VISUAL VERSUS PHOTOELECTRIC STELLAR MAGNITUDES: THEORY AND COMPARISON WITH OBSERVATIONS

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Abstract

Quantitative predictions concerning the difference between visual and photoelectric magnitudes are compared with observations.

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I. PURPOSE

This paper supplements Landis' (1977) observational study of the difference between visual (m_v) and photoelectric (V) magnitudes as a function of spectral class or color. This difference is useful for certain specialized studies such as the visual monitoring of red supergiant variables or suspected variables that have not been adequately observed photoelectrically or photographically. It should not actually be applied to estimates being reported to the AAVSO. As Landis has remarked, it is produced by greater relative sensitivity of the dark-adapted eye to blue and green light than the V-passband, and lesser sensitivity to orange and red.

II. ANALYSIS

I have calculated the quantity $\Delta m_V = M_V - V$ for several B0-M2 stars with no interstellar reddening, by integrating Code's (1960) normalized spectral distributions weighted by the scotopic (rod vision) sensitivity function and atmospheric transmission for zenith angles (z) 0° and 45° (Allen 1963, pp. 105 and 122, respectively). All integrations were standardized to 3.92 x 10^{-12} watt $cm^{-2}\mu^{-1}$ for $V=0^m.0$ (Johnson 1966) and were performed on a programmable calculator using Simpson's Rule with wavelength step $\Delta\lambda = 0.02\mu$. The required magnitude difference is just $-2^m.5 \log F/F_s$ where

$$F = \int_0^\infty f_{\lambda o} K_{\lambda sc} T_\lambda(z)\, d\lambda \quad , \qquad (1)$$

in which $f_{\lambda o}$ = monochromatic flux density at wavelength λ outside the atmosphere for $V=0^m.0$,

K_{sc} = the scotopic sensitivity function

$T_\lambda(z)$ = atmospheric transmission at z,

and F_s = standard or zero-point value of F.

The last quantity was determined by setting $f_{\lambda o}$ = 3.92 x 10^{-12} watt $cm^{-2}\mu^{-1}$ = constant in (1), a flat spectral distribution approximately simulating class A5 with no reddening, consistent with the calibration of UBV versus photographic and photovisual magnitudes and with Landis' results. It was found to be 2.78 x 10^{-13} and 2.54 x 10^{-13} watt cm^{-2} for z = 0° and 45° respectively. All final values of Δm_V were corrected for small deviations of the flux integral over the V passband (Allen, p. 195) from the mean of 3.47 x 10^{-3} watt cm^{-2}.

As Code does not include any very red stars in his list of spectral energy distributions, I derived approximate distributions for three such objects from UBVRI photometry (Johnson *et al.* 1966 for U Hya, type $C7_3$; Lee 1970 for BC Cyg, type M3.5Ia) and by artificially reddening the nominal distribution for M2Iab (αOri) using Allen's (p. 252) formula to bring A_v to $2^m.0$. For U Hya, the empirical bandwidth corrections based on data for αOri and αTau (K5III) were applied to the raw distributions given by the UBVRI magnitudes. For BC Cyg, the more definitive TiO-opacity bandwidth corrections given by Humphreys (1974) were applied.

III. RESULTS

Figure 1 shows Δm_v versus B-V for z = 45°. Compared to these, the z = 0° differences are the same to within $0^m.01$ for B0-F0, $0^m.01$ greater for G4-M2, and $0^m.02$ to $\approx 0^m.05$ for the very red stars. At z ≯60° the range of differences decreases substantially due to short wavelength atmospheric absorption, approximate representative values being $0^m.0$ at B0 and $0^m.3$ at Ma. The values shown in Fig. 1 are 0.1-0.2 greater than Landis' data for SAO spectral classes F8-M0 due to the evident comparison of his test stars with one another as well as with the A5 standard.

Table I lists some additional selected comparisons of m_v with V for orange and red variables based on my own and AAVSO visual estimates. Here the Type 1 comparisons are direct, i.e., they involve the same or nearly same observation dates; Type 2 comparisons involve long series of visual and PEP observations made during different periods and use the resulting average mags; Type 3 comparisons are the average of maximum and minimum differences only, also involving long series of observations by both methods. Asterisks denote variables with peculiar spectra and all-PEP comparison sequences. Although the quality of the tabular data varies considerably, its consistency argues strongly for essential accuracy. Thus the prediction of Fig. 1 of visual minus PEP differences as great or even greater than $0^m.5$ for very red variables compared with early-type stars is borne out by observation. But when more yellowish comparison stars are used, as in the case of the first two Per OB1 M-supergiant samples, the difference is somewhat less. Finally, when the colors of variable and comparison stars becomes similar, as for many RV Tauri stars, the difference becomes negligible.

IV. CAVEAT

The systematic magnitude differences derived above assume pure rod vision by the visual observer, which is strictly valid only for faint stars within about 3 magnitudes of the visibility threshold. Ordinarily, brighter stars are viewed at aversion angles of only a few degrees, enabling both rods and cones to function. Such vision is termed <u>mesopic</u> and the absolute spectral sensitivity is intermediate between scotopic and pure cone (photopic) sensitivities. This means that m_v - V will be smaller than the values in Fig. 1. Differences based on a mesopic model will be presented in a future paper.

