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Temperature and luminosity effects in photoelectric spectrum scanner measurements of F0-K5 stars

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Abstract. — We study the possibility to classify the stars with the use of the photoelectric spectrum scanner designed at Astronomisches Institut at Bochum using a spectral resolution of about 10 Å. We analyse temperature and luminosity effects in two spectral indices which were expected to be promising as spectral classification criteria from previous studies.

Key words: stars: fundamental parameters

1. Introduction

Quantitative spectral and/or photometric classification of stars provides the main physical parameters of stars for statistical stellar samples; classification data are applicable to studies of galactic stucture and evolution. Classification may involve evaluation of criteria of very different nature, from the equivalent widths of lines measured on high resolution spectra till to photoelectric indices measured by filters with widths of some hundreds Angstroms. High resolution spectra allow to classify only apparently bright stars. On the other hand classification with photoelectric indices, like Strömgren photometry and similar systems, although being applicable to large samples of faint stars, may in many cases present not enough information and give rise to problems with picking out the stars with chemical peculiarities (CN stars, Ba stars) and in recognizing binaries. Therefore spectra with intermediate resolution (between 5 and 50 Angstroms[1]) seem to be a good compromise for many classification problems.

Among spectral devices producing intermediate resolution spectra, photoelectric scanners or diode-array systems are the most versatile instruments combining high quantum efficiency and linear energy response with flexibility in choice of wavelengths for measurements; some connaissance works have shown that spectral scans are very suitable for classification purposes (van den Berg & Sackman 1965; Beavers & Cook 1980; Tobin & Nordsieck 1981; Schmidt-Kaler 1982a, etc.). This classification approach has until now not been used much; this is mainly because of the restricted number of spectral scans. However developing new devices like Rubikon (Schmidt-Kaler 1996) and similar ones may significantly improve the situation in the nearest future.

Here we study the possibility to classify the stars with the use of the photoelectric spectrum scanner designed at Astronomisches Institut at Bochum using a spectral resolution of about 10 Å. Our classification criteria are based on narrow-band measurements in these scanner spectra. Although the use of bands instead of detailed energy distributions leads to certain deterioration of spectral resolution this step is inevitable in our approach because the channel width (10 Å) is comparable with the errors of the wavelength calibration (about ±2 Å) in scanner data. Therefore at least some channels have to be merged to supress the influence of these errors on our measurements. Wider bands imply blends of more lines and we combine into one band a number of such lines which behave similarly with respect to temperature or luminosity effects. Many authors have defined narrow-band indices to measure temperature, luminosity and metallicity effects from medium-low resolution spectra of stars as well as integrated spectra of stellar systems (a recent example has been provided by Covino et al. 1995).

In defining the bands we try to draw into consideration different authors' experience in choosing the classification criteria on photographic spectra of higher or similar resolution as well as in analyzing photoelectric narrow-band measurements. Two selected criteria were measured and

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[1]Jaschek & Jaschek (1987) designated such measurements as a spectrophotometry which may be considered as either a multicolor narrow-band photometry or a low resolution spectroscopy.

analysed here with respect to MK spectral types and luminosity classes. Malyuto & Schmidt-Kaler (1996) have chosen additional spectral criteria and elaborated a scheme of quantitative spectral classification based on these spectral scans.

In principle methods applicable to stellar quantitative spectral classification, can be broken down into two basic categories: criterion-evaluation and pattern-recognition methods. We are using here the first method (other recent applications of the method are in Malyuto & Shvelidze 1989; Meyers-Rice & Young 1994). Although the second method (Demmer 1989; von Hippel et al. 1994) is able to provide the maximum information (which is important especially in the case of noisy spectra of faint stars) this method presupposes the knowledge of a continuum or pseudocontinuumn, and of the interstellar reddening which itself should be determined later when the classifications are applied to stellar-statistical problems. Another advantage of the first method is its direct applicability to multi-color intermediate and narrow-band photometries.

