TWO DIMENSIONAL SPECTRAL CLASSIFICATION OF EARLY TYPE STARS BY NARROW BAND PHOTOMETRY*

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ABSTRACT

Spectrophotometry data of 775 early type stars in a narrow band photometric system are analyzed, looking for the best parameters for a two dimensional spectral classification in the spectral region 3575 Å - 6000 Å. A correlation is established with the MK classification. The statistical technique of Principal Componant Analysis is applied to determine the number of linearly independent parameters among the data.

1. INTRODUCTION

A photometric system has been designed by Barbier, Morguleff and Gerbaldi, to point out the regions of the stellar spectra characteristic of the atmosphere of early type stars including peculiar stars (Be, Ap, Am). There are seven color indices of the form C(J) = m(J) - m(2). These indices have been measured for 775 stars in the spectral range B0 to F5. Two more color indices C(9) and C(10) have been selected for Ap, Am stars. The spectral regions are shown in Fig. 1.

2. SELECTION OF REDDENING-FREE PARAMETERS

It is well known that the intensity of the lines H_γ, K(CaII) and of the Balmer jump can provide a two dimensional classification

*The observations have been made at the Observatoire de Haute-Provence

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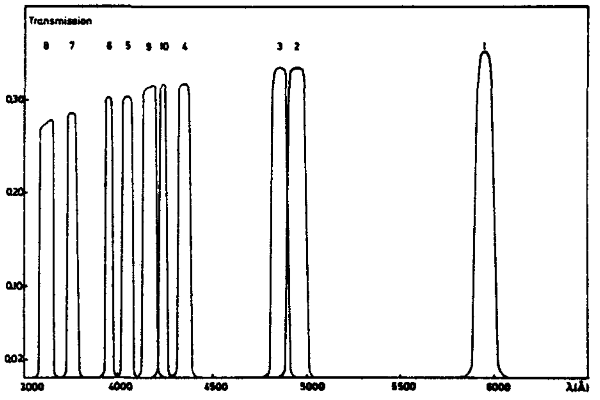

NO OF PASS-BAND	1	2	3	4	5	6	7	8	9	10
Mean Wavelength (Å)	5937	4951	4859	4350	4043	3946	3753	3618	4162	4235
Equivalent Width (Å)	93	99	89	70	60	40	60	73	80	40

Fig. 1. The passbands of the photometric system.

related to MK spectral classification.(Barbier et al. 1941; Hack 1953).

In our narrow-band photometric system, we define three parameters which are well correlated to these features (Gerbaldi 1977). Those parameters are linear combinations of the color indices:

$$C(J)-C(5)\ \frac{\frac{1}{\lambda_5}-\frac{1}{\lambda_2}}{\frac{1}{\lambda_J}-\frac{1}{\lambda_2}}$$

where HGAMA = C(4) - 0.618 C(5)
DB = C(8) - 1.644 C(5)
KCA = C(6) - 1.131 C(5)

These parameters can be considered as reddening-free. The coefficients of these relations are near those that we can determine from reddening line in diagrams C(J) vs C(5) with stars of type B0, B1, B2 and different amounts of reddening. We also computed these values with Mihalas atmosphere models (Mihalas 1966). We verify whatever coefficients we choose, the dispersion is not reduced in the diagrams.

We need those three parameters to define the two dimensional classification due to the maximum intensity of hydrogen parameters between types B9 and A3. The monotonic increase of the intensity of K(CaII) line with spectral type permits us to discriminate the classification of a star before or after the maximum.

3. RELATION WITH MK SPECTRAL CLASSIFICATION

To study the behavior of this photometry as a function of spectral classification, we used the compilation of the spectral classification in the MK system supplied to us by the Stellar Data Center in Strasbourg (Jaschek et al. 1964; Kennedy 1971). As the spectral types in different catalogues did not always agree, we carefully selected the best according to Morgan et al. (1973). The metallic, peculiar and emission line stars have been excluded, and 25 stars were excluded because spectral classes disagreed. We did not take into account stars which have only been studied by objective prism. Close binaries were also excluded.

