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Standard UBV Observations at the Çanakkale University Observatory (ÇUO)

Hicran BAKIŞ, Volkan BAKIŞ, Osman DEMİRCAN, Edwin BUDDING*
Çanakkale Onsekiz Mart University Observatory,
17100 Çanakkale-TURKEY

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Abstract

By using standard and comparison star observations carried out at different times of the year, at Çanakkale Onsekiz Mart University Observatory, we obtained the atmospheric extinction coefficients at the observatory. We also obtained transformation coefficients and zero-point constants for the transformation to the standard Johnson UBV system, of observations in the local system carried out with the SSP5A photometer and T40 telescope. The transmission curves and the mean wavelengths of the UBV filters as measured in the laboratory appear not much different from those of the standard Johnson system and found inside the transmission curve of the standard mean atmosphere.

Key Words: techniques: photometric-stars: photometric-standards.

1. Introduction

The observed flux from any stellar object is a function of the transmission of the receiver, filters used, optical system of the telescope and the atmosphere, itself a function of wavelength. In astronomy, it is common practice to convert such flux to a historically-based magnitude system; and at the same time it is important to have the measurements in absolute physical units.

There has been an ongoing process of refinement in such calibration, as has occurred, for example, with the introduction of a formal logarithmic representation for stellar magnitudes [1], or particularly, since photon registration through digital electronic means became widespread after the 1960s ([2]; [3]).

The aim of multi-color photoelectric photometry is to obtain extinction-free, properly calibrated magnitude values from light fluxes passing thorough a given filter system (e.g. Johnson & Morgan's [4] UBV system). For different optical systems (telescope, filters, receiver etc.) the fluxes actually measured, and their Pogson conversions to a local magnitude scale, will be different. Hence, it is necessary to transfer such 'raw' magnitudes to out-of-atmosphere values and calculate their transformation constants to the standard system, so that the data may be of general use.

Broadband filter systems, such as those of Johnson & Morgan, are of the bandpass type, which are usually produced by suspending rare earth metal ions in a glass substrate (producing colored glass). The work functions associated with charge displacement effects in the substrate tend to produce broad absorption bands, whose widths are an appreciable fraction of the main central frequency in the optical range and with auxiliary absorption which increases at around double this frequency [5]. The intervening transmission range has thus a suitable broad inverted-U shape, but this design often implies that some secondary absorbing material has to be chosen to block off unwanted transmissions from beyond the main bandpass. Existent

*Research Fellow, Carter National Observatory of New Zealand broadband filter systems are thus combinations of two or three colored glasses: those used in the ÇUO photometer are for U:(Schott) BK-7 2 mm + BG-38 3 mm + UG-1 2 mm; B: BG-23 4 mm + BG-12 1 mm + GG-385 2 mm; V: GG-495 3 mm + BG-18 2 mm + BK-7 2 mm.

2. Procedure

Photometric reductions are usually done in two stages (cf. [6]). Firstly, they are corrected for the effect of atmospheric extinction. For this, observations are made over a wide air-mass range and the resulting local magnitudes are then converted to the standard system. For the first step, the following equations can be used:

$$v_0 = v - k_v X - k_v^{'} XC; \tag{1}$$

$$(b-v)_0 = (b-v) \ - k_{bv} X - k_{bv}^{'} XC; \tag{2}$$

$$(u-b)_0 = (b-v) \ - k_{ub} X - k_{ub}^{'} XC. \tag{3}$$

Here, X is the air-mass; the subscript zero indicates out-of-atmosphere values; k_v, k_{bv} and k_{ub} are linear extinction coefficients of colors v, b-v and u-b respectively; and $k_v^{'}$, $k_{bv}^{'}$and $k_{ub}^{'}$ are the second order extinction coefficients that involve standard colors C (cf., e.g., [7]). (Note that local system is denoted by lower case letters.) The second order terms are usually comparable to typical measuring uncertainties, so it is normal to insert theoretical values (which are used in local system calculations) for these small corrections so that the parameter determination may concentrate more effectively on just the first order coefficients.