2. Observations and definition of classification criteria

The observations were performed by various observers with the photoelectric spectrum scanner of the Astronomical Institute of the University of Bochum attached to the 61 cm Cassegrain telescope of the University of Bochum which is located at the European Southern Observatory at la Silla, Chile. A description of telescope and instrument has been given by Schmidt-Kaler & Dachs (1968) and by Haupt et al. (1976). Scanner spectra (resolution 10 Å, wavelength range 3500–8500 Å) for about 200 MK standards of all spectral and luminosity classes were compiled and reduced to absolute intensities by Demmer (1989). The MK classifications were compiled from various most reliable sources but, if possible, we prefer to use the best standard MK determinations compiled by Garcia (1989). We restrict the spectral domain to F0-K5 where both metal and hydrogen lines are present. In total the spectra of 58 stars are available.

Our stars are classified in literature as normal standard stars in the MK system. Therefore we may suggest that these stars have nearly normal metallicities. In fact the [Fe/H] values are known from the catalogue of Cayrel de Strobel et al. (1992) for the majority of our stars and indeed only three G-stars have moderate metal deficiency ([Fe/H] about −0.5).

An example of the spectrum for a whole wavelength range is presented for the star HD 36079 (G5II) in Fig. 1. The same spectrum for narrower wavelength range (3600–4600 Å) is presented in Fig. 2.

The choice of the intervals selected for measurements (M, T, G and H marked in Fig. 2) has been made after examination of the scanner data and many publications where sensitivity of different spectral lines to main phys-

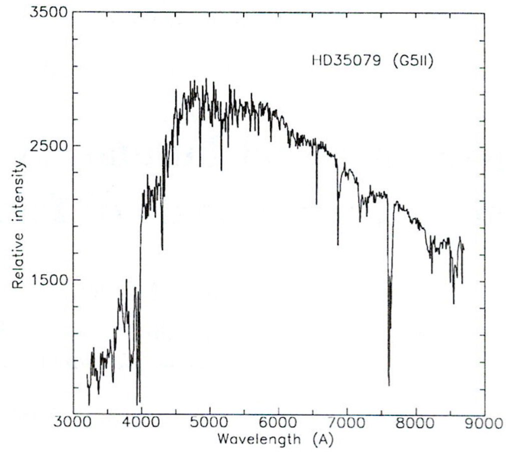

Fig. 1. The spectrum of HD 36079 (G5 II) obtained with the Bochum scanner

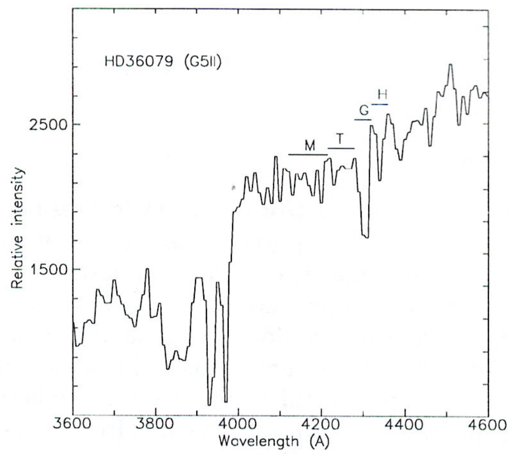

Fig. 2. The same spectrum as in Fig. 1 but for the narrower wavelength range (3600–4600 Å). The intervals M, T, G and H selected for measurements were marked with the horizontal bars

ical parameters was estimated in photographic spectra of higher resolution.

The intervals chosen in our analysis are the following: M = 4120–4215 (Δ=95 Å), T = 4215–4280 (Δ=65 Å), G = 4280–4320 (Δ=40 Å), H = 4320–4360 (Δ=40 Å).

Each interval includes at least four channels of 10 Å each. We hope therefore that the inaccuracy of borders (due to errors of the wavelength calibration with about ±2 Å) does not influence the results of our measurements very much. In determining the borders we tried to choose them to be close to peaks in the spectral energy distribution thus diminishing the influence of inaccuracies on measurements.