For each spectral type, for at least four stars, and by luminosity group defined by luminosity classes (V, IV-V, IV), (IV-III, III) and (II, Ib, Ia, Iab) we computed the mean and the sample variance for all the parameters of our system. These results for the three parameters HGAMA, DB, and KCA are given in Table I.

Fig. 2 represents a grid for a quantitative spectral classification. A rather important scatter is noted; it must be ascertained that it is not due to errors in the data and we must look for the problem of additional dimensions.

4. PRINCIPAL COMPONENT ANALYSIS

Unexplained discrepancies between our photometric measures and the uvbyβ system (Oblak et al. 1976), with MK classification tempts us to introduce further parameters of classification.

Instead of looking for those parameters through physical reasons, we tested the intrinsic classification capacity of our system by means of an analysis of variance of the colors. The statistical technique known as principal component analysis (CPA) is suitable (see e.g. Lebart 1971). This method, has been applied occasionally by astronomers (for example: Deeming 1964; Brosche 1973; Heck 1976 and Christian et al. 1977). So, we do not define an apriori limited set of fundamental quantities to determine the measurable properties of stars but we take all the photometric indices for our sample of stars and we try to find the number of independent factors which account for the variations in the data.

We give here a brief summary of the PCA method. The basic idea is to determine the dimensionality of the problem for each star. We have a number of original variables x_j, $j \in [1, n]$, so we start with a system whose dimension is n. If we form the variance-covariance matrix of the x_j for all objects observed, we can determine the eigenvalues λ_j and the associated eigenvectors e_j. Then we transform the original variables x_j into new ones $_j$ which are the coordinates along the new base of the system defined by the eigenvectors.

The size of each eigenvalue is a measure of the relative contribution of the associated parameter ξ_j to the total variance of the system. By analyzing the size of all the eigenvalues, we can define the m statistically significant factors and the remaining n-m values are considered as "noise".

TABLE I

MEAN AND SAMPLE VARIANCE FOR THREE PARAMETERS

Luminosity Classes III, IV-III

Type	N	HGAMA	σ	DB	σ	KCA	σ
B1	7	0.113	0.017	0.108	0.043	0.535	0.026
B2	13	0.111	0.018	0.306	0.088	0.549	0.020
B3	23	0.135	0.023	0.473	0.058	0.553	0.016
B4	9	0.152	0.014	0.546	0.051	0.562	0.028
B5	18	0.164	0.012	0.581	0.042	0.552	0.018
B6	11	0.177	0.022	0.662	0.036	0.571	0.020
B7	10	0.195	0.021	0.722	0.071	0.589	0.028
B8	16	0.203	0.018	0.861	0.105	0.581	0.037
B9	29	0.235	0.031	1.008	0.117	0.606	0.024
A0	29	0.274	0.027	1.225	0.057	0.636	0.057
A1	17	0.312	0.022	1.276	0.057	0.678	0.036
A2	20	0.315	0.020	1.336	0.060	0.705	0.029
A3	21	0.300	0.040	1.296	0.137	0.767	0.044
A4	9	0.324	0.016	1.246	0.060	0.793	0.031
A5	16	0.292	0.023	1.230	0.075	0.827	0.045
A6	5	0.275	0.046	1.079	0.134	0.809	0.069
A7	19	0.278	0.029	1.113	0.099	0.847	0.040
A8	11	0.246	0.019	1.019	0.067	0.851	0.050
F0	18	0.232	0.042	0.983	0.104	0.860	0.030
F5	6	0.126	0.014	0.532	0.060	0.928	0.025

LUMINOSITY CLASSES II, Ib, Ia, Iab.

Typo	N	HGAMA	σ	DB	σ	KCA	σ
B1	6	0.099	0.014	0.036	0.030	0.529	0.018
B2	4	0.087	0.016	-0.015	0.092	0.507	0.026
B3	4	0.081	0.022	0.195	0.172	0.545	0.021
B9	6	0.107	0.027	0.702	0.239	0.567	0.019
A0	4	0.112	0.018	0.786	0.313	0.564	0.014
F2	5	0.157	0.028	1.251	0.187	0.894	0.066
F5	4	0.128	0.021	1.081	0.013	1.120	0.075

