IV CORRELATION OF SPECTROSCOPIC AND PHOTOMETRIC DATA

Discussion Leader, A. G. Davis Philip

CORRELATION OF SPECTROSCOPIC AND PHOTOMETRIC DATA

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ABSTRACT

This paper reviews first of all the various problems connected with the establishment of a relationship between MK type and various photometric parameters: reddening, binarity, rotation. Mention is then briefly made of the various relationships proposed in the literature for the UBV, uvbyβ, DDO, Vilnius and Geneva systems. The MK classification is a bi-dimensional classification which provides also indication of peculiarity (Ap, Am, Ba stars, for example). The problems arising from stars having a peculiar chemical composition are examined. The establishment of a relationship between a color index and the MK type or the location of the various MK types in a photometric diagram are both classical methods to obtain a correlation between a photometric system and the MK schema. However a new solution is proposed by the method of stellar boxes, which allows us to find all the stars having the same colors. If many photometric systems are limited in their possibilities of classifying all stars from O to M, the GENVIL (or VILGEN) system, formed with four filters of the Geneva system and three of the Vilnius system and at present under consideration, will certainly provide a very good means to this end. Finally, the new spectroscopic and photometric catalogues available at the Stellar Data Center in machine-readable form offer us the possibility of improving the present correlations.

1. INTRODUCTION

The problem of the correlation between spectral classification and parameters of the various photometric systems is

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undoubtedly a basic problem for spectroscopists and photometrists. I think that one of the first aims of a photometric system is to provide a schema of stellar classification. A comparison of photometric parameters with spectral classification (and by spectral classification I imply throughout this paper the MK system) is the first step in the operation of a photometric system and was, in fact, prior to the use of stellar atmosphere models (with various T_{eff}, log g and chemical compositions), the only way to approach the physical information contained in a photometric system.

The first work in this direction is surely that of Chalonge and Divan (1952) who use the D and λ1-3700 parameters of the BCD system, which is in fact a spectrophotometric system. This follows a previous publication by Barbier and Chalonge (1939) where the spectral type came from the HD classification. This was the point of departure of some very important research and induced much other research. The latest study on a relationship between a parameter of this system and the MK type is given in a paper by Chalonge and Divan (1977). With the BCD system we have, in fact, the beginning of spectral classification by means of photometry.

If we turn to the various systems with broad and intermediate bands, we see that the procedure generally used to correlate MK types and photometric parameters is to have a relationship (graphic or tabulated) between the MK type and photometric parameter or to use the location of the various MK types in a color vs. color (or parameter vs. parameter) diagram. It is generally assumed that the MK type is correct. In fact, as we will see later, a dispersion around each MK type exists.

Various effects can influence this type of correlation and they will be discussed briefly in the next section.

2. PROBLEMS ARISING CONCERNING A CORRELATION BETWEEN MK TYPES AND PHOTOMETRIC PARAMETERS

Many problems arise when you want to correlate MK types and photometric parameters. The first is certainly to have a color index or a parameter for the O to M stars, that is to say having approximately the same interval for the B stars as for the K stars. For example, the sensitivity of (B-V), (b-y) or (B2-V1) to the spectral type is relatively bad for the hot stars. We can of course define various indices to give a representation of the spectral type but if this is useful for the study of a particular group it is not so convenient in many cases and a calibration of a color vs. color diagram is certainly preferable.

A second problem is the interstellar reddening affecting the indices. Important progress is made if we can use a parameter which is independent, or supposedly so, of the reddening, such as for example, Q for the UBV system. Perhaps a good way of obtaining parameters free of interstellar reddening is to look into the use of multivariate analysis. Massa and Lillie (1978) have recently applied the vector space method to O stars and interstellar reddening and have obtained intrinsic Hβ values for the O and B stars.

The color indices of stars with emission or a different chemical composition may be affected, but these effects can in turn be detected photometrically.

