A new catalogue of Strömgren-Crawford $uvby\beta$ photometry

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ABSTRACT

Context. The $uvby\beta$ photometric system is widely used for the study of various Galactic and extragalactic objects. It measures the colour due to temperature differences, the Balmer discontinuity, and blanketing absorption due to metals.

Aims. A new all-sky catalogue of all available $uvby\beta$ measurements from the literature was generated.

Methods. The data for the individual stars were cross-checked on the basis of the Tycho-2 catalogue. This catalogue includes very precise celestial coordinates, but is magnitude and spatial resolution limited. However, the loss of objects is only marginal and is compensated for by the gain of homogeneity.

Results. In total, 298,639 measurements of 60,668 stars were used to derive unweighted mean indices and their errors. Photoelectric and CCD observations were treated in the same way.

Conclusions. The presented data set can be used for various applications such as new calibrations of astrophysical parameters, the standardization of new observations, and as additional information for ongoing and forthcoming all-sky surveys.

Key words. astronomical data bases: catalogues – techniques: photometric

1. Introduction

One of the most successful and powerful astronomical photometric systems is $uvby\beta$ introduced by Bengt Strömgren (Strömgren 1956, 1960) and extended by David Crawford (Crawford 1958). It was mainly designed to investigate stars and their basic astrophysical characteristics in an accurate way. It measures the effective temperature, the Balmer discontinuity, and blanketing due to metallic lines. Furthermore, it can be used to estimate the interstellar extinction and reddening. Several reddening-free indices for many different purposes and spectral type regions have been developed so far. In addition, some very successful extensions have been developed such as the $\Delta\omega$ (Paunzen et al. 2005) and Stromvilt (Straizys 1996, 1999) systems.

More than two dozen papers have been dedicated to the calibration of stellar astrophysical parameters of objects across the complete Hertzsprung-Russell diagram (HRD; e.g. Olsen 1988; Gray 1992). It was also used, for example, to investigate both open and globular clusters (Beaver et al. 2013; Calamida et al. 2014), the stellar population in the Magellanic Clouds (Livanou et al. 2013), and the ages of early-type galaxies (Rakos et al. 2008). These are just a few of the applications of this photometric system. Recently, Wang et al. (2014) announced a new all-sky $uvby\beta$ survey to a completeness limit of about 19th magnitude on the basis of one-metre class telescopes.

In order to prepare the grounds for new astrophysical calibrations, and also to supplement spectroscopic, photometric, and kinematic surveys such as Gaia (Jofré et al. 2014), LAMOST (Li et al. 2015), and RAVE (Piffl et al. 2014), it is essential to have a homogeneous set of mean $uvby\beta$ photometry. Starting with Lindeman & Hauck (1973), a continuous update of the available photoelectric measurements were compiled until the last version by Hauck & Mermilliod (1998) at the Institut d’Astronomie de l’Université de Lausanne (Switzerland). Since then, no efforts have been made to also include CCD data into this compilation.

In this paper, a new catalogue of the published and available $uvby\beta$ measurements, through to the end of 2014, is presented. It builds upon the data set published by Hauck & Mermilliod (1998). It includes photoelectric as well as CCD data. The cross reference of the objects has been done using the positional data of the Tycho-2 catalogue (Høg et al. 2000). Such a procedure is especially important for close binary systems, high proper motion stars, and objects in dense star cluster fields. In total, 298,639 data points were used to get the final mean values for 60,668 stars with $-1.09 < V_T < +14.05$ mag. However, about 98% stars are between 4th and 12th magnitude.

2. Sample selection and analysis

The Tycho-2 catalogue (Høg et al. 2000) and its two supplements were used as the basis to identify and cross-reference the stars and their measurements. The catalogue provides celestial positions, proper motions, and two-colour photometric data for about 2,550,000 stars. Components of binaries with separations down to 0.8" are included. The catalogue is about 90% complete to magnitudes of $V \sim 11.5$ mag with the faintest objects around $V \sim 11.5$ mag.
the 15th magnitude. Only objects included in the Tycho-2 catalogue were considered in the following. With that constraint very close binary systems, fainter objects, and stars in very dense fields (star clusters) are not incorporated, but possible false identifications are minimized.

The starting point for the compilation of the available $uvby\beta$ data was the catalogue by [Hauck & Mermilliod (1998)], which includes only photoelectric measurements. It contains 105,873 individual measurements of 63,313 stars without an a priori magnitude limitation. Since then, regular updates until 2007 were incorporated in the General Catalogue of Photometric Data (GCPD, Mermilliod et al. [1997]). However, the most recent version is not available in a compiled form and does not include any CCD observations. For the new catalogue, the literature though the end of 2014 was searched for photoelectric and CCD $uvby\beta$ measurements.

