FROM MULTICOLOR PHOTOMETRIC INDICES TO THE HR DIAGRAM

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ABSTRACT

The Vilnius photometric system permits one to determine photometrically temperatures and log g's or spectral types and M_V's of stars in spite of the presence of interstellar reddening. The position of any normal star in the HR diagram can be determined by its direct calibration in five reddening-free quantities Q. The position of the star in the HR diagram corresponds to the point at which five Q-isolines intersect. This is the most direct way to find the position of the star in the HR diagram from photometry.

The Vilnius photometric system, which consists of seven bands at 3450 (U), 3750 (P), 4050 (X), 4660 (Y), 5160 (Z), 5440 (V) and 6560 Å (S) has been developed for two-dimensional classification of both unreddened and reddened stars of spectral types from B to M. Later on the system was shown to be applicable in detecting photometrically some types of stars with certain peculiarities, e.g. subdwarfs, late-type metal-deficient giants, Am- Ap- and Be-type stars, white dwarfs, double stars, etc.

The general classification scheme proposed by Straižys (1970) can be applied to stars of various spectral types, luminosities, chemical compositions, peculiarities and various values of interstellar reddening. It is based on Q, Q diagrams calibrated in spectral types and absolute magnitudes (Sviderskienė and Straižys, 1971; Straižys and Sviderskienė, 1972). Later on Straižys

A. G. Davis Philip and D. S. Hayes (eds.), The HR Diagram, 293-300.

(1974a, b, 1975) proposed another method of classification based on reddening-free energy curves Q_{mVS}, λ, where

$$Q_{mVS} = (m-V) - \frac{E_{m-V}}{E_{V-S}} (V-S).$$

In this paper the calibration of quantities, Q in temperature and log g is given and the new method of quantitative classification or quantification as suggested by Barry et al. (1977), is described. The calibration of quantities Q in spectral types and M_V can be made and used in a similar way. However, one should not forget that photometric quantities actually depend on gravity, not on absolute magnitude.

The color indices of the Vilnius photometric system (U-V), (P-V), (X-V), (Y-V), (Z-V) and (V-S) were calibrated in T_{eff} and log g in two different ways: (1) by using model stellar atmospheres and (2) by transferring the calibration from the MK classification system. In the first case the model stellar atmospheres by Kurucz (1976) and Peytremann (1974) and the response curves of the system by Straižys and Zdanavicius (1970) were used. In the second case the color indices of stars with different T_{eff} and log g were obtained from intrinsic color indices of different MK types determined from observations by Kurilienė (1977). The calibration of B-type stars against T_{eff} is based on Code et al. (1976). The T_{eff} for A-M-type stars were averaged from different sources. The log g values are based on the data of 280 main sequence stars, 140 giants and 80 supergiants compiled from literature.

The Kurucz models in general show satisfactory agreement with real B-type stars of different luminosities including supergiants. However, the Kurucz energy curves for A-F-G V models in the blue and ultraviolet parts of the spectrum are too bright and this discrepancy between models and stars increases with later spectral types. A similar effect has been found by Philip and Relyea (see page 443 of this volume). This may mean that Kurucz models need some additional line blocking corrections in short wavelengths. Indices (Y-V), (Z-V) and (V-S) of the main sequence stars representing longer wavelengths also show some systematic differences. The same is true for all the indices of A-F supergiants.

Peytremann models of spectral types A-F-G V in the ultraviolet show much better agreement with real stars than Kurucz models do. However, for supergiants we observe the opposite situation: The indices (U-V) and (P-V) of A-G-F I models are reddened by $0^m.1$-$0^m.2$ in comparison with real stars.

It can be concluded that the energy distribution curves of Kurucz and Peytremann model stellar atmospheres may be used for the calibration of color indices and other photometric quantities

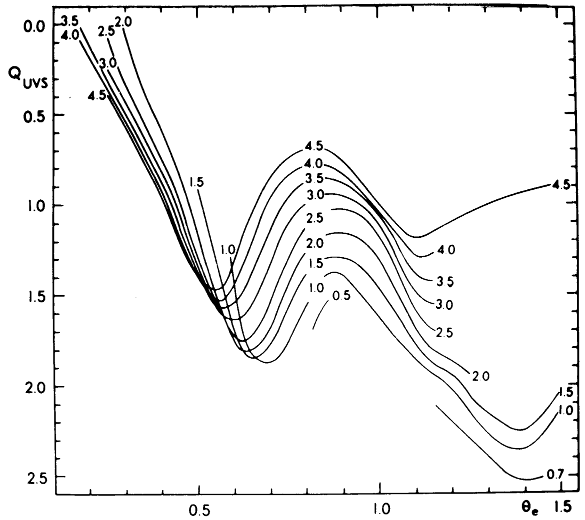

Fig. 1. Q_{UVS} versus Θ_{eff} for different values of log g.

for B-type stars and A-F stars of luminosities V-III but certain precautions must be taken. Until better models appear for A-F supergiants and stars of later types it is more reasonable to transfer the calibration in T_{eff} and log g from the MK system. This method has the advantage of being free not only from the errors introduced by inaccuracy of model atmospheres, but from the errors of response curves and integration errors as well. It can be used to calibrate all the spectral types including late ones for which model energy curves are absent.

