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A PHOTOMETRIC SYSTEM FOR INVESTIGATION OF GALACTIC STRUCTURE

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Abstract. A medium-band multicolor photometric system for the classification of stars in the general Galactic field is proposed. The system is based on the experience obtained by the authors in selecting optimum passbands for completely photometric three-dimensional classification of a mixture of stars containing samples of different temperatures, luminosities, metallicities and interstellar reddenings. Many types of peculiar stars (emission-line stars, chemically-peculiar B and A stars, white dwarfs, horizontal-branch stars, carbon stars) are also recognizable. The full system consists of 10 passbands covering spectral range from 350 to 1000 nm. Various combinations of passbands are possible, depending on stellar population in the field and on the presence or absence of interstellar reddening. If necessary, the system may be supplemented by ultraviolet passbands in the region of the interstellar extinction bump (for the extinction law determination).

Key words: techniques: photometric – stars: fundamental parameters, classification

1. INTRODUCTION

A photometric system for the classification of stars in the general Galactic field must be able to recognize all types of stars. For example, before determining the physical parameters of K0 III stars of the thin disk one must be able at first to identify them, i.e., to select them from the remaining stars. These "remaining" stars include OBAFGKM stars of all luminosities, Be, Bp, Ap, Am, BHB, RHB stars, white dwarfs, FGKM subdwafs, metal-deficient subgiants and giants, barium and carbon stars, T Tauri and Herbig Ae/Be stars, etc. Additionally, about 50% of stars are unresolved physical binaries and many optical binaries. All these stars must be classified with sufficiently good accuracy before determining their physical parameters (effective temperatures, gravities, absolute magnitudes, metallicities, interstellar reddenings, etc.). Consequently, the optimum photometric system for wide-field imaging from space must be selected for stars in the general Galactic field where stars of all temperatures, luminosities, metallicities, peculiarities and interstellar reddenings are mixed together.

During the 20th century many different systems were proposed. The systems have very different capabilities in determining physical parameters of stars, each system being most effective in certain temperature and luminosity ranges. Some of them are more or less capable of eliminating interstellar reddening effects. Photometric systems can contain from one to more than ten passbands.

2. THE VILNIUS PHOTOMETRIC SYSTEM

The problem of photometric classification of a mixture of stars of different types and reddenings was successfully solved in a very good approximation about 40 years ago selecting the optimum positions of passbands of the *Vilnius* medium-band photometric system. The selection was based on energy distribution functions of stars of various spectral and luminosity classes obtained by the photoelectric scanning method and on the real interstellar extinction law. The aim was to find a minimum number of passbands which would give two-dimensional classification (temperature and luminosity) of reddened stars situated on all sequences of the HR diagram. The selection of optimum passbands was based on the synthetic two-color and interstellar reddening free Q, Q diagrams, by varying positions, widths and shapes of the response functions. The details of the selection process are described in Straižys (1992, 1999b). The mean wavelengths and half-widths of the resultant seven-color system are given in Table 1.

Table 1. Mean wavelengths and half-widths of passbands of the *Vilnius* photometric system.

Passband	U	P	X	Y	Z	V	S
λ_0 (nm)	345	374	405	466	516	544	656
$\Delta\lambda$ (nm)	40	26	22	26	21	26	20

The accuracy of determination of the physical stellar parameters by *Vilnius* photometry, when the accuracy of photometry is ± 0.01

mag, is:

• spectral class: ±0.8 of decimal subclass;

• temperature: from ±2000 K for hot stars to ±200 K for cool stars;

• absolute magnitude M_V:
±(0.4–0.6) mag for luminosity V–III stars,
±(0.8–0.9) mag for supergiants;

• surface gravity $\log g$: ±(0.2–0.5) dex;

• metallicity [Fe/H]: ±(0.15–0.2) dex;

• color excess E_{B-V}: ±(0.02–0.03) mag;

• interstellar extinction A_V: ±0.1 mag;

• distance d: ±25 % for luminosity V–III stars.

Additionally, the system makes it possible to identify many types of peculiar stars, including F–G–K subdwarfs, G–K metal-deficient giants, white dwarfs, Ap, Am, carbon, barium and CH stars, emission-line stars of the types Be, Herbig Ae/Be, T Tauri, WR and many types of unresolved binaries. The system was used for investigation of stellar population in the Galaxy. A number of sky areas containing dust and molecular clouds have been investigated. Till the end of 2003 about 10 000 stars have been observed with photoelectric photometers and more than 2000 stars by CCD detectors.

