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A Recalibration of Optical Photometry Based on STIS Spectrophotometry

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Abstract. I use STIS spectrophotometry to test the published sensitivity curves $P(\lambda)$ and calculate the zero points ZP_P for three optical photometry systems: Tycho-2 $B_\mathrm{T}V_\mathrm{T}$, Strömgren $uvby$, and Johnson UBV. The analysis includes the new recalibration of grating/aperture corrections, vignetting, and charge transfer inefficiency effects produced by the STIS group and considers the consequences of both random and systematic uncertainties. For Tycho-2 B_T and V_T, Strömgren v, b, and y, and Johnson B and V, I find that the published sensitivity curves are consistent with the available photometry and spectrophotometry and I provide new values for the associated zero points. The situation is different for the Strömgren u and the Johnson U filters. There I find that the published sensitivity curves yield results that are inconsistent with the available photometry and spectrophotometry, likely caused by an incorrect treatment of atmospheric effects in the short-wavelength end. I reanalyze the data to produce new average sensitivity curves for those two filters and new values for ZP_{c_1} and ZP_{U-B}. The new computation of synthetic $U-B$ and $B-V$ colors uses a single B sensitivity curve, which eliminates the previous unphysical existence of different definitions for each color.

1. Description

- I use STIS spectrophotometry to test the published sensitivity curves $P(\lambda)$ and calculate the zero points ZP_P for three optical photometry systems.

$$m_P = -2.5\log_{10}\left(\frac{\int P(\lambda)f_\lambda(\lambda)\lambda\,d\lambda}{\int P(\lambda)f_{\lambda,\mathrm{ref}}(\lambda)\lambda\,d\lambda}\right) + \mathrm{ZP}_P$$

- The spectrophotometry was obtained from (a) the Next Generation Spectral Library (NGSL, Gregg et al. 2004 and this meeting) which includes 255 non-variable good-quality stars and from (b) the Bohlin sample (Bohlin et al. 2001, Bohlin & Gilliland 2004a) which includes another 19 stars. The two samples span a wide range of temperatures, gravities and metallicities. For each of the 274 stars a high S/N spectrum that includes the 3 000-7 000 Å wavelength range was built by combining data obtained with the STIS G430L and G750L gratings. The data were processed using the latest calibration files and algorithms from the STIS pipeline.

- The Tycho-2 photometry for the NGSL and Bohlin samples was collected directly from Høg et al. (2000) while the equivalent Strömgren and Johnson photometry had

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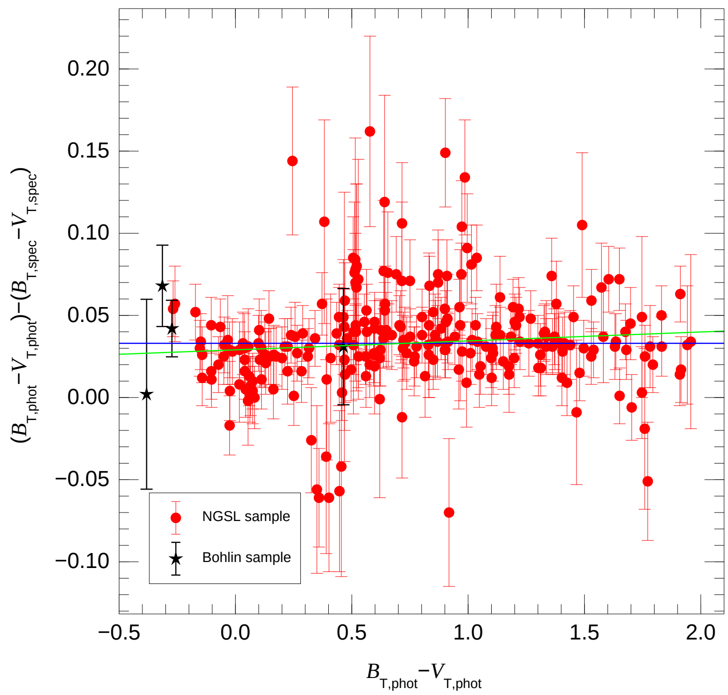

Figure 1: Comparison between photometric and spectrophotometric $B_{\mathrm{T}} - V_{\mathrm{T}}$ colors as a function of photometric $B_{\mathrm{T}} - V_{\mathrm{T}}$ for the NGSL + Bohlin samples using the Bessell (2000) sensitivity curves. The error bars represent the photometric uncertainties and the horizontal blue line marks the proposed $\mathrm{ZP}_{B_{\mathrm{T}}-V_{\mathrm{T}}}$. The green line shows the result of a weighted linear fit to the data.

to be compiled from the General Catalogue of Photometric Data (GCPD, Mermilliod et al. 1997). A careful procedure to eliminate incorrect photometric values and to assign more significance to the data with better quality was followed in the latter case.

- The full results of this work are presented in Maíz Apellániz (2006). The ZPs and the new sensitivity curves (see below) will be implemented in the version 2.0 of CHORIZOS (Maíz Apellániz 2004)

2. Tycho-2 $B_{\mathrm{T}}V_{\mathrm{T}}$

- I have reanalyzed the previous results of Maíz Apellániz (2005), which were obtained using a previous STIS calibration.
- The B_{T} and V_{T} sensitivity curves of Bessell (1990) are accurate, as evidenced by the small slope present in the fit in Figure 1. This confirms the previous results on the stability for the Tycho-2 photometry and the adequacy of the NGSL and Bohlin datasets for the testing of UV-optical sensitivity curves and the calculation of ZPs.
- New ZPs are presented in Tables 1 and 2 which are only slightly different from those given by Maíz Apellániz (2005).
- The consistency of the V_{T} calibration was checked by computing $\mathrm{ZP}_{V_{\mathrm{T}}}$ using two different datasets and methods.

