STEPS TOWARD A PHYSICAL CALIBRATION OF UBV PHOTOMETRY

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1. INTRODUCTION

The large data base of photoelectric measurements on the Johnson UBV system has been a primary source of information in many fields of astrophysical interest. The availability of UBV data for virtually all types of stars known to make up the stellar populations in galaxies requires a continued effort toward establishing a fully physical calibration of these data in order to propagate effectively our improving knowledge on stellar evolution and stellar atmospheres (i.e., the HR diagram) through the observations relevant to the structure and evolution of the galaxies. One of the major links in this long chain of scientific progress is provided by the synthesis of stellar photometric properties from theoretical model atmospheres. This paper will briefly address some of the basic problems involved in the synthetic color calculations and discuss the theoretical calibration of UBV photometry as obtained from various grids of model atmospheres covering a large range of stellar types.

2. IMPORTANCE OF PHOTOMETRIC PASSBANDS

An accurate knowledge of the photometric passbands is vital to synthetic photometry in the same way as the knowledge of the standard stars and the proper reduction procedure is vital to observational photometry. A unique set of passbands and normalization equations should be established which apply to all (grids of) model atmospheres used to compute the quantities observed on a given standard photometric system. Unless this basic requirement is met, a full interpretaion of the data in terms of physical parameters as well as an assessment of the relative merits and defects of the theoretical models is impossible and may be achieved only with recourse to independent data.

D. S. Hayes et al. (eds.), Calibration of Fundamental Stellar Quantities, 513–518.

The passbands of the UBV system have been studied by Buser (1978) who reevaluated the effective wavelength and width of the U-filter using a large sample of spectrophotometric data. It was shown that the mean observed U-B and B-V colors can be computed to within the observational uncertainties from the adopted set of response functions and normalization equations simultaneously for the whole variety of stellar types of normal chemical composition. This normalization was fully confirmed by Buser and Kurucz (1978) in a study of theoretical UBV colors calculated from Kurucz' (1979a) grid of model atmospheres. The revised response function for the U passband was demonstrated to adequately monitor the nonlinear color effects produced by the Balmer lines in early-type spectra, thus eliminating hitherto existing large systematic discrepancies between theory and observation.

Since the ultraviolet colors provide most sensitive measures of different atmospheric parameters for different types of star, a more systematic investigation of various grids of model atmospheres appears justified.

3. THE U-B COLORS OF VARIOUS GRIDS OF MODEL ATMOSPHERES

We have computed theoretical colors from three grids of model atmospheres for DA white dwarfs, F-G stars, and G-K giants, respectively.

3.1. DA White Dwarfs

For the hotter DA stars ($T_{eff} > 12500$ K), the U-V color has been known as a sensitive temperature parameter. While Terashita and Matsushima (TM, 1969) failed to calibrate these colors from their models and the UBV response functions of Matthews and Sandage (MS, 1963), because the large systematic discrepancies between theory and observation were left unexplained, Schulz (1978) successfully reconciled the discrepant results by adjusting the transformation coefficients. This adjustment, however, is unnecessry for synthetic colors calculated using the improved U response function, which accurately accounts for the confluence of the Balmer lines in the DA-spectra. The temperature calibration of the U-V index thus obtained from the TM models ($\theta_{eff} < 0.4$) is almost identical to that given by Weidemann (1982).

3.2. F-G Stars

The normalized ultraviolet excess, $\delta(U-B)_{0.6}$, has been widely used as a metallicity parameter for F- and G-type dwarf stars. But in this temperature range incomplete coverage of atomic and/or molecular line opacity and problems with the treatment of convection conspire to produce large systematic errors (< 0.1 mag) in the synthetic colors of model atmospheres (Relyea and Kurucz 1978, Buser and Kurucz 1978).

