

DETERMINATION OF ATMOSPHERIC EXTINCTION USING A SUPPLEMENTARY FILTER

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Abstract. A method for the determination of the spectral dependent fraction of the atmospheric extinction for an arbitrarily observed star in the case of broad-band photometry is suggested. This method involves measurements in an auxiliary photometric passband, defined by an additional filter with the spectral transmittance curve similar to that of the atmosphere. In this case, the atmospheric extinction is a linear function of the color index (we name it as D -index) obtained from the flux measurement in these two passbands. This method is estimated to provide an accuracy which is better than 0.002 mag for the ultraviolet W passband. An example for the practical realization of such “atmospheric” filters is constructed from colored glasses. The D -index may be also used for photometric classification of stars and for transformation of photometric systems.

Key words: methods: observational — techniques: photometric — atmospheric effects

1. INTRODUCTION

In the case of a heterochromatic photometry, the atmospheric extinction depends on the spectral energy distribution of the observed star (the band-width effect). The spectral dependent component of the atmospheric extinction appears as a difference between the extinction values of two stars at the same air mass but having different energy distribution functions. This dependence is the largest for the photometric passbands located in the ultraviolet and violet spectral

regions, where the atmospheric extinction coefficient changes considerably with the wavelength (King 1952, Golay 1974, Young 1974, Straizys 1977, 1992). If the dependence of the atmospheric extinction coefficient on the spectral type of a star is not taken into account sufficiently exactly, this limits the accuracy of the extraatmospheric values of color indices. Especially large errors can arise in the case of a variable or a peculiar energy distribution. Incorrect reduction to outside the atmosphere for some peculiar stars leads to errors up to 0.1 mag in the U passband which may be wrongly interpreted as a variability in the brightness of a star.

Reduction methods based on the relation between the value of extinction and color indices of the observed star are usually used. For short wavelength photometric passbands, such methods do not provide sufficient accuracy because these relations are very complicated (nonlinear and luminosity-dependent).

The reduction methods using measurements of the star at different air masses are more adequate. However, these methods are not applicable for stars located near the celestial pole and for variable stars. Also, these methods require a precise control of the equipment response and of the atmospheric transparency during a period of several hours.

The method described below unites in a specific way the reduction methods discussed above. It will be applied to the W passband of the $WBVR$ photometric system (Straizys 1973, Kornilov et al. 1991).

2. THE BASIC IDEA

The slope of the energy distribution curve in the ultraviolet can be measured by two passbands located beyond the Balmer jump. For this, one may add an additional passband to one of the standard passbands, for example, to the W passband. The idea of using two close passbands for measuring the spectral gradient was discussed by Sterken (1992).

On the other hand, measurements of a star at different air masses M_1 and M_2 may be considered as observations at the same air mass M_1 but in two slightly different photometric passbands. In this case, the second passband is formed by the original response curve W and the "atmospheric" filter which has a smooth extinction function of wavelength. The corresponding color index is the atmospheric extinction at air mass $M_2 - M_1$.

The essence of the suggested method for the determination of the spectral dependent fraction of the atmospheric extinction for an arbitrary star is the following: the second specific filter is added to the standard W filter. This auxiliary filter consists of the same filter W and a glass having the wavelength dependence of the absorption coefficient similar to the extinction curve of the atmosphere. Measurements of the brightness of a star in the W passband and in the auxiliary W' passband define a new color index D_W which is related practically linearly with the atmospheric extinction $A_W(\mu)$, where μ is the air mass.

3. THE "ATMOSPHERIC" COLOR INDEX D

Let $\tau_0(\lambda)$ be the extinction coefficient of the atmosphere at the zenith ($M = 1$). Then the extinction in the W passband for a star with the energy distribution $F(\lambda)$ depends on air mass as

$$A_W(M) = -1.086 \ln \frac{\int F(\lambda)W(\lambda)e^{-M\tau_0(\lambda)}d\lambda}{\int F(\lambda)W(\lambda)d\lambda}.$$