3. THE STRÖMVIL PHOTOMETRIC SYSTEM

Straižys, Crawford and Philip (1996) have demonstrated, that the addition to the four-color *Strömgren* photometric system of three passbands at 374, 516 and 656 nm from the *Vilnius* system makes the combined *Strömvil* system more universal. The system becomes capable of classifying stars in spectral classes and luminosities (or determining their temperatures and surface gravities) everywhere in the HR diagram. The *Strömvil* system was recommended for the photometric classification of faint stars where it is difficult or even impossible to obtain narrow-band Hβ photometry and where the classification of G–K–M stars is needed in the presence of interstellar reddening. The *Strömvil* system is as good as the parent systems in determining the metallicities and peculiarities of stars. The parameters of the passbands of the *Strömvil* system are given in Table 2. Now the calibration of the system in physical parameters and the establishment of a set of standards is under way (Kazlauskas et al. 2003).

Table 2. Mean wavelengths and half-widths of passbands of the *Strömvil* photometric system.

Passband	u	P	v	b	Z	y	S
λ_0 (nm)	350	374	411	467	516	547	656
$\Delta\lambda$ (nm)	30	26	19	18	21	23	20

4. THE PASSBANDS AT THE PASCHEN JUMP

One of the main criteria for the classification of B–A–F stars in temperatures and luminosities is the Balmer jump. For the measurement of its height and position we use three passbands of the *Strömvil* system at 350, 374 and 411 nm. However, when the stars are affected by a considerable interstellar reddening, they become too faint to be measured in the vicinity of the Balmer jump. However, at the Paschen jump stars remain sufficiently strong: the extinction at the Paschen limit is lower by a factor of 1.4 than in the green part of the spectrum (A_V). Consequently, this spectral region seems to be promising to replace the Balmer jump for temperature and luminosity measurement in early-type stars. Unfortunately, the Paschen jump is smaller by a factor of 5 in comparison with the Balmer jump. This gives a somewhat lower accuracy of classification.

One of the authors (Straižys 1998, 1999a) has made a numerical simulations of a number of photometric passbands in the region of the Paschen jump. The conclusion has been made that the infrared passbands at 810, 875 and 940 nm (with the widths of 40, 30 and 20 nm, respectively), combined with the passbands at 405, 466, 516 and 544 nm, contain sufficient information to be used in two-dimensional classification of reddened early-type stars, without ultraviolet passbands. At the same time these passbands can be effectively used for photometric identification of M-type and carbon-rich stars.

5. THE STRÖMVIL–GAIA PHOTOMETRIC SYSTEM

The *Strömvil* seven-color system, supplemented by the three infrared passbands at the Paschen jump, was proposed as one of the potential systems for the *Gaia* orbiting observatory of ESA, planned for launch in 2010–2012 (Straižys & Høg 1995, Høg et al. 1999, 2000a,b). For this project the response functions were modified to almost rectangular shape in order to increase the limiting magnitude. These response functions $R(\lambda)$ are shown in Figure 1 together with the energy distribution functions $F(\lambda)$ of A0 V and K5 V type stars.

For testing the quantification possibilities of this system we have applied the method described by Straižys et al. (1998). The method is based on synthetic color indices and interstellar reddening-free Q-parameters calculated for a grid of synthetic spectra of stellar model atmospheres of R. L. Kurucz for different values of $T_{\rm eff}$ and $\log g$ of solar metallicity. The grid contains 409 models with effective temperatures ranging from 50 000 K to 3500 K and logarithms of gravities from 0.0 to 5.0. By interpolation the total number of models was increased to 5673.

The quantification process is based on a comparison of a set of color indices of each model with the same color indices of all other models. For each model 100 sets of "observed" color indices are generated taking statistically accidental errors of color indices of ± 0.01 mag (1% photometry). For each of these 100 simulated "measurements" we have determined $T_{\rm eff}$ and $\log g$ by fitting the "observed" color indices of the models with color indices of the 5673 Kurucz models. Each of these simulated "observations" is plotted on the $T_{\rm eff}$ vs. $\log g$ diagram. As a result, each Kurucz model in this diagram is smeared into a cluster of 100 points of different form and orientation. These point clusters are circumscribed by the confidence ellipses. The size of each ellipsis characterizes the accuracy of determination of $T_{\rm eff}$ and $\log g$ for a given model.

