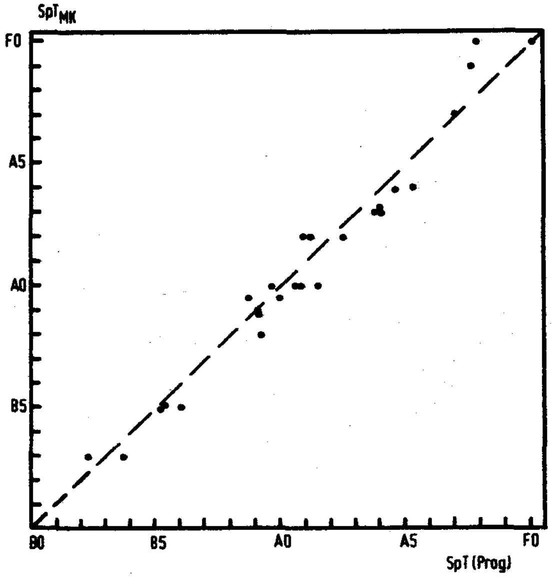

Fig. 5. The relation between the standard spectral class (ordinate) and the calculated spectral class (abscissa).

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4. RESULTS

At present our computer program is still incomplete and in an experimental stage. It is not yet ready for practical work. The detectors for which the program is being developed are not yet operational either. Thus, we have so far only very preliminary results based on the photographic spectra described above. In Fig. 3 we have plotted M_V values taken from the literature as a function of two of our programmed luminosity criteria for early type stars. A similar diagram for G type stars is given in Fig. 4. In Fig. 5 we compare standard spectral types with the spectral types derived for the same stars by our program. Note that the mean error is smaller than one spectral subclass.

5. CONCLUSION

At the present stage it is probably too early to draw definite conclusions. However, the results obtained so far seem to indicate that, even with relatively poor input material, spectral classification of normal stellar spectra by computer can be done at least as accurately as by conventional visual inspection by an average trained astronomer. We therefore expect that a combination of future linear low noise detectors and a computer program of the kind outlined above will indeed lead to a considerable improvement of the accuracy of spectroscopic parallaxes.

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DISCUSSION

Jaschek: You mentioned that you had a step in your program to see if the HeI lines you use had normal strength. What happens if you have an additional strong unexpected line (like CII or MgII)?

Zekl: If the line is in the program catalog, the program will give, for the criteria which use this line, a spectral type differing by a large amount from the mean spectral type determined by other criteria. The program lists a spectral type for each criterion used, so one can detect the discrepancy. If the line is not in the program catalog there is currently no way to detect such an effect as you mention.

Cowley: When one classifies spectra by eye, one basically uses the technique that has been called "pattern recognition." In the past those who have attempted to use methods of classification by the measurement of equivalent widths have had problems with the accuracy of photographic photometry. Apparently, the eye can distinguish a "null pattern" with greater accuracy than one can measure equivalent widths. A "null pattern" means that the spectrum of an unknown equals that of a standard. Thus I would like to suggest that it might be useful to consider some automated analogue of pattern recognition.

Zekl: I cannot answer since I am not familiar with the technique of "pattern recognition."

Cowley: It might be useful to put in an abundance parameter if you want to get luminosities of distant stars, since the CN strength, which is luminosity-sensitive, is also variable due to abundance gradients in the Galaxy.

Zekl: This is true, but we have thus far tried to handle only normal stars. In the final version an abundance parameter must be introduced to account for the large number of peculiar spectra.

Ardeberg: You use a step length of 20μ. What is the projected slit width?

Zekl: The slit width is equal to the step length.

Ardeberg: Would you not do better using smaller values for these parameters and add a filtering phase?

Zekl: Yes, smaller values would probably be better. I have made only preliminary tests with filtering phases and cannot give a final statement.

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Ardeberg: As spectral-type criteria you used absolute or pseudo-absolute line strengths. I think it would be rather advantageous to exchange these for line-strength ratios.

Zekl: This is true but currently, because the spectra are uncalibrated, it is difficult for the program to detect weak lines. It only accepts lines whose relative depths are greater than 2%. On well exposed spectra I can see lines whose relative depths are less than 2%. The problem, I think, is that the mean calibration curve is wrong at high photographic densities. The result is that the program cannot determine enough line ratios to establish good classification criteria. With well calibrated spectra I will be able to establish a better ratio for detecting weak lines and thus obtain better results.

Geyer: From information theory we hear that the original information contained in the spectrogram is considerably degraded by transforming and storing it in another form. Therefore in my opinion we should design more or less automatic instruments which make use of the "zero method" along the lines of the famous Hartmann spectro-comparator for the information extraction we wish to have. Here the error could be brought down to $\sqrt{2}$! Also no interpolation fitting methods are necessary!

Zekl: By doing this you will get a luminosity grid defined by the standard stars. But we want to have accurate absolute luminosities and such a grid would not be adequate.

Garrison: One of the problems with your treatment of the equivalent widths of hydrogen lines is that your method of drawing the continuum eliminates the wings of the lines and it is the wings which are most sensitive. I think that if you can draw the continuum differently, you may improve the accuracy of your results.

Zekl: I agree with you and I plan to make more tests to improve the definition of the continuum and thus improve my accuracy.

Kinman: The synthetic spectra computed nowadays (e.g. those by Carbon at Kitt Peak) are getting to be so good that in the future one may wish to make the comparison with a grid of such spectra which differ in T_{eff} and g rather than the traditional spectral type and luminosity class.

Zekl: I am not familiar with the models for the synthetic spectra. There may be storage problems for small computers. We wish to know M_V, not g, so these grids would not be useful to us.

Schmidt-Kaler: This is a remark concerning pattern recognition versus quantitative measurement. Pattern recognition is, I believe advisable, if there is a rather restricted number of patterns or boxes into which items are sorted; quantitative measurement is advisable if a great deal of information is available. Therefore pattern recognition is a good method for low dispersion spectra, but not for medium and high dispersions. Of course, pattern recognition can be done in many ways using both digital and analog methods. For instance one can use spectral patterns which are Fourier transformed by a laser to scan a plate and select like spectra. Quantitative measurement is definitely preferable if continuously variable physical quantities like T_{eff}, M_V etc. are involved.