If the spectral absorption coefficient of the supplementary filter is $\mu\kappa(\lambda)$, then the response function of the auxiliary passband is $W'(\lambda) = W(\lambda)\exp(-\mu\kappa(\lambda))$. Factor μ represents the effective thickness of the filter. The color index generated by the W and W' passbands for the observed star is:

$$D_W = -1.086 \ln \frac{\int F(\lambda)W'(\lambda)d\lambda}{\int F(\lambda)W(\lambda)d\lambda} = -1.086 \ln \frac{\int F(\lambda)W(\lambda)e^{-\mu\kappa(\lambda)}d\lambda}{\int F(\lambda)W(\lambda)d\lambda}.$$

The constant term for the zero-point definition is omitted here, since it is usually determined by the accepted system of standards. If $\kappa(\lambda) = \tau_0(\lambda) + \text{const}$ within the W passband, then the expression for D_W completely coincides with that of the atmospheric extinction $A_W(\mu)$. More precisely, for two arbitrary stars a and b:

$$A_W^a(\mu) - A_W^b(\mu) = D_W^a - D_W^b.$$

In reality, this equation is only approximate, since it is impossible to construct the filter which would be completely identical to the real atmosphere. However, the non-selective difference between $\kappa(\lambda)$ and

$\tau_0(\lambda)$ has no effect on this relation. The difference between the two mean gradients can be reduced by varying the quantity μ .

To test the possibility of practical realization of the method, the synthetic photometry method has been used. For modeling the atmospheric extinction coefficient, the data of Mironov (1994) for the altitude of 2760 m were used. For this atmosphere at the air mass $\mu = 2$, the supplementary filter, consisting of glasses BS 6 (colorless glass) with a thickness of 0.65 mm and SZS 20 (blue-green glass) with a thickness of 0.8 mm, was constructed. The wavelength dependence near the W passband of the extinction coefficient of the atmosphere and of the absorption coefficient of the supplementary filter are shown in Fig. 1. The mean additional absorption in the filter is about 0.3 mag.

The relation between the D_W -index and the extinction $A_W(M)$ for $\mu = 1$ is shown on Fig. 2. It was calculated from energy distributions of 77 stars with various spectral classes and luminosities (Sviderskienė 1988). The extinction coefficient of the atmosphere has been changed by increasing the aerosol contribution. Differences between the D_W -index and the extinction A_W can be reduced even more if the variations of the extinction coefficient of the real atmosphere are taken into account. Fortunately, the main part of the variation of the atmospheric extinction (due to aerosols) has a very small influence on the slope of the extinction coefficient function.

The D_W -index should be also transformed to outside the atmosphere. It can be shown that the extinction of the D_W -index, $\Delta D_W(M)$, can be expressed through the coefficient of the Forbes effect Φ_W (see Fig. 3). Since both these values are ≤ 0.02 mag, they can be calculated precisely even from approximate energy distribution data or determined together from special observations. After that, the color correction of extinction for different air masses can be calculated.

The numerical experiments demonstrate that the method can provide an accuracy better than 0.002 mag for the W passband and 0.003 mag for the U passband of the UBV photometric system not only for normal but also for reddened and peculiar stars.

4. CONCLUSIONS

The use of the supplementary filter method requires more observational time but this should be compensated by the photometric data of high quality. In addition to much better account of the at-