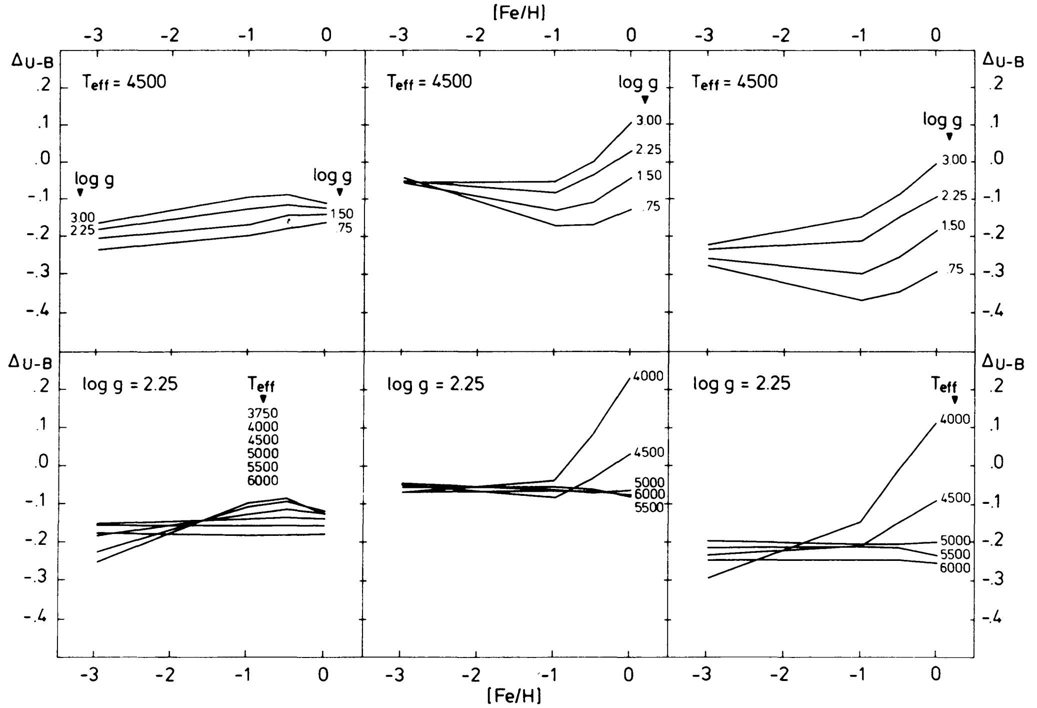

Fig. 1. Effects of instrumental response and normalization (left), molecular or atomic line opacity input (center), and combined effects (right) on the U-B colors of G-K giant model atmospheres.

We have investigated the photometric properties of an extended grid of models (Kurucz 1979b) which incorporates improved convection treatment (Lester et al. 1982). We found that for the log g = 4.5 models the theoretical uv-excess as a function of metal abundance is in very good agreement with the most recent empirical relations (Carney 1979, Cameron 1984) as determined for the dwarf stars listed in the catalog of spectroscopic [Fe/H]-determinations by Cayrel de Strobel et al. (1980). For the zero-metallicity models $\delta(U-B)_{0.6}$ = 0.32, which exactly matches the observational limit. The new models thus appear to provide sufficiently accurate fluxes in the ultraviolet and blue spectral ranges to be useful in differential abundance analyses of F-G dwarf colors.

3.3. G-K Giants

The "ultraviolet discrepancy" shown by Gustafsson and Bell (GB, 1979) to exist between observed and computed colors of G-K-type giants has motivated us to study the nature of this phenomenon by considering the effects on the U-B colors produced by the improved U response function and by different opacity source input. The grid of model atmospheres by Gustafsson et al. (1975) was used along with the updated Kurucz and Peytremann (1975) atomic lines list to compute new model fluxes. While GB's own synthetic spectrum calculations include a large list of molecular opacities but a rather limited number of atomic lines, our spectra neglect molecules completely but instead involve a massive body of atomic data.

U-B colors were computed from our new fluxes in two ways: first, we followed the procedure adopted by GB (which essentially employs the MS response functions for one air mass and normalization to the observed colors of the cool star ϕ^2 Ori), and second, we used the improved response functions and the normalizations as given by Buser (1978). The differences, Δ_{U-B} , between our two sets of U-B colors and the colors published by Bell and Gustafsson (BG, 1978) were constructed in order to separate the effects due to the differences in instrumental or physical input.

A representative plot illustrating the behavior of Δ_{U-B} as a function of atmospheric parameters is shown in Fig. 1. Instrumental effects are illustrated in the left-hand panel, which (again) demonstrates the existence of (nonlinear) color equations that apply in the transformations of computed colors to standard colors. Furthermore, a zero-point error of about -0.2 mag is indicated to be present in the BG colors (which is what GB considered likely to be the case).

The central panel shows the effects of different physical input. For the cooler models Δ_{U-B} strongly depends on [Fe/H] in the sense that our model colors are in general bluer than BG's for the lower metallicities but tend to become redder than BG's at solar abundances.

The right-hand panel of our Fig. 1 combines the instrumental and physical effects and should be compared to GB's Figure 16, where Δ_{U-B} = (observed)-(computed) is plotted as a function of [Fe/H] for a sample of about fifty giants. The striking similarity between these two figures suggests that while the neglect of molecular opacities in model atmospheres of cool stars cannot possibly be correct, atomic line blocking due to the known opacity sources compiled in the Kurucz-Peytremann list may actually account for much of the systematic uv-discrepancy, which is further diminished by using proper instrumental response functions in the calculation of theoretical U-B colors.

ACKNOWLEDGMENTS

This work has been partially supported by the Swiss National Science Foundation.

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DISCUSSION

GUSTAFSSON: The basic philosophy behind the line list of Kurucz and Peytremann is different from that of Bell, on which our models and colors are based. The Kurucz-Peytremann list contains more than 10^6 calculated atomic lines, while the Bell list was based on laboratory data for atomic lines ($<10^5$); on the other hand it contains a very great number of molecular lines.

When we analyzed the "UV discrepancy" for the red giants, we found it reasonable to relate it to a "veil" of very weak metal lines, not included in our line list. It is therefore very interesting to see the indications, presented by Buser and Kurucz, that a significant fraction, if not all, of this discrepancy may possibly vanish when the extensive Kurucz-Peytremann list is merged with adequate list of molecular lines.

BUSER: I should add that the (B-V) colors of our new model flux distributions are slightly bluer (0.02 mag.) than those calculated from models including many molecules, but there is nothing like a systematic dependence on [Fe/H] which is so pronounced in (U-B). For (B-V), we probably have only a small zero-point correction.

PHILIP: Does one of your next steps towards a calibration include a calibration for Population II Stars?

BUSER: Well, yes, the present theoretical calculations actually do include Population II characteristics, i.e. F-G dwarf and G-K giant model atmospheres with solar to 10^{-3} times solar abundances. Work on Population II stars is, however, being continued using scanner observations and UBVRI data of globular cluster and high-velocity field stars, which should help us in progressing towards a more complete understanding of their atmospheres and in establishing a consistent calibration for a large range of stellar types.