In identifying spectral lines within these intervals we follow the analysis of Abastumani objective prism spectra by West (1970, 1972). In the interval T (4215–

4280 Å), the most noticeable spectral lines are 4227 Å (CaI), 4253 Å (CrI, FeI) and 4272 Å (FeI) and all of them are useful in establishing the spectral type in the MK classification system (Keenan 1963; where the usefulness of the line 4227 Å, applied already by Cannon to the "Henry Draper" classification, has been mentioned). The ratios 4227/Hγ and 4272/Hγ has been measured by West (1972) as a criterion for spectral type in his scheme of automatic quantitative spectral classification based on Abastumani objective prism spectra for G-K stars.

In the interval M (4120−4215 Å) the most prominent lines include CN: 4176 Å (FeI, CN), 4200 Å (FeI, CN), 4215 Å (CN, SrII) together with 4132 Å (FeI). Already in the twenties Lindblad recognized that the absortion near 4215 Å was strongly correlated with luminosity and this feature was extensively used it as classification criterion in a number of works (see Keenan 1963). In the description of the Atlas of objective prism spectra Seitter (1975) marked that "in type G0-K0 blend 4132−4216 Å is absent or marginal in luminosity class V, increasingly stronger with increasing luminosity class and advancing spectral type". The ratios 4132/Hδ, 4176/Hδ and 4200/Hδ were used as quantitative criteria of luminosity class by Shiukashvili (1969) and West (1972), in their analysis of Abastumani objective prism spectra.

We summarize that the intensities of lines in the intervals T and M both increase with decreasing temperature but their sensitivity to luminosity is quite different. Therefore we may expect that the ratio of intensities of lines in the two intervals (T and M) may depend mainly on luminosity and may therefore serve as a luminosity criterion.

Two other intervals (G and H, 4280−4320 Å and 4320−4360 Å, respectively) include mainly G-band (4308 Å and 4299 Å, CH, FeI), on one side, and the hydrogen line Hγ (4340 Å), on other side. These features were widely used as the criteria of spectral type in the "Henry Draper" classification as well as in MK classification (see Keenan 1963). The ratio of these two features is the well known criterion of spectral type in visual (Bartaya 1979) and quantitative (Shiukashvili 1969) spectral classifications based on Abastumani objective prism spectra. Therefore we may expect that the ratio of intensities of lines in intervals G and H may serve as a temperature criterion.

Each measurement in our analysis is an area confined by the border wavelengths for an interval, the spectral energy distribution and the zero level. Then the area ratios (M/T and G/H) are calculated and treated as spectral indices. The intervals in each ratio were chosen to be adjacent to minimize possible effects of interstellar extinction on our measurements. For some stars repeated measurements are available and were averaged. We tried to estimate an internal accuracy of our measurements of the ratios from the repeated measurements for eight stars. It has been found that the internal rms errors of the M/T and G/H ratios per one measurement (expressed in per cent) are 1.9±0.6%.

3. Analysis of the measurements

The list of stars together with the criteria measurements may be found in Malyuto & Schmidt-Kaler (1996). Our measurements are analysed as a function of MK spectral types. Because MK spectral types represent discrete values, we replaced them by continuous MK spectral codes (following West 1972), correspondingly for F0 = 4.0, G0 = 5.0, K0 = 6.0. The use of the linear scale, instead of the spectral types, means that some distortions of this scale may exist (in the MK system not all decimal sub-types are used). To check it, in Fig. 3 we compared both spectral types and codes with a continuous physical parameter – effective temperature for different MK luminosity classes (the MK calibration by Schmidt-Kaler 1982b, has been involved). We see that only small deviations from linearity exist for luminosity class III, for other luminosity classes the deviations are systematical and significant. However, all of the them are smooth. If necessary, one may relate codes to effective temperature (in such a case luminosity-dependent corrections should be introduced).