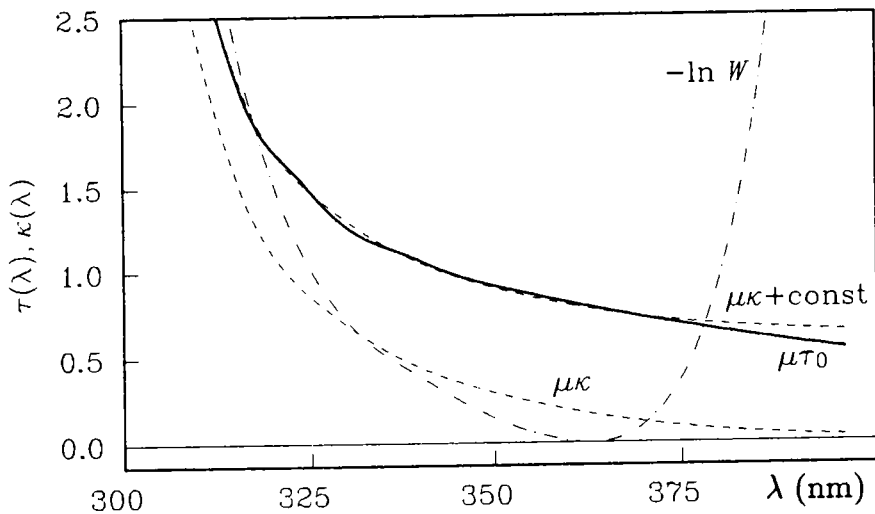


Fig. 1. Extinction coefficients of the atmosphere $\mu\tau_0(\lambda)$ (solid line) and absorption coefficients of the supplementary filter $\mu\kappa(\lambda)$ (dashed line) as a function of wavelength λ for $\mu = 2$. The response curve W (Kornilov et al. 1991) in the absorption form is plotted, too.

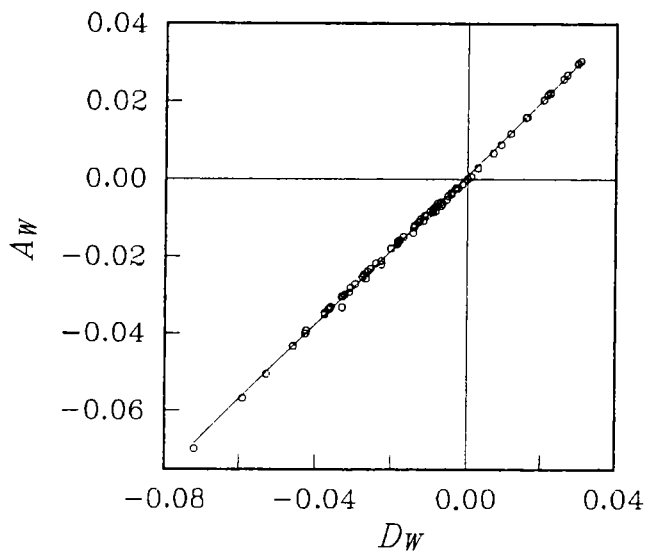


Fig. 2. The relation between the D_W -index and the extinction A_W for $\mu = 1$. A standard deviation is 0.0006 mag, a slope of the regression line is 0.96.

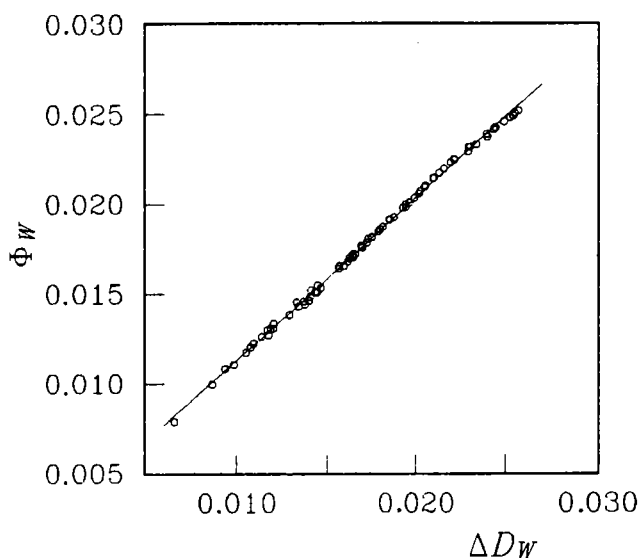


Fig. 3. The relation between ΔD_W and the Forbes coefficient Φ_W ; a standard deviation is 0.0002 mag

mospheric extinction, the D_W -index gives also control of the mean gradient of spectral energy distribution within the W passband (and within B , V and R passbands, too). The exact gradient of the observed star is of great importance both for photometric classification and for transformation of photometric systems (Young 1974, 1992).

Therefore, the suggested method helps in solving the following problems at the same time:

- (1) transforming photometric observations in broad-band systems to outside the atmosphere with a higher accuracy,
- (2) helping in the photometric determination of spectral types in some ranges of spectral classes,
- (3) improving the accuracy of transformation of the instrumental photometric system to the standard system.

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