Color indices calibrated in T_{eff} and log g can be used for two-dimensional quantification of unreddened stars only. If interstellar reddening is present one should use the five independent reddening-free quantities Q_{UVS}, Q_{PVS}, Q_{XVS}, Q_{YVS} and Q_{ZVS}. These quantities can be calibrated in T_{eff} and log g in the same way as the color indices. An example of the calibrated diagram of the Q_{mVS}, θ_{eff} type with isolines of log g is shown in Fig. 1 (see the monograph Straižys, 1977 for more details). It is obtained by combining both methods of calibration described above. The calibration of B- and early A-type stars is based on Kurucz models with only small corrections added. The calibration of G-K-M stars is transfered from the MK system as shown in Table I.

The parameters θ_{eff} and log g of a star can be derived in the following way:

1) Enter the diagram Q_{UVS}, θ_{eff} with the observed value Q_{UVS} and read out a series of pairs of log g and θ_{eff} at the points where the line Q_{UVS}= const intersects the lines log g = const.

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TABLE I

CALIBRATION OF MK TYPES IN TEMPERATURE AND LOG g

Sp Type	T_{eff} V	log g V	log g III	T_{eff} I	log g Ib	log g Ia
O7	35400	4.00	3.5			
O8	34100	4.00	3.5			
O9	33600	4.02	3.5	30000		
B0	31400	4.03	3.5	27000	3.60	3.20
B1	26000	4.04	3.5	23500	3.15	2.90
B2	22700	4.06	3.5	19500	2.90	2.65
B3	18100	4.08	3.5	16500	2.70	2.40
B5	14800	4.10	3.5	14000	2.50	2.00
B6	13800	4.13	3.5	13000	2.30	1.80
B7	12900	4.16	3.5	12000	2.20	1.70
B8	12100	4.18	3.5	11500	2.12	1.55
B9	10400	4.20	3.5	10400	2.04	1.45
A0	9600	4.20	3.5	9800	1.98	1.33
A1	9400	4.20	3.5	9500	1.92	1.24
A2	9150	4.20	3.5	9200	1.88	1.15
A3	8900	4.20	3.5	8900	1.83	1.08
A5	8400	4.20	3.5	8300	1.74	0.97
A7	8000	4.20	3.4	7900	1.67	0.88
F0	7300	4.20	3.1	7400	1.57	0.78
F2	7000	4.20		7100	1.50	0.72
F3	6850	4.20		6900	1.47	0.70
F5	6500	4.20		6500	1.40	0.65
F8	6150	4.20		6000	1.30	0.56
G0	5950	4.30		5700	1.23	0.50
G2	5800	4.40		5400	1.17	0.45
G5	5600	4.45	2.7	5000	1.07	0.37
G8	5440	4.50	2.7	4600	0.97	0.29
K0	5240	4.55	2.7	4400	0.90	0.24
K1	5120	4.57	2.6	4300	0.86	0.21
K2	4960	4.60	2.5	4200	0.83	0.19
K3	4780	4.62	2.2	4100	0.80	0.16
K4	4600	4.64	1.9	3950	0.77	0.14
K5	4400	4.65	1.7	3850	0.74	0.11
K7	4000	4.65	-	-	-	-
M0	3750	4.65	1.6	3700	0.70	0.08
M1	3600		1.5	3600		
M2	3400		1.3	3500		
M3	3300		1.1	3300		
M4	3200		0.9	3100		
M5	3100		0.7	2950		
M6	2950		0.4			
M7	(2850)					
M8	(2750)					

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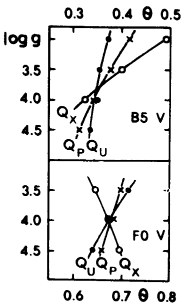

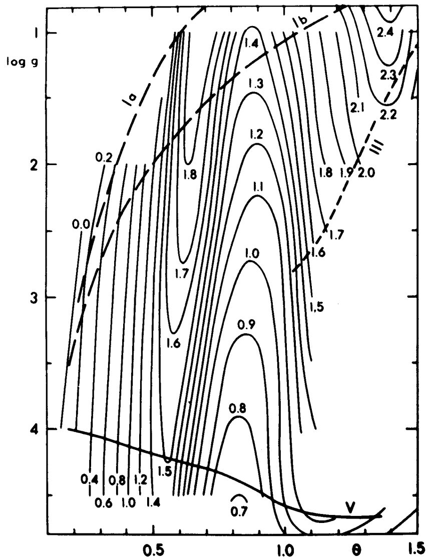

Fig. 2. Log g versus θ_{eff} for a B5 and F0 main sequence stars. The log g, θ_{eff} value for each star is indicated by the intersection of the three lines.