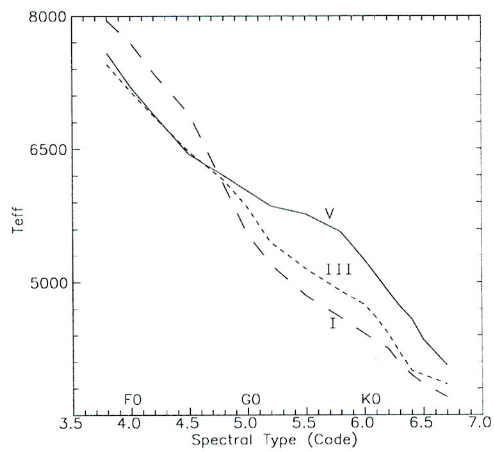

Fig. 3. The relationships between effective temperature and MK spectral types (codes) according to Schmidt-Kaler (1982b). The following designations are used: solid line – luminosity class V, short-dashed line – III, long-dashed line – I

The results of measurements are presented in the form of diagrams "Ratios versus MK spectral types" in Figs. 4-5 (for the M/T and G/H ratios, respectively). The spectral types and codes both are given in Figs. Explanation of the used symbols is given in Fig. 4. We see that the ratio M/T displays a very distinct luminosity effect (Fig. 4). The temperature effect is the most prominent feature of the diagram "Ratio G/H versus MK spectral type" (Fig. 5) although some high luminosity stars are

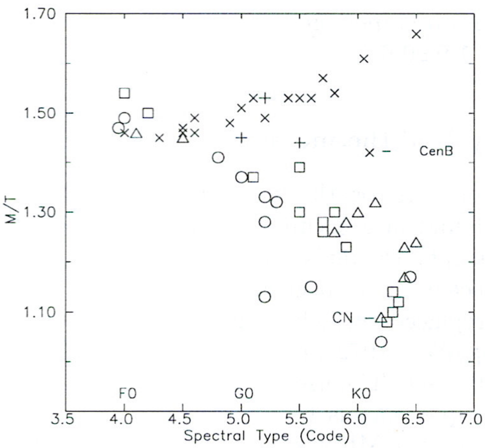

Fig. 4. The diagram "Ratio M/T versus MK spectral type" for the MK standard stars. The following designations are used: crosses – luminosity class V, plus signs – IV, triangles – III, IIIab, squares – IIIa, II-III, IIb, II, Ib-II, circles – Ib-IIa, Ib, Ia, I. The component B of the binary system αCen and the CN-star (HD 140573, K2IIIbCN) are marked

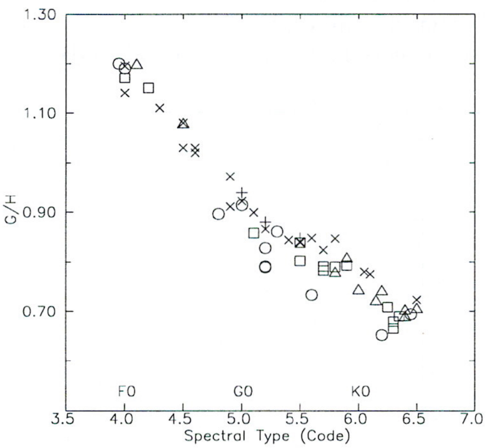

Fig. 5. The diagram "Ratio G/H versus MK spectral type" for the MK standard stars. The designations are the same as in Fig. 4

deviating slightly from the sample distribution populated mainly by giants and dwarfs.

In Figs. 4-5 the supergiants (circles) are scattered more than the stars of other luminosity classes. This feature usual for such diagrams (see, for example, Shiukashvili 1969) is due mainly to real differences in luminosities within the sample of supergiants as well as to the variability of some supergiants. For example, the latest supergiant HD 78647 (K4.5Ib according to Keenan & McNeil 1989) is closer to giants than to supergiants in these diagrams. In the Simbad database the star is marked as a variable, its cited luminosity classes range from IV to Ib (!), so there is no real contradiction with our data.