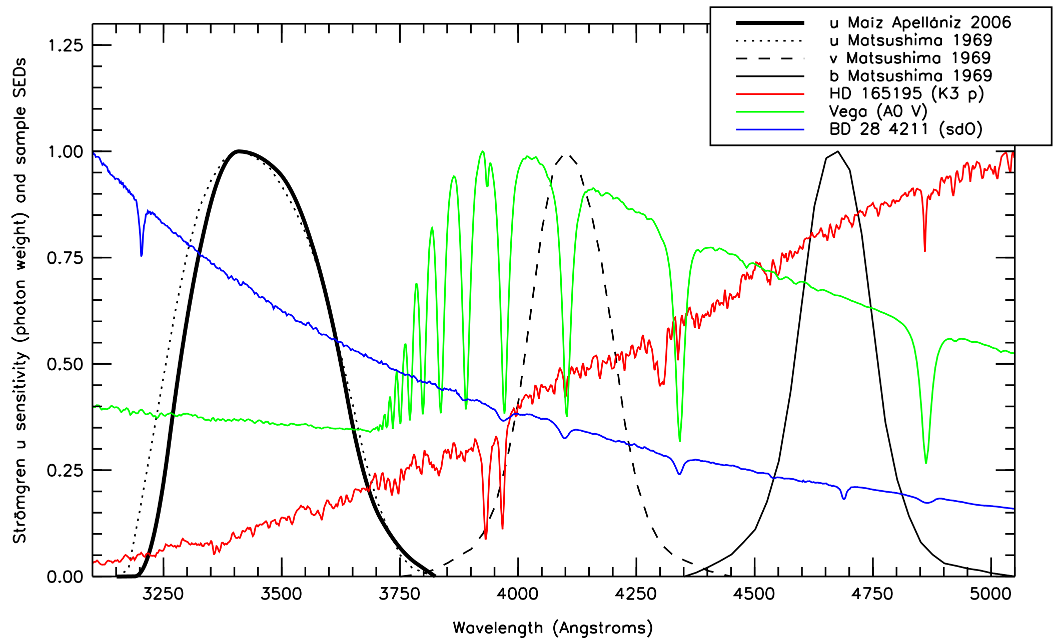

Figure 2: Matsushima (1969) photon-counting normalized sensitivity curves for the the three Strömgren filters u, v, and b filters and the new Maíz Apellániz (2006) curve for u. Three normalized SEDs from the two samples used to calibrate the Strömgren photometry are also shown as f_λ.

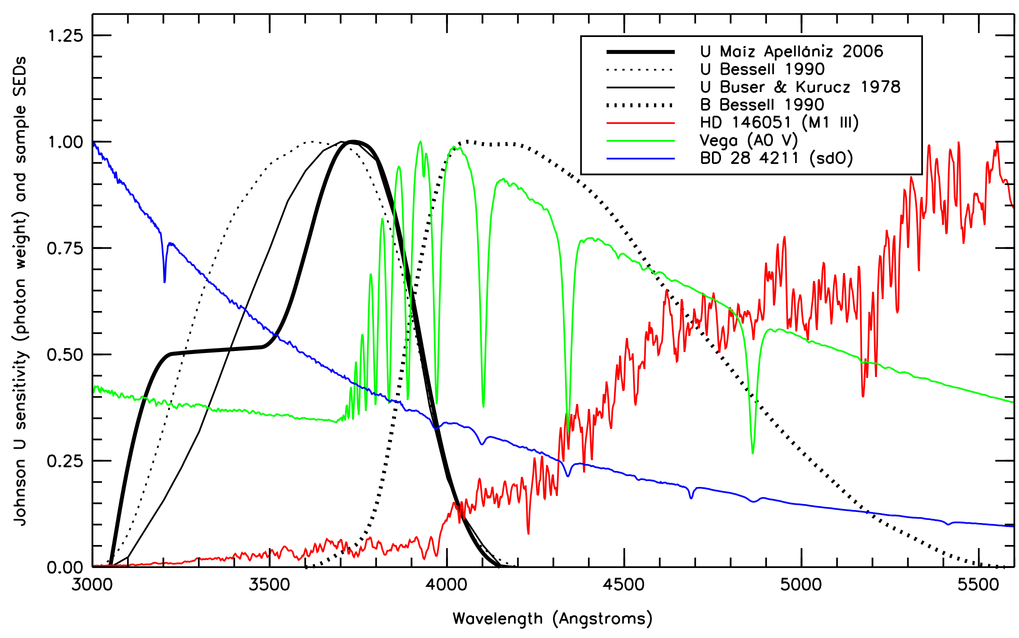

Figure 3: Bessell (1990) U (UX) and B (B) and Buser & Kurucz (1978) U (U_3) photon-counting normalized sensitivity curves and the new Maíz Apellániz (2006) curve for U. Three normalized SEDs from the two samples used to calibrate the Johnson photometry are also shown as f_λ.

- The Tycho-2 ZPs have precisions better than one hundredth of a magnitude, implying that the published uncertainties (which are typically several times larger) can be in most cases directly compared with synthetic photometry results without having to invoke additional sources of systematic errors.

3. Strömgren *uvby*

- I have collected $b-y$, m_1 ($v-2b+y$), and c_1 ($u-2v+b$) data from the GCPD. After the selection and filtering process, I ended up with a total of 104 stars, 100 from the NGSL sample and 4 from the Bohlin sample.

- The v, b, and y sensitivity curves of Matsushima (1969) are accurate.

- The u sensitivity curve of Matsushima (1969