Fig. 3. Log g versus θ_{eff}. Luminosity classes Ia, Ib, III and V are indicated as well as lines of constant Q

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2) Plot this series of points on the diagram log g, θ_{eff} and join them with a line.
3) Repeat the same procedure for Q_{PVS}, Q_{XVS}, Q_{YVS} and Q_{ZVS}.

If the calibration of diagrams, Q, θ_{eff} is correct and if the star is a normal one and observed with sufficient accuracy, all five lines in the diagram log g, θ_{eff} must intersect at one point. The coordinates of this point give the temperature and gravity for the star. Two examples of such a diagram are shown in Fig. 2. Only three Q isolines are plotted. The remaining two give us information for early-type stars. Due to errors of calibration and observation the lines in the diagram log g, θ_{eff} will not intersect at one point. Optimum values of both the parameters log g and Θ_{eff} can be evaluated taking into account error bars of different Q quantities.

Also the lines log g, θ_{eff} will not intersect at one point in the case of stars having certain peculiarities in their spectra. The character of deviations of different lines in the diagram log g, θ_{eff} can be used to evaluate the peculiarity type of the star: Looking only at these five lines a trained investigator will be able to decide - is the star a subdwarf, metal-deficient giant, metallic-line star, Ap-star, white dwarf or double star? A computer makes it possible to determine the degree of peculiarity or metallicity.

The calibrated diagrams of Q, θ_{eff} can be transformed into another form, with log g and Θ_{eff} on the axes and with isolines Q=const (Fig. 3). If M_V or M_{bol} are substituted for log g we have a calibrated HR diagram which can be used for quantification of stars. The position of a star on this diagram corresponds to the point at which five isolines Q_{UVS}, Q_{PVS}, Q_{XVS}, etc. intersect. This is the most direct way from photometry to the HR diagram. If one is observing with a photoelectric photometer on-line with a computer the position of the star just measured can be seen on the HR diagram within a few seconds.

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DISCUSSION

KEENAN: Did I understand you to say that you can detect barium stars by your photometry? How do you do it?

STRAIŽYS: The barium stars show a weakening in the blue-violet part of the spectrum in comparison with ordinary K-giants of the same temperature. As a result the Vilnius color index (X-V) is larger for barium stars. This problem is discussed in greater detail in my monograph Multicolor Stellar Photometry, which was just published by Mokslas Publishers in Vilnius. This book is available from the Vilnius Astronomical Observatory.

HAUCK: Yesterday, Dr. Greenstein made a remark concerning a possible gap in the distribution of late B stars in the diagrams presented by Dr. Crawford. We have observed such a gap at B7 in the Geneva system, and a paper by J.C. Mermilliod was published in Astronomy and Astrophysics (**53**, 289, 1976). Do you observe the same gap in your diagram?

STRAIŽYS: I can't answer this question because we have not looked for the gap in our diagrams.

BELL: Have you made similar calculations for metal deficient stars and do you have observations of such stars?

STRAIŽYS: The Vilnius Observatory astronomers, A. Bartkevicius and J. Sperauskas have published three lists of Pop II stars observed in the Vilnius system (Bull. Vilnius Obs. Nos. 26, 36, and 40). These lists contain the F-G subdwarfs, late-type metal deficient giants, horizontal-branch stars, hot subdwarfs, etc. We have developed the method of detection and determination of [Fe/H] for subdwarfs and MDG's when interstellar reddening is present. We are continuing our observations of metal-deficient stars and a new catalogue of photometric data containing about 250 stars will soon be published.

GLIESE: How well is it possible to determine absolute magnitudes M_V from data in the Vilnius system? Especially, is it possible also for late type main-sequence stars and has it been done already?

STRAIŽYS: For the determination of M_V we usually use the Q, Q diagrams calibrated in spectral classes and M_V. The absolute magnitudes determined in this way for about 700 stars have been published in Bull. Vilnius Obs. Nos. 34 and 36.

Considering late-type dwarfs the problem is complicated because we have not investigated the effects of chemical composition differences on our colors. However, we estimate that the method permits us to determine M_V for red dwarfs with a mean square error of $\pm 0\overset{m}{.}5$ (Bull. Vilnius Obs. No. 31).

PARTHASARATHY: There are now many photometric systems. With the improved detectors, the broad band systems are not so necessary. Is it not better to unify some of the photometric systems which have some bands in common?

STRAIŽYS: Yes, I agree with you. Some systems could be unified. We are making the first steps in this direction by trying to join the Vilnius and Geneva Observatory systems. Discussions with Dr. Golay and Dr. Hauck are in progress and we have agreed to introduce a joint seven-color system which we shall call the VILGEN system. This new system will have all the best properties of both of our systems.

D. EVANS: Why not call it the GENIUS system?