Linear transformation equations to the UBV standard system, in terms of magnitude and color, are given as

$$V = v_0 + \varepsilon \left(B - V\right) \ + \xi_v \tag{4}$$

$$(B-V) = \mu \left(b - v\right)_0 \ + \xi_{bv} \tag{5}$$

$$(U-B) = \psi \left(u - b\right)_0 \ + \xi_{ub}. \tag{6}$$

In Eqs. (4),(5) and (6), ε , μ and ψ are the usually cited transformation coefficients; and ξ_v, ξ_{bv}, ξ_{ub} are zero point constants. If the local system coincided with the standard system, ε, μ, ψ would, of course, be 0, 1, 1, respectively. In practice, we expect variations, due to normal tolerance factors, of the order of a few percent implicit in colored glass manufacturing of the filters or the detector properties. The proper calibration of variable star observations can be made only after determining such coefficients.

Since the zero point constants depend on systemic factors, such as the amplification and recording electronics, stray fields, ambient temperature and atmospheric conditions, these coefficients change from season to season (even from night to night) and should be monitored regularly. For primary checks, a standard star whose magnitude is very well known and with location close to the comparison star is often useful. The magnitude and color of such a standard star should be close to that of comparison stars. Regular calibration of the comparison objects will enable a more reliable standardization of a light curve.

3. Observations

In order to determine the transformation coefficients accurately, observations of approximately fifteen standard stars were carried out on a clear and stable night. The local observations were obtained with the SSP5-A photometer attached to the 40 cm telescope (T40) of ÇUO during the observing runs in 2003, June 28, July 15/20/29, August 17, and in 2004, June 25. Local u, b and v observations of selected stars can be found at at *http://physics.comu.edu.tr/caam/obs/katsayilar.htm* together with their spectral types and the standard UBV magnitudes from Landolt's Bright Photometric Standards [8] and Bright Star Catalogue [9].

BSC 6103 and HD 196395 were observed as comparison stars to determine the atmospheric extinction coefficients on the nights 15.07.03 and 25.06.04, respectively. On other nights, different comparison stars (BSC 6641, BSC 4687 on 20.07.03, HD 183324 on 29.07.03 and HD 162132 on 28.06.03) chosen from the list of an ongoing project "Photometric observations of Be stars" in ÇUO were observed.

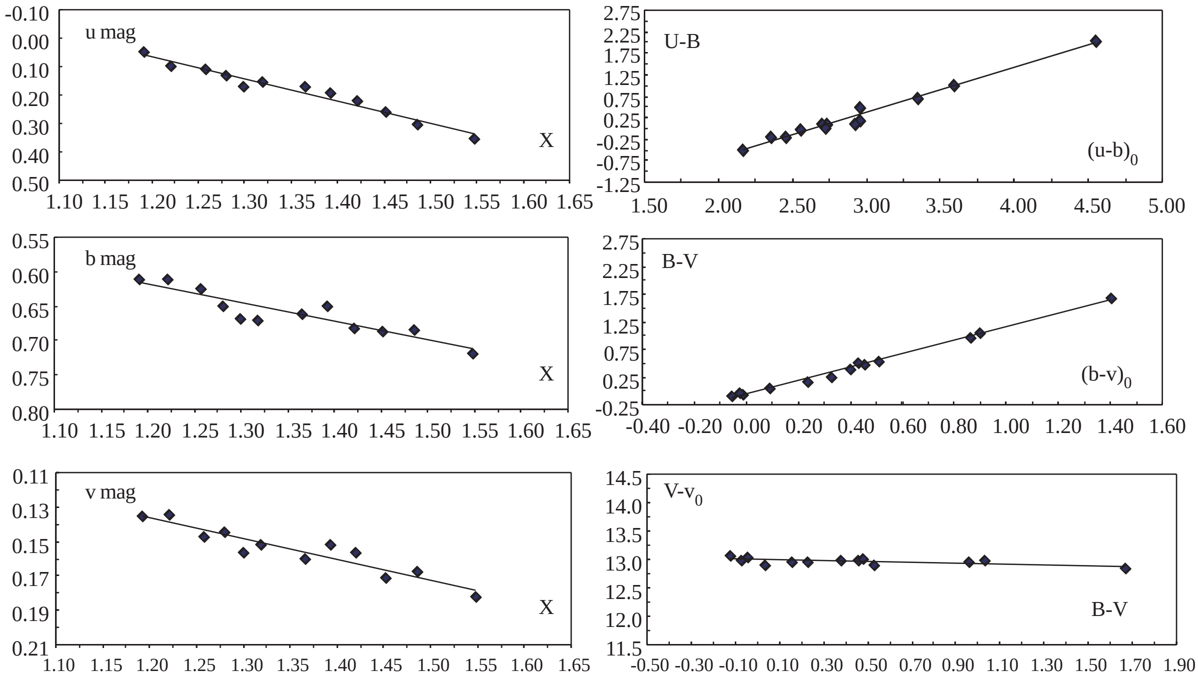

Figure 1. Comparison star's magnitudes in u, b and v vs. air-mass (a, at left) and color-color ((u-b)$_0$-(U-B), (b-v)$_0$-(B-V)) and magnitude-color ((V-v$_0$)-(B-V)) diagrams for the observations of 13 stars in July 15, 2003 (b, at right).