Duplicity (unresolved visual binaries and spectroscopic binaries) can also affect the intrinsic color of a star. For example, if we consider the A2V stars of the Cowley et al. (1969) catalogue we have a mean value for (B2-V1) of $-0^m.130$ (n = 14), but if we include the spectroscopic binaries we have $-0^m.121$. A more detailed study on the effects of binarity in some photometric diagrams was made by Maeder (1968) and we can see clearly this effect on (B2-V1) in the d vs. B2-V1 diagram. Stellar rotation can be another factor which causes a difference and in a previous study using stellar atmosphere models, Maeder (1971) has shown the influence of rotation on (B2-V1). Jordahl (1970) has shown a similar effect on (b-y). This effect is also present on Hβ as shown by Collins and Harrington (1966) or by Hardorp and Strittmatter (1968). Nevertheless this effect is only detectable for large values of V sin i as shown by Warren (1970) who finds no systematic effects for the B stars below Vsini ~ 250 kms^{-1}, in accordance with theoretical studies. It is the reason why Crawford (1970) can point out that rotation has no or little effect on the calibration he proposes and that C. Jaschek (1970) can assert that the correlation between (B-V) or (U-B) and Vsini is difficult to determine. Concerning the effect of rotation on spectral type, Warren (1976) points out also a small effect on the MK type for the late B stars, while C. Jaschek (1970) finds also an effect on the MK type for AV stars. But more recent results concerning rotation effects on spectral classification are discussed at this colloquium by Slettebak.

The above discussion takes into account only problems arising from photometry and we now turn to the effects on MK type.

It can sometimes be alarming if you consider the various spectral type determinations given for one star in the catalogue of stellar spectra classified in the MK system (C. Jaschek et al.

1964). To give only one example:

HD 119756: F0V, F2III, F4III and F4IV

But the situation is not always so bad and C. and M. Jaschek (1966) have shown that the precision on the spectral type class determination was ± 0.6 of spectral class. Recently, Cucchiaro et al. (1978) mentioned an unpublished work of Houk, Jaschek and Jaschek in which we find $\sigma_{sp} = \pm 1.0$ and $\sigma_L = \pm 0.7$. It is obvious that an error in the spectral type affects the correlation between a color index and the spectral type, but there is also the error in the luminosity class because in many cases the giants and supergiants are bluer or redder than the dwarfs.

In a recent study E. Fleck (1978) has examined the problem of the choice of standard stars (for example those used by Morgan and Keenan, by Houk or by Cowley et al.) used to obtain the MK classification. Can this choice play a role in a correlation between a color index and the MK type? She studied for each list of MK standard stars the correlation between (B2-V1) and the spectral type and concluded that there is no effect.

3. CORRELATIONS BETWEEN MK TYPES AND PHOTOMETRIC PARAMETERS OF VARIOUS SYSTEMS

In this chapter I wish to mention briefly some of the most important possibilities to obtain a determination of spectral type and luminosity class from various photometric systems, either from a correlation with a color index or a parameter, or from the location in a photometric diagram.

3.1 The UBV System and the UBVRIJKLMN System

Many relations exist between the spectral type and (B-V) and (U-B) indices for the various classes of luminosity. It is difficult to give an exhaustive list and I shall limit myself to those covering the sequence of spectral types, from the O to M stars. We found essentially the relationships of Schmidt-Kaler (1965), FitzGerald (1970) and Deutschmann et al. (1976). The paper of Johnson (1966) contains also relations for the red and infrared colors of the UBVRIJKLMN system. The relationships of Schmidt-Kaler and Deutschmann et al. were obtained by using relationships of various authors, most of the time established for a limited range in spectral types. That of FitzGerald was obtained by a study of the catalogue of Blanco et al. (1968). Relationships between the spectral type and various red and infrared indices are given by Kurilienė and Straižys (1977) for the supergiants from O to M5.

3.2 uvbyβ System

The first relationship we find for the uvbyβ system is that of Strömgren (1963). This relationship is valid for main sequence stars from A3 to G1. Strömgren (1967) gives other correlations between spectral type and [u-b]β for stars between B2 and A0 and A4 to F0. Crawford (1975) has given a relationship between MK type and β for stars of luminosity classes V and IV in his study on the calibration of the F stars. More recently (1978) he gives a relationship between the spectral type and the various parameters of the uvbyβ for luminosity classes V and III of the B stars. In the same paper Crawford announces a further paper on the comparison of the uvbyβ system and calibration to the MK and UBV system for stars of spectral types O-G0. Another calibration of the B stars can be found in the paper of Warren (1976). Barry (1970) has studied the problem of spectral classification of the A and F stars and the relationship between b-y and the MK type.