LUMINOSITY CLASSES III, IV-III

Type	N	HGAMA	σ	DB	σ	KCA	σ
B2	4	0.098	0.014	0.236	0.085	0.541	0.007
B5	6	0.147	0.026	0.564	0.058	0.542	0.022
B6	7	0.172	0.030	0.737	0.054	0.571	0.027
B7	8	0.174	0.021	0.778	0.060	0.572	0.035
B8	13	0.177	0.031	0.791	0.070	0.574	0.026
B9	11	0.195	0.019	0.987	0.097	0.582	0.046
A0	10	0.269	0.025	1.173	0.067	0.627	0.031
A5	4	0.288	0.032	1.292	0.130	0.733	0.040
A7	4	0.279	0.023	1.203	0.127	0.835	0.048

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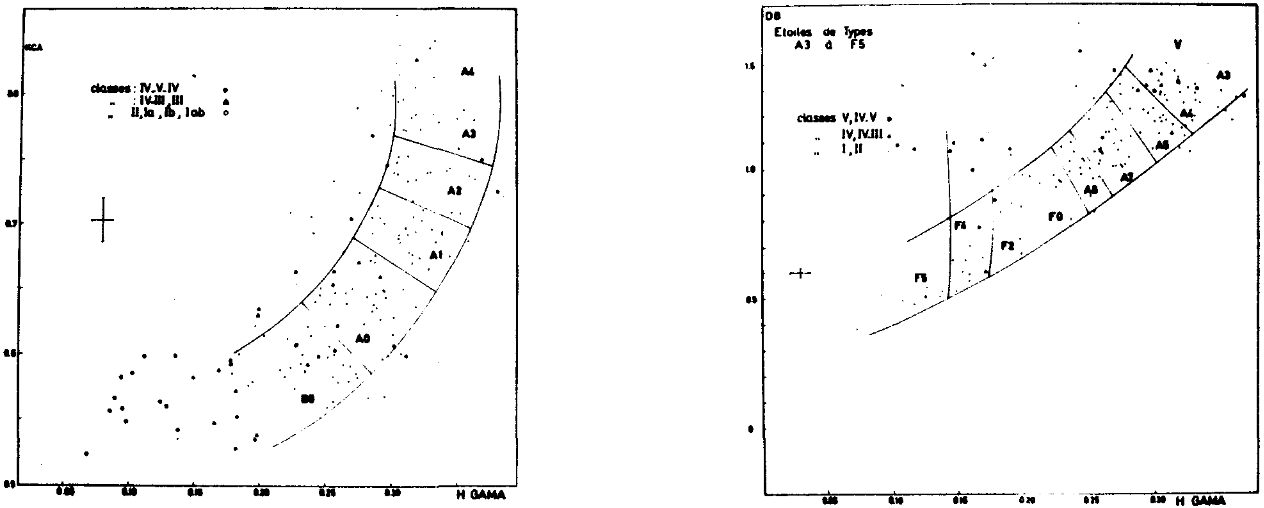
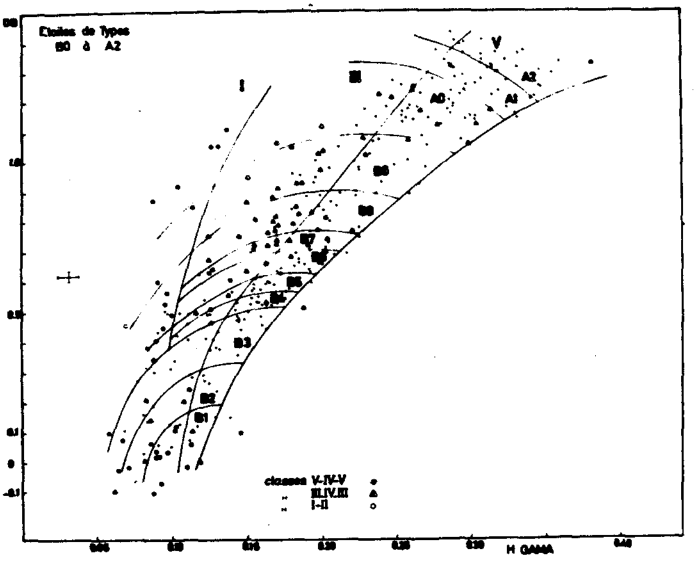


2a.