Figure 2 shows the results of quantification of the Kurucz models by color indices in the 7-color system, without the three infrared passbands. The quantification results are shown in a form of four $T_{\rm eff}$, $\log g$ diagrams corresponding to the following temperature intervals: 30 000–10 000 K (B-type stars, blue), 10 000–7500 K (A-type stars, green), 7500–5000 K (F–G-type stars, orange) and 5000–3500 K (K–M-type stars, red). Trying to escape overcrowding in the diagrams, we have plotted the error ellipses on them only for 128 models.

Figure 3 shows the results of quantification by reddening-free Q-parameters.

6. DISCUSSION AND CONCLUSIONS

The investigation of the *Strömvil-Gaia* 7-color system shows that it gives quite good accuracy of determination of effective temperatures and gravities for solar metallicity stars both in the absence or presence of interstellar reddening. This is most important for Population I stars which concentrate near the Galactic plane where interstellar reddening is most significant. Metal-deficient stars (F-G-K-M subdwarfs and G-K giants) are expected to be met at high Galactic latitudes where interstellar reddening is small or even absent. For their identification color indices with small dereddening corrections can be used. However, the experience in applying the *Vilnius* system shows that metal-deficient dwarfs and giants can be identified by their Q-parameters even in the case of the presence of a considerable interstellar reddening.

The quantification errors may be considerably decreased by (1) increasing the accuracy of photometry by measuring the star for a longer time or adding together the results of multiple exposures and (2) increasing the accuracy of calibration of photometric parameters (color indices or Q-parameters) in physical parameters of stars.

As it was mentioned, for the calculation of Q-parameters we have used color-excess ratios with the normal interstellar extinction law which holds for diffuse dust and dust clouds of low density. It is known that extinction laws are peculiar in dense dust clouds or in the surroundings of hot O–B2 type stars (OB-associations). However, these objects are quite rare in the Galaxy. The Orion anomaly has a large angular size only due to its proximity to the Sun. At large distances OB-associations and the dense clouds are apparently small, and their influence on the population studies of the Galaxy is negligible. On the other hand, 2MASS photometry is always at hand to verify the normality of the interstellar extinction law.

On the other hand, if necessary, the 7-color system may be supplemented by additional passbands placed in the ultraviolet, for example, in the region of the bump of interstellar extinction law. This would make it possible to investigate the form of interstellar extinction law in hot stars and to detect its possible anomalies.

We conclude that the *Strömvil-Gaia* 10-color system, or its 7-color variety, may be successfully applied for wide-field imaging and classification of stars both from ground-based and space telescopes. For example, the system would be extremely efficient when used with the planned 8.4 meter Large-Aperture Synoptic Survey Telescope (LSST, http://www.lsst.org/lsst_home.html).

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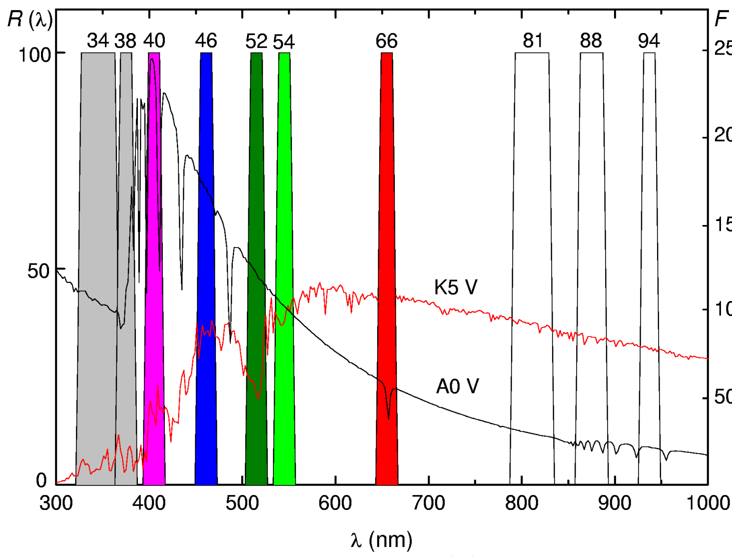

Fig. 1. The response functions $R(\lambda)$ of the revised *Strömvil–Gaia* photometric system and the model energy distribution curves $F(\lambda)$ for A0 V and K5 V stars.