The three G-dwarfs with the moderate metal deficiency ([Fe/H] about −0.5) do not deviate from the G-dwarfs of normal metallicity in Figs. 4-5. But it is apparent that at the latest spectral types the CN-abundance seems to influence the ratio M/T sensitively (possibility of abundance effect on blend 4132−4216 Å including CN-feature was marked by Seitter 1975, too). The star HD 140573 has MK type K2IIIbCN according to Garcia (1989). Therefore its spectrum has enhanced CN-bands and that is why this star is way down from the normal position of the giants in Fig. 4 (M/T=1.09). The star HD 128621 (K1V) is the component B of the well-known binary system αCen. The present secondary at earlier epoch has been the primary of the system losing mass and consequently uncovering its CN-enriched inner layers, which may explain why this star is way down from the normal position of dwarfs in Fig. 4 (M/T=1.42).

4. Comparison with the narrow-band measurements of Griffin and Redman

Narrow-band photoelectric photometry has been carried on at the Cambridge Observatories by Redman (1966) and others (see references therein). A lot of spectral features has been measured and CN 4200 Å and G-band were among them (Griffin & Redman 1960). It is interesting to compare the results.

Table 1. The borders of measured intervals

Band	Griffin & Redman	Our study
CN-band	4164–4214 Å	4120–4215 Å (M)
Comparison bands	4097–4149, 4230–4283 Å	4215–4280 Å (T)
G-band	4285–4315 Å	4280–4320 Å (G)
Comparison bands	4230–4270, 4342–4380 Å	4320–4360 Å (H)

One can see from Table 1 that our interval M including the CN-band is about twice as wide than the one in the study of Griffin & Redman (1960) because we included also other lines expected to be sensitive to the luminosity effect, too. We used only one comparison band instead of two in the study of Griffin & Redman, and one of Griffin & Redman's comparison bands was very similar to ours one. Good separation of luminosity classes is marked in respective diagrams "Ratios versus $B-V$ or MK spectral types".

The interval including the G-band almost coincides in both studies, one of Griffin and Redman's comparison bands is also rather similar to ours. It is natural that similar conclusions resulted: non-linear dependence of ratios on $B-V$ or MK spectral type and poor separation of luminosity classes were evident in both studies. Griffin &

Redman noted the maximum for luminosity class III near $(B-V)$=1.3. According to the calibration of $(B-V)$ versus MK spectral type (Schmidt-Kaler 1982b) this corresponds to spectral class K3. In our measurements (Fig. 5) the respective minimum may be marked (note that the G-band is the numerator of the ratio in our study but is the denominator of the ratio in Griffin & Redman 1960).

We underline close similarity of the results obtained by Griffin & Redman (1960) and by us in temperature and luminosity effects in the spectral intervals including CN- and G-bands, although the spectral devices, the stellar samples and the exact border intervals were different.

Extension of our measurements to other spectral intervals sensitive to the main physical parameters seems to be promising. It may be the additional intervals containing Mgb lines and FeI triplet 5250 Å (Redman 1966, found very good separation of luminosity classes in these cases), NaD lines with strong variation with $(B-V)$ also according to Redman (1966). In the Atlas of objective prism spectra by Seitter (1975) some promising features were marked too. It may be, for example, the luminosity sensitive ratios 4046−4078 Å (FeI, CrII) to 4102 Å (Hδ) at spectral class G0 and 3889 Å (H_8) to 3934 Å (CaII) at spectral class F2. Measurements in the region 3845−3885 Å seem to be very promising to study metallicity effects (Malyuto & Jimsheleishvili 1977; van den Bergh 1963; van den Bergh & Sackmann 1965).

5. Conclusions

The Bochum spectral scanner data have been used to study temperature and luminosity effects in some spectral indices which were expected to be promising as spectral classification criteria from previous studies. It was demonstrated that the two measured quantities M/T and G/H (the ratios of line intensities in the selected intervals) are very sensitive to luminosity class and spectral type, respectively. Malyuto & Schmidt-Kaler (1996) have extended the measurements to other spectral regions and created a scheme of quantitative spectral classification of F-K stars based on narrow-band measurements of the scanner data. This classification scheme may be applicable to studies of galactic structure and evolution.

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