2b.

Fig. 2a,b,c. Grid for quantitative spectral classification.



2c.

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We present the analysis of the six parameters defined by

$$
\begin{aligned}
\text{HBETA} &= C(3) - 0.082\ C(5) \\
\text{HGAMA} &= C(4) - 0.618\ C(5) \\
\text{KCA} &= C(6) - 1.131\ C(5) \\
\text{DELTA} &= C(7) - 1.421\ C(5) \\
\text{DB} &= C(8) - 1.644\ C(5) \\
\text{GB} &= 2.197\ C(5)
\end{aligned}
$$

which represents respectively the following measures: of hydrogen lines H_β and H_γ, of K line of CaII, of the total intensity of the last lines of the Balmer series, the Balmer jump, and a blue gradient. The columns of Table II represent the analysis of these parameters for three groups of stars of all luminosity classes.

TABLE II

VARIANCE COMPONENTS

Component	FRACTION OF TOTAL VARIANCE		
	B0 to B9 all classes 236 stars	A0 to A3 all classes 120 stars	A4 to F5 all classes 135 stars
1	0.740	0.674	0.781
2	0.134	0.198	0.121
3	0.082	0.073	0.065
4	0.030	0.042	0.024
5	0.010	0.007	0.006
6	0.004	0.005	0.003
Cumulative variance of the first 4 components	0.986	0.992	0.991

For this system, the first four components represent about 99% of the total variance.

When we correlate our photometric system to the MK spectral classification, we used only two parameters, so, we reduced considerably the dimension of our initial system and this explains the

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dispersion of the results.

The dimension of the initial cluster of points are not conserved in the projection on the subspace reduced to a plan.

We extended the investigation of our photometric system in PCA to peculiar stars. Preliminary results concerning Am stars with color indices C(3) to C(8) compared to a set of normal stars of luminosity classes IV, V and with spectral type later than A2 are presented in Table III.

TABLE III

VARIANCE COMPONENTS

	FRACTION OF TOTAL VARIANCE	
Component	Am stars 88 stars	A2 to F5 Classes IV, V 121 stars
1	0.639	0.552
2	0.216	0.318
3	0.090	0.107
4	0.030	0.017
5	0.014	0.004
6	0.011	0.002
Cumulative variance of the first 4 components	97.5	99.4

It is tempting to say that for Am stars we have a shift of about 10% towards the last components but the two populations compared are not strictly equivalent and we have not tested to see if in both cases the observations are distributed normally.

We have performed a last PCA for the Am and Ap stars observed with two more continuum indices C(9) and C(10) to discriminate Ap, Am and normal stars.

TABLE IV

VARIANCE COMPONENTS

Component	Fraction of Total Variance			
	Am 69 stars	Ap 99 stars	Ap, Am "normal" 42 stars	A2 to F5 Classes IV, V 73 stars
1	0.593	0.827	0.580	0.675
2	0.192	0.094	0.220	0.205
3	0.098	0.041	0.110	0.096
4	0.072	0.022	0.070	0.012
5	0.024	0.008	0.014	0.005
6	0.011	0.004	0.002	0.004
7	0.009	0.003	0.001	0.002
8	0.001	0.001	0.001	0.001
9			0.000	

We added a ninth factor which is [Fe/H] value as given by Morel et al. (1976) for 42 stars (18 Ap, 11 Am, 13 "normal"). It is evident that we do not change drastically the results of the previous calculus even if the colors C(9) and C(10) were specially chosèn for detection of Ap and Am stars (Gerbaldi 1977).

All these results show that a multivariate analysis can give valuable information on the general trend of photometric indices but will never replace a fine analysis.

5. CONCLUSION

The PCA gives us the number of independant factors in a given set of variables, but nothing about the physical meaning of these factors. Nevertheless, it would be extremely instructive to pursue these kinds of investigations by combining spectroscopic and photometric results. This can be done, using the discriminant analysis technique because this method does not require quantified data. So, we could introduce in the analysis some factors such as the fact that in some stars it has been noticed in a spectral classification program broadened lines compared to spectrum of standard stars utilized. In that case we must consider our data in the same way as it is done with enquiries in social science.

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