The weighting procedure and calculation of the means by [Hauck & Mermilliod (1998)] was not duplicated here. They introduced a two-step iterative procedure, where the first step consists of a simple weighted mean, the weight being the number of measurements to the $2/3$ power and a publication weight. The latter are individual heuristic weights between zero and four for each publication depending on the quality of the data (for example, known offsets). The second step uses the differences of the individual values to the mean to compute the final weighted mean values. The main reasons why this procedure was not applied is that a) most authors are no longer listing the actual number of individual measurements/frames/images and b) there is no objective way to derive the publication weight. The comparison of the internal accuracy of CCDs to photoelectric measurements and the reliability of standardization procedures has often been discussed (Bessell [2005]). In particular, the found differences in the blue wavelength region ($u$ filter) make a comprehensive weighting complicated.

A simple averaging, without weighting, of all individual measurements for one single star was applied and the standard deviation of the mean calculated. For only one available data point either its error from the corresponding reference or no value is listed.

The unique numbering system of [Hauck & Mermilliod (1998)] was not continued. Its designation ‘uvby98’ is followed by eight digits, which is based on the identification according to the Geneva seven-colour photometric system (Rufener [1988]). It is based on a hierarchical system of secondary catalogues and numbering systems. There are special codes for members of clusters, associations, different kind of stars (for example, Faint Blue Stars, White Dwarfs, and Emission-Line Stars), and common acronyms. Since the new compilation is based on the Tycho-2 catalogue, those numbers together with celestial coordinates, are used as identifiers. Several cross identification of the Tycho-2 catalogue with other sources are available in the literature (e.g. Fabricius et al. [2002]).

Table [1] lists the number of individual measurements for the four indices. In total, 298,639 data points were used to get the final mean values. This is almost a factor of three more than in the catalogue by Hauck & Mermilliod (1998).

The final catalogue includes the four mean observables ($b - y$), $m_1$, $c_1$, and $\beta$, their standard deviations, the number of individual measurements, and the complete information of the Tycho-2 catalogue. A separate file will also be provided in the VizieR database [1] and a mirror of the GCPD [2], which includes all individual measurements and the references.

3. Results and outlook
The final catalogue represents a sample of stars distributed over the whole sky as shown in Fig. [1] Several very important Galactic

\begin{equation}
N_{\text{total}} = 60668
\end{equation}

\[ -1.09 < V_T < 14.05 \]

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{The distribution of the 60,668 catalogue stars on the sky.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{The $V_T$ distribution of the 60,668 catalogue stars.}
\end{figure}
features such as the disk and the north and south poles are seen. There is a belt of stars visible at zero declination, which is due to many standard stars measured in this region being accessible from both the northern and southern hemispheres.

The distribution of the $V_T$ magnitudes of the catalogue stars is shown in Fig. 2. The transformation to Johnson $V$ can be done by taking in account a colour term with a factor of 0.09, and an additional correction $\delta V$. The latter reaches more than 0.05 mag (Kharchenko 2001). The catalogue includes stars from which 98% are in the magnitude range of $4.0 < V_T < 12.0$ mag, with a peak at about 8.5 mag.

One of the most severe complications when using photometric indices for calibrating and estimating stellar parameters is the interstellar extinction. Depending on the Galactic location and the location of dust and gas clouds, it could reach up to 4.0 mag kpc$^{-1}$ (Chen et al. 2014). Therefore, even in the early history of the photometric systems, such as Johnson $UBV$ or 2MASS $JHKs$, Strömgren (1966) already suggested using the reddening independent indices $[c_1]$, $[m_1]$, and $\beta$.

The $[m_1]$ index measures the depression due to metal lines around 4100Å (metallicity), $[c_1]$ measures the Balmer jump (luminosity), and $\beta$ measures the strength of the H$\beta$ line (effective temperature). Depending on the spectral region, these indices could also be slightly sensitive to other parameters than the listed basic astrophysical ones (Strömgren 1966; Golay 1974).

For the calculation of the reddening–free parameters $[m_1]$ and $[c_1]$, the coefficients by Crawford & Mandewewala (1976) were used:

\begin{align}
[m_1] &= m_1 + 0.33 (b-y) \\
[c_1] &= c_1 - 0.20 (b-y).
\end{align}

Figure 3 shows the $[c_1]$ versus $[m_1]$ (upper panel) and $[c_1]$ versus $\beta$ (lower panel) diagrams for the catalogue stars.

who died during its preparation. This work reflects only the authors’ views, and the European Union is not liable for any use that may be made of the information contained therein.

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