4. Extinction Coefficients

The air-mass dependence of the comparison star's magnitude in each filter for each observing night were formed (see e.g. Figure 1a (left) for a particular night). (u-b)$_0$-(U-B), (b-v)$_0$-(B-V) color-color diagrams and (V-v$_0$)-(B-V) magnitude-color diagram, which were also formed for each observing night, are also presented in Figure 1b (right).

The atmospheric extinction coefficients k_u, k_b and k_v were obtained as the mean slopes of the diagrams formed by the plots of comparison star's instrumental magnitudes versus air-mass for the respective night (see, for example, Figure 1). Extinction coefficients obtained by the least squares method are given in Table 1. The variations in the values of coefficients can be explained by the changing sky conditions for the respective night.

Table 1. The list of extinction coefficients calculated.

Date	$\boldsymbol{k_U}$	$\boldsymbol{k_B}$	$\boldsymbol{k_V}$
28 June 2003	0.80 ± 0.03	0.63 ± 0.01	0.50 ± 0.01
15 July 2003	0.78 ± 0.02	0.27 ± 0.03	0.16 ± 0.02
20 July 2003	0.66 ± 0.02	0.38 ± 0.01	0.21 ± 0.02
29 July 2003	0.80 ± 0.05	0.44 ± 0.02	0.32 ± 0.04
17 August 2003	0.76 ± 0.04	0.44 ± 0.03	0.35 ± 0.02
25 June 2004	0.85 ± 0.04	0.50 ± 0.03	0.38 ± 0.03
Averages	0.77 ± 0.03	0.44 ± 0.02	0.32 ± 0.02

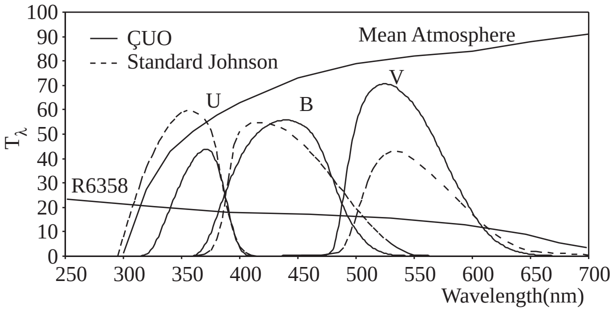

Figure 2. Transmission curves of UBV OptecTM filters (continuous lines), transmission curves of standard Johnson UBV filters (from [10]) (dashed line), response curve of Hamamatsu R6358 photocathode in SSP5A model photometer (continuous lines) used at ÇUO and transmission curve of atmospheric transparency (continuous lines) (from [11]).

5. Transformation coefficients and Zero Point Constants

Transformation coefficients and zero point constants as described by Eqs. (4–6) for the UBV filters of a SSP5A photometer attached to the 40 cm Cassegrain-Schmidt telescope of ÇUO were obtained as the mean slopes and the intersecting points of the mags-color, and color-color diagrams observed on the respective nights (see Figure 1, for an example). All evaluated nightly values and the weighted averages of transformation coefficients are listed in Table 2.

Table 2. Transformation coefficients to standard system for the SSP5A photometer attached to T40 of ÇUO.

Date	ε	μ	ψ
28 June 2003	-0.076 ± 0.030	1.238 ± 0.038	———
15 July 2003	-0.054 ± 0.044	1.177 ± 0.018	1.025 ± 0.044
20 July 2003	-0.070 ± 0.026	1.186 ± 0.025	0.969 ± 0.022
29 July 2003	-0.071 ± 0.049	1.235 ± 0.042	0.991 ± 0.050
17 August 2003	-0.057 ± 0.033	1.238 ± 0.036	1.050 ± 0.053
25 June 2004	-0.057 ± 0.026	1.241 ± 0.025	1.038 ± 0.022
Averages	-0.064 ± 0.037	1.213 ± 0.034	1.011 ± 0.040