TABLE I

SELECTED VISUAL AND PHOTOELECTRIC MAGNITUDE COMPARISONS

Star(s)		Avg. B-V	Avg. Δm	Type	Remarks
NQ Vul*		$+1^{m}.1$	$+0^{m}.5$	1	1 vis, 1 PEP on JD 2,443,115.6 (Landolt 1977a)
RV Tau	(10)	+1.2	+0.02	3	1/75-3/78 vis observations; PEP from Dupuy (1973)
V1057 Cyg*		+1.6	+0.21	1	1975,1976,1977 AAVSO observations (Circular Nos. 62,74, 75); 8,10,4 PEP observations by Landolt (1977b)
S Vul		+1.9	+0.4	3	20 vis 6/75-11/77; PEP from GCVS (1971)
VV Cep		+1.9	+0.42	1	4 vis, 5 PEP (IAU Circulars Nos. 3006,3013,3019), JD 2,443,083-3,115
CE Tau		+2.1	+0.7:	2,3	25 vis 10/75-4/78; V=4.1-4.5 adopted from several sources
M1-M4.5I (Per OB1)	(4)	+2.4	+0.44	2,3	1974-1978 vis observations, m_{pv} (AAVSO) comparison stars only; PEP from Wildey (1964), Humphreys (1970) and GCVS (1969, 1971, 1974)
"	(6)	+2.3	+0.35	3	High weight 1950-1954 AAVSO observations (Quarterly Reports Nos. 18-20)
"	(4)	+2.3	+0.64	2,3	1974-1978 vis observations, m_{pv} plus PEP comparison stars
RW Cyg		+2.8	+0.6	3	22 vis 6/75-12/77; PEP from GCVS (1971)
"		+2.8	+0.4:	3	AAVSO raw observations 1966-1973 (private communication)

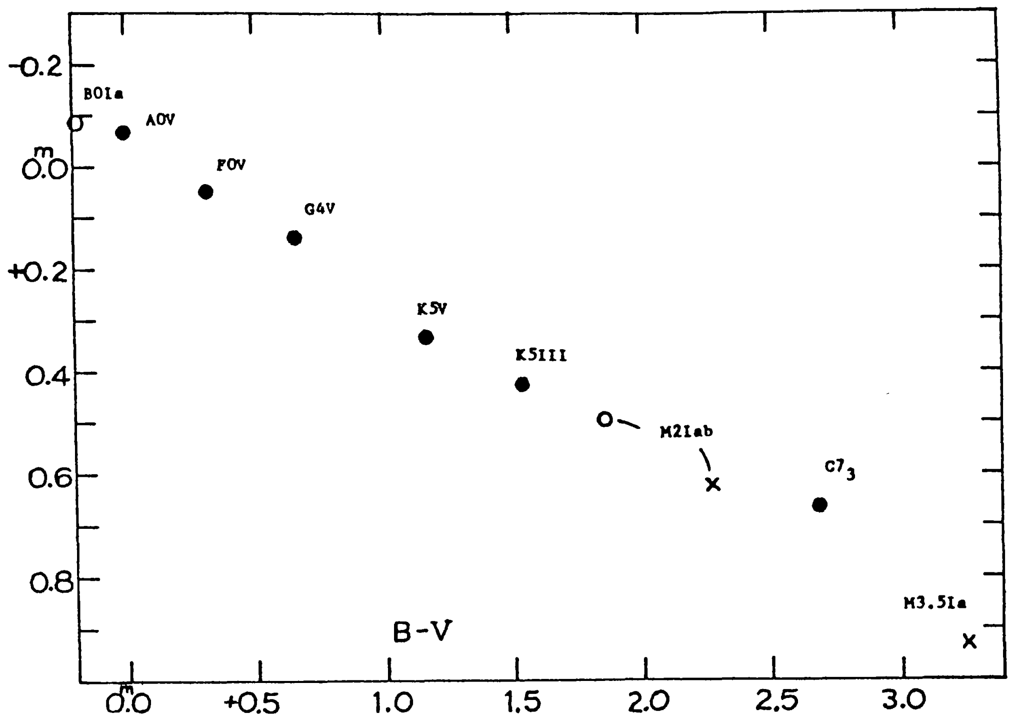

Figure 1. Difference between visual and V magnitude as a function of stellar color, plotted as $\Delta m_V = m_V - V$ versus B-V. Spectral types on the MK system are indicated.

REFERENCES

Allen, C. W. 1963, Astrophysical Quantities (London: Athlone Press), Second Edition.

Code, A. D. 1960, Stellar Atmospheres, ed. J. L. Greenstein, (University of Chicago Press), Chapter 2.

Dupuy, D. L. 1973, Ap. J., 185, 597.

Humphreys, R. M. 1970, A. J., 75, 602.

---------------- 1974, Ap. J., 188, 75.

Johnson, H. L. 1966, Ann. Rev. of Ast. and Astroph., 4, 193.

Johnson, H. L., Mitchell, R. I., Iriarte, B., and Wisniewski, W. Z. 1966, LPL Comm., 4, 99 (No. 63).

Landis, H. J. 1977, JAAVSO, 6, 4.

Landolt, A. U. 1977a, Pub. A. S. P., 89, 574.

-------------- 1977b, ibid., 704.

Lee, T. A. 1970, Ap. J., 162, 217.

Wildey, R. L. 1964, Ph.D. Dissertation, California Institute of Technology, Table 4.