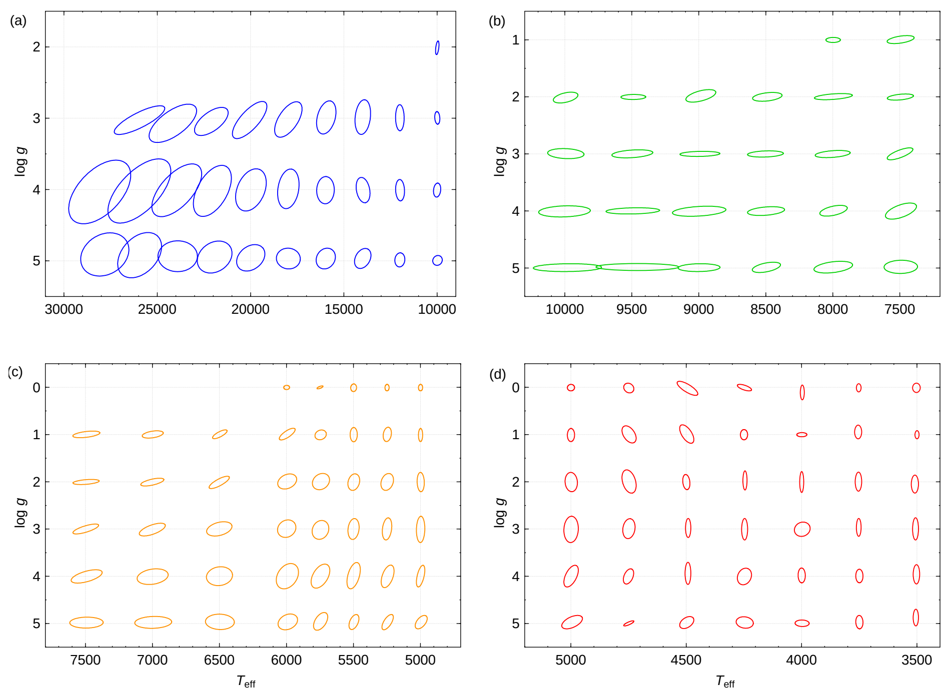

Fig. 2. The $\log g$, $T_{\rm eff}$ diagram for the simulated observations of unreddened stars in the *Strömvil–Gaia* photometric system: (a) B-type stars, (b) A-type stars, (c) F- and G-type stars, (d) K- and M-type stars. The models are quantified by their color indices with the r.m.s. errors of 0.01 mag.

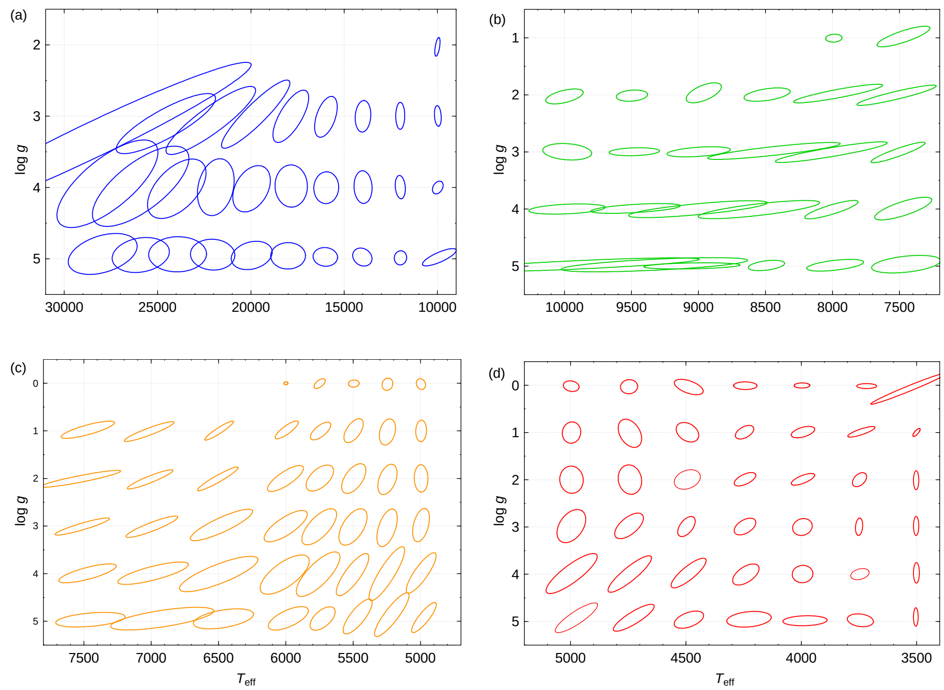

Fig. 3. The $\log g$, $T_{\rm eff}$ diagram for the simulated observations of reddened stars in the *Strömvil–Gaia* photometric system. The models are quantified by their interstellar reddening-free Q-parameters with the r.m.s. errors of 0.02 mag.