6. Laboratory Checks

UBV photometry applied in this investigation is a system based on filters having peak wavelengths of approximately 3600, 4200, 5400 Å, and half widths of 700, 900, 850 Å, respectively (Johnson & Morgan, [4]). The transmission curves and mean wavelengths of the OptecTM filters used were obtained via a Shimadzu UV-1208 spectrometer in the Chemistry Department of the Çanakkale University. This spectrometer can trace transmissions of optically mounted specimens over the range 300–900 nm. Figure 2 shows UBV transmission curves for Johnson standard versus ÇUO UBV filters. Note that the ÇUO B and V filters exhibit upper cut-offs at wavelengths shorter than the Johnson standard filters, but is more stable against ultraviolet air transmission variation, which below ∼3600 Å can change by an order of magnitude, depending on natural environment-related transparency effects.

Mean wavelength of the transmission curves for each filter were found by applying numerical integration methods on laboratory data over the wavelength, and the experimental transformation coefficients were calculated by using the following approximations (cf. [6]):

$$\varepsilon \simeq \frac{1/\lambda_1 - 1/\lambda_1'}{1/\lambda_1 - 1/\lambda_2} \tag{7}$$

$$\mu \simeq \frac{1/\lambda_1 - 1/\lambda_2}{1/\lambda_1' - 1/\lambda_2'} \tag{8}$$

and

$$\psi \simeq \frac{1/\lambda_2 - 1/\lambda_3}{1/\lambda_2' - 1/\lambda_3'}. \tag{9}$$

Here, λ_i' denotes the mean wavelength of the filter-cathode combination as used, and λ_i is the corresponding quantity for the standard system. Our data and subsequent calculations show $\lambda_1' = 5412\mathring{A}$, $\lambda_2' = 4447\mathring{A}$, $\lambda_3' = 3648\mathring{A}$, $\varepsilon = -0.10 \pm 0.03$, $\mu = 1.12 \pm 0.06$, $\psi = 0.99 \pm 0.10$. These parameters are complicated by other effects, in which the role of the Earth's own atmosphere is most prominent. Relatively large variations in the value of ψ may arise because ψ involves the more steeply varying UV atmospheric transmission (see Figure 2). The mean of the U filter is thus rather sensitive to changing atmospheric conditions. The relatively large values of ε could perhaps be reduced with a more suitable choice of colored glass combinations. The value of μ at 1.21 ± 0.03 seems rather high and still a bit wider than the result $\mu = 1.12$ from formula (8). That we should find $\mu > 1$ can be gathered from Figure 1. The discrepancy must come mainly from the V′-filter, whose blueward mean transmission was already noted from the negative value of ϵ. Taking into account also the manufacturer's representative cathode efficiency data, the net response moves still further to the blue (∼5300 Å). The blue filter, meanwhile, yields a fair agreement with its standard specification (mean λ ∼ 4450 Å). Hence the difference $1/\lambda_B' - 1/\lambda_V'$ will be smaller than $1/\lambda_B - 1/\lambda_V$, and so $\mu > 1$ according to (8).

7. Results and Discussion

1. We determined atmospheric extinction coefficients for June/July/August in 2003 at the Çanakkale University Observatory. The mean values of $k_u = 0.77 \pm 0.03$, $k_b = 0.44 \pm 0.02$ and $k_v = 0.32 \pm 0.024$ are reasonable for the atmospheric conditions at Çanakkale. The mean value of extinction reported here are more consistent with a $1/\lambda$ (aerosol scattering) law than pure molecular scattering (Rayleigh scattering ∼ $1/\lambda^4$). We are looking for a possible seasonal correlation for the dependence of k on wavelength.

2. We see that for single night observations a simple linear transformation to the standard (Johnson) UBV system is very suitable in all three filters (see e.g. Figure 1). No evidence of a slope change in the transformation diagrams and no evidence of a systematic difference relative to the standard system were seen in all three filters. The mean linear transformation coefficients $\varepsilon = -0.064 \pm 0.037$, $\mu = 1.213 \pm 0.034$, $\psi = 1.011 \pm 0.040$ are found close to expectations (see Table 2).

3. We conclude from observational and experimental studies that manufacturing imperfections in filters used in observatories can be detected by careful observations. It is necessary to take account of these results in order to measure relative fluxes accurately, so that both physical conditions on the sources and also the scattering and absorbtion properties of the terrestrial atmosphere can be inferred.

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