Heck (1976) has applied a method of multivariate statistical analysis to the uvbyβ catalogue of Lindemann and Hauck (1973) and obtains valuable predictions of spectral type. In a further paper Heck et al. (1977) have applied methods of cluster analysis to the same catalogue and were able to point out 249 stars for which the spectral type should be reconsidered or the photometric parameters redetermined. Heck (1978) assumed that spectral classification can be predicted from photometry with 92% chance of being correct if we use the methods of cluster analysis.

Faber (1977) has proposed a graphical method to estimate MK type from measurements in the uvbyβ system. For this she uses the location of the star in the $[m_1]$ vs. $[c_1]$, β vs. $[c_1]$ and $[m_1]$ vs. β diagrams, these diagrams being calibrated in terms of MK types. It is necessary to use more than one diagram because of the overlap by stars of different luminosity classes. To check the accuracy of the method, 20 stars were chosen at random from the original list of basic data and were classified. In all cases the adopted spectral type was correct to within one-tenth of a class and in 17 out of 20 cases the adopted luminosity class was correct, the margin of error for the remainder being never greater than one luminosity class. I would mention also the work of Oblak et al. (1976) giving a correlation between β, $[m_1]$, $[c_1]$, [u-b] and the spectral type for the various luminosity classes. Finally, we can consider a paper by Davis (1977) in which he derives a relationship between UBV, β photometry and MK type. He uses a β vs. Q diagram and concludes that UBVβ is not by itself entirely sufficient to distinguish between stars of luminosity classes III, IV and V. Nevertheless it it possible to separate emission-line and supergiant B stars from the other types

3.3 The Vilnius System

Many correlations are given for this system by the Vilnius people. The most recent calibration of various indices of this system is given by Straižys (1977) in his book on multicolor stellar photometry in a tabular form or also in a paper by Kurilienė (1977). Calibrated diagrams in terms of MK type are found in a paper by Straižys and Sviderskienė (1971) and also in Straižys' book. All these tables and diagrams show very well the ability of this system to determine by photometric means the spectral type and luminosity class. Nevertheless, it is necessary to use various Q, Q diagrams for the various spectral types.

3.4 The DDO System

This system is devoted more to the late-type stars and in fact little is done with a view to obtaining a correlation between MK types and photometric parameters. McClure (1973) and Osborn (1973) have proposed the diagram C(45-48) vs. C(42-45). Other calibrations of this diagram can be found in Janes and McClure (1975) and Claria and Osborn (1976). Yoss (1977) has made a determination of a two-dimensional type derived through the DDO system. When comparing his type with the MK type he finds an agreement within two spectral subclasses in 89% of the sample 240 stars and an agreement within one-half luminosity class in 83% of the cases.

3.5 The Geneva System

A first relationship was given for the A and F stars on the main sequence by Hauck (1968). For these stars the (B2-V1) index is a good indicator of spectral type. Goy (1972) has given the intrinsic color of O stars. Golay (1974) has also given a relationship between (B2-V1) and the spectral type between B2 and G5. Recently Grenon (1978) has published the intrinsic colors of dwarfs and giants between G0 and M5. A new relationship between (B2-V1) and spectral type is given in Table I. The determination of this relationship is based mainly on stars belonging to the Cowley et al. catalogue or to the Gliese catalogue and having an MK type in the new catalogue prepared by M. Jaschek (1978).

For the O and B stars we use the unreddened stars found by Lucke (1978) in his study of the distribution of color excesses in the solar neighborhood (the MK type coming from the new catalogue of M. Jaschek) and the calibration of Goy, while for the coolest stars we adopt the calibration of Grenon. For some spectral types among the A stars we have calculated the dispersion in (B2-V1). The value of σ is of the order of 0.018, which is in good agreement with the error on (B2-V1) and the fact that each

TABLE I

(B2-V1) FOR STARS OF LUMINOSITY CLASSES V AND III

SP	V	III	SP	V	III
O 4	-.325		G 0	.348	-
O 5	-.324		G 2	.363	-
O 6	-.324		G 4	.400	-
O 7	-.323		G 6	.425	-
O 8	-.323		G 8	.459	.620
O 9	-.323		G 9	.480	.641
B 0	-.321		K 0	.505	.692
B 2	-.310		K 1	.518	.733
B 4	-.280		K 2	.547	.842
B 6	-.254		K 3	.607	.942
B 7	-.240		K 4	.695	1.096
B 8	-.223	-.219	K 5	.718	
B 9	-.210	-.210	K 6	.826	
B 9.5	-.186	-.191	K 7	.935	
A 0	-.166	-.176	M 0	.950	1.175
A 1	-.158	-	M 1	1.115	1.214
A 2	-.130	-	M 2	1.071	1.217
A 3	-.095	-.064	M 3	1.168	1.275
A 5	-.041	-.039	M 4	1.171	1.226
A 7	-.005	-.001	M 5	1.276	1.270
A 8	.035	-	M 6	1.497	
F 0	.088	-			
F 2	.140	-			
F 4	.190	-			
F 5	.220	-			
F 6	.250	-			
F 8	.302	-			

spectral type covers a limited interval in (B2-V1). This relationship agrees quite well with that obtained by Fleck (1978) for the standard stars of the MK system.

3.6 Other Systems

The systems reviewed above are those for which relationships exist for all or almost all the MK sequence. But there exist also other systems which are useful for the classification of spectral kinds of stars. It would be tedious to mention all these systems and I refer only to the most recent: that of White and Wing (1978), being a photoelectric system defined by eight narrow bands between 0.7 and 1.1 μm used to classify the M supergiants in the MK system.

4. STARS WITH A PECULIAR CHEMICAL COMPOSITION

The MK schema is bi-dimensional and it appears very rapidly that a third parameter, sensitive to chemical composition, is necessary. In fact this is already included in the *Atlas of Stellar Spectra* since Ap, Am and carbon stars are mentioned. In 1950 Nancy Roman published a paper giving the MK type for 94 stars, dwarfs and giants between F5-G5. She has shown that some stars have systematically weaker lines, or stronger lines, than others of the same MK type and she introduced the notion of weak and strong lined stars, publishing in 1952 a very important list. The subdwarfs were since discovered and Sandage and Eggen (1959) showed that their position in a magnitude *vs.* color diagram is due to their character of metal-deficient stars. More recently Houk and A. Cowley (1975) have introduced for the G stars a special notation for the weak metal stars (e.g. G5w F0): temperature type based on the H lines followed by a "w" and then the type based on the metal lines.

It is not my intention to review all blanketing parameters or to review all the problems with chemical composition since you can find many papers on this subject in the proceedings of the *IAU Symposium No. 72* on *Abundance Effects in Spectral Classification.* I prefer to examine breifly some possibilities of detecting by photometric means the peculiarities mentioned with MK type. The Ap and Am stars can be detected in many systems: uvbyβ, Vilnius, Mendoza, Gerbaldi and Morguleff, and Geneva (Hauck 1975, 1978b) while the metal-deficient stars can be detected in the UBV, uvbyβ, Vilnius and Geneva systems. For the uvbyβ and Geneva systems a blanketing parameter, Δm_1 and Δm_2 respectively, is well correlated with [Fe/H] (Crawford and Perry 1976; Hauck 1978a). I have examined the mean value of Δm_2 for the weak and strong lined stars

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of Roman's (1952) list. The result is given in Table II and it is seen clearly that the weak-lined stars have a smaller Δm_2 value than the strong-lined stars. The results of Table II are mean values and it is necessary to mention the study of Casini and Pasinetti (1971) which pointed out that the detection of an individual star on the basis of Δm_2 as a weak-lined or strong-lined star is difficult. Barry (1970) had also pointed out some individual disagreement between Δm_1 and the indication weak-lined or strong-lined. Another correlation is now under consideration: the metal-weak stars of the Houk and Cowley catalogue are now on the observation program of Geneva and a study of these stars will be made by Grenon.

The problem is certainly greater concerning carbon stars. Yamashita (1972) has found a poor correlation between his type and the infrared color index, (R + I)-(J + K), of Mendoza and Johnson (1965). More recently Honeycutt et al. (1974) have proposed the use of a red color system ([0.57]-[0.68]μ) for the carbon stars and they obtain a good correlation with Yamashita's spectral class. Grenon (1978) has shown that in some cases it would be possible to detect both carbon and barium stars in the Geneva system.

5. SPECTRAL CLASSIFICATION WITH PHOTOMETRIC "STAR BOXES"

Golay et al. (1977) have shown that the concept of a photometric "star box" defined by Golay et al. (1969) can be used for the classification of stars. They have assumed that stars having almost the same seven colors in the Geneva system have the same M_V, T_{eff} and chemical composition. It is necessary to adopt a criterion, $|\varepsilon|$, which is the maximum difference for each color between the color of a given star, the central star of the box, and the other stars belonging to the same box. Golay and Mandwewala (1977) have published the list of photometric "star boxes" in the Geneva system with $\varepsilon_u = 0.02$ and $\varepsilon = 0.01$ for all the other colors. A study is now being undertaken by M. Jaschek, C. Jaschek and Chmielewski to examine the stars belonging to the same box but having a different MK type. Fleck (1978) has obtained the list of stellar boxes for which the central star is a star belonging to a list of standards stars in the MK classification. 94 stellar boxes were found including stars from O6 to M1, of which 49 between B3 and G0. In some cases it was not possible to find the MK type for the stars in the boxes. In all 59 stars with an MK type between B3 and G0 appear in the boxes. For 15 the agreement in spectral type and luminosity class is good, for 12 the agreement is good for the spectral type only, for 15 the agreement is good for the luminosity class only and for

TABLE II

MEAN VALUES OF Δm_2 FOR WEAK- AND STRONG-LINE STARS

	wk			st		
	$\overline{\Delta m_2}$	σ	n	$\overline{\Delta m_2}$	σ	n
F V	-0.020	.016	17	-.006	0.016	25
G V	-0.031	-	4	-.0012	.015	6
G III	-0.039	.018	19	-.034	.019	16
G V + G III	- .037	.020	23	-.028	.020	22
K III	- .040	.034	25	-.003	.014	9
All stars	- .034	.026	65	-.012	.024	58

TABLE III

RANGE FOR VARIOUS COLOR INDICES

Range for:	B-V	B2-V1	b-y	R-I	B2-S
O5-B0	.02	.004	-	-	-
B0-A0	.29	.155	.10	.26	.36
A0-F0	.33	.254	.20	.19	.49
F0-G0	.28	.260	.19	.14	.40
G0-K0	.21	.157		.11	.36
K0-M0	.56	.445		.49	1.00
M0-M5	.24	.326		.76	.53
B0-M5	1.91	1.56		1.95	3.14

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17 we have disagreement for spectral type and luminosity class.

The method of stellar boxes may have many applications, as pointed out by Golay et al. But the search for stars having the same colors as an MK standard star is certainly a very fruitful application and can be used to obtain secondary standard stars.

6. DESIDERATA FOR THE FUTURE

The present situation for a correlation between MK types and photometric classification is relatively good, but it can be improved in two ways. Firstly we can use the various catalogues available at the Stellar Data Center at Strasbourg and determine new calibrations. For this the catalogue of M. Jaschek (1978) giving one MK type per star and the catalogues for homogeneous data in the UBV system (Nicolet 1978) and the uvbyβ system (Hauck and Mermilliod 1978) in addition to the already published catalogue of measurements in the Geneva system (Rufener 1976) can be very useful.

The second way to improve the classification by photometric means is to investigate whether there is a system which allows a better classification schema. To this effect we can search for a color index with the largest range from O to M stars. The range for some color indices is given in Table III, the last column giving the B2-S index which is formed by using a filter both of the Geneva system and the Vilnius system. Straižys (1977) has proposed using a system formed with four filters of the Geneva system (U, B1, B2, V1) and three of the Vilnius system (P, Z, S). This system could be named the Vilgen or the Genvil system. North (1978) has made a preliminary study of the properties of this system. For this he has used the fluxes of Kurucz et al. (1974), the stellar energy distributions of Straižys and Sviderskienė (1972) and the stars in both systems. The system proposed keeps the properties of both systems for the O to G stars and seems to be very good for the coolest stars. We can see from Table III that it offers a very wide range in (B2-S) from B0 to M5, which can be a very good feature of this system. This relation is shown in Fig. 1.

An improvement of spectral classification by photometric means can be very useful for our knowledge of the galactic structure and stellar evolution.

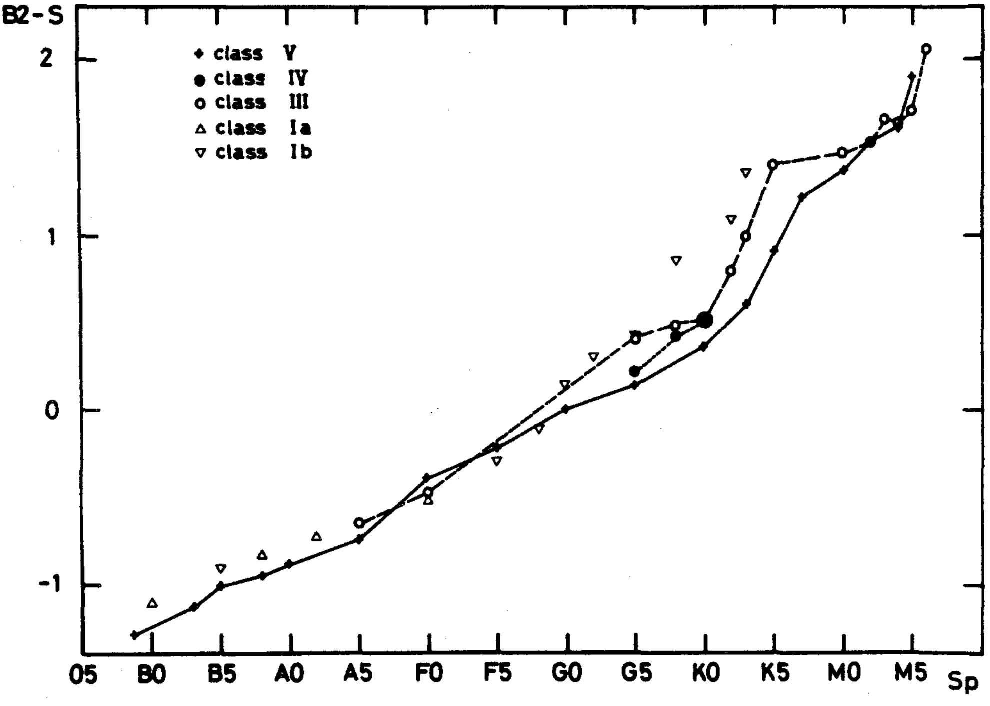

Fig. 1. (B2-S) vs. spectral type from the energy distribution of Straižys and Sviderskienė (1972).

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DISCUSSION

Nandy: You have not mentioned what sort of accuracy is required to detect the small differences in spectral type and luminosity for different types of stars. I think that the accuracy you require for photometric classification is difficult to achieve if the system is extended to fainter stars. My last comment is that, if you require n number of colors ($n \doteq 8$), it would be easier to use the whole spectrum, considering the telescope time required to observe even a few hundred stars.

Hauck: It is obvious that the accuracy is different for the bright stars as compared to faint stars. Concerning your last comment, I think that the purposes of photometry and spectroscopy can be common and also different.

Houk: You referred several times to obtaining "MK type" or "spectral types" from photometric studies. But these terms imply that

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a spectrum is involved. It would be better to use some different term, perhaps photometric type. It is also better not to use the word "classify" when referring to photometric analyses. Straižys uses "quantify." Andersen mentioned the other day the great confusion that can result when photometric types are given as spectral types in the literature.

Hauck: I agree with you. We can give only correlations between color indices and MK types, so the indication of the value of the index is sufficient.

McCarthy: I would like to ask if you could explain the dispersion in spectral and luminosity class derived by comparing your work with Houk, Jaschek and Jaschek.

Houk: The spectral classification errors (unpublished, by Houk, Jaschek and Jaschek) quoted by Hauck (σ_{temp} = 1.0, σ_{lum} = 0.6) were derived by comparing spectral types from the Michigan Spectral Catalogue, Vol. 1 (Houk and Cowley, 1975) with those from the Jaschek Catalogue, the latter being very inhomogeneous and of uneven quality. Better values may be obtained by, for example, comparing types by Houk with those by Garrison, for which σ_{temp} = 0.6, σ_{lum} = .45.

Keenan: I understand that the correlations for type G0 to M are based on the old MK types. This is much the same as using old photographic magnitudes for the colors. I hope and believe that the revised MK types will give much tighter correlations. It is true that not many revised types have been published, but I (and Dr. Garrison also, I believe) are working hard to improve that situation.

Abt: Do you have any comments on the work done about 10-15 years ago by Olin Wilson (in Ap. J.) that showed that for late-type (G-K) main sequence stars there is a very large scatter in the photoelectric colors at a given (high-quality) type or in type at a given color?

Hauck: No.

Lesh: I would like to make an urgent request of those workers who set up correlations of this type to be careful in choosing the stars on which the correlation is based (by measuring their photometric parameters). It is very important to have a set of stars which have been classified in a homogeneous way, and it is better to have a relatively small number of stars that meet this criterion than a larger number that have been heterogeneously classified.

Hauck: That is the reason why E. Fleck has worked with the list of standard MK type stars.

Andersen: A question and a comment: Do the bands in the combined Geneva-Vilnius system overlap?

Hauck: No, except in t and V_1.

Andersen: Then a comment to Dr. Nandy's question: In that case, there is ample experience to show that spectrograph photometers measuring the bands simultaneously can in fact measure faint stars with very good accuracy and excellent efficiency. In fact, a multicolor system that can be measured in this way and is applicable to all spectral types (like the Geneva system), may hold the best prospects for obtaining the necessary astrophysical information for the 50-100,000 faint stars considered in the Space Astrometry project of ESA.

Coyne: You spoke of separating Be and B normal stars. Is there really a good separation?

Hauck: You can use the UBVβ (Davis, 1977) measurements, the Vilnius and Geneva systems.

Coyne: What is the best photometric system for correlation with MK spectral type for Be stars?

Straizys: We can distinguish between normal B and Be-type stars in the Vilnius photometric system by using our magnitude S which is placed exactly on the Hα line. Such extreme Be-stars as λ Cas and ϕ Per can be recognized quite easily. At the same time it is difficult to detect limiting cases with faint Hα emission. On the other hand, the separation between B and Be-type stars depends on the half-width of the filter at Hα. The separation is much better for a 200 Å filter than for a 300 Å filter. For the detection of Be-type stars affected by interstellar reddening we use the reddening-free parameter Q_{XZS}. With filter S having a half-width of the order of 200 A the separation between extreme Be-type stars and the normal ones is as large as $0^m_.2$-$0^m_.3$ (see Astron. and Ap. 17, 312, 1972).

Fehrenbach: You have only 94 boxes with the standard MK stars, and 49 boxes with other stars; the agreement between the spectral types and the standard star is not as good as expected. Are your boxes not too small?

Hauck: No, if one takes a larger value for e, one cannot keep the hypothesis that the stars which belong to the same box have identical absolute magnitude, temperature and chemical composition.

Philip: In the Strömgren four-color system relations have been derived which allow stars to be classified into broad spectral intervals (B, A intermediate, late A and F-type). There exists for each interval an appropriate formula to deredden the star in order to obtain the intrinsic colors. These formulas apply only to main sequence and near main sequence Population I stars. Do such relations exist for the Geneva System?

Hauck: No, we prefer to use unreddened parameters.

Cowley: It certainly seems worthwhile to me to make correlations between MK types and photometric classifications. I think these correlations work remarkably well. Obviously if there are inaccuracies in the photometry or the spectral types one will see a large scatter, and one can perhaps learn something about errors in one system by making this kind of comparison. On the other hand, if one looks at the finest differences that occur between accurate photometry and accurate spectral types, I see no reason to suppose *a priori* that one is in error. After all, different things are being measured or evaluated.

Lesh: I think Fehrenbach's comment raises a fundamental point. Your boxes, which are defined by the errors in the photometry, are smaller than the boxes defined by MK spectral type and luminosity class. This reflects the fact that your photometric system is really directly correlated with the physical parameters of the star — T_{eff} and log g — rather than with the MK spectral classification system. Under these circumstances, there is no need to go through the intermediate step of determining the MK type. You might as well go directly from the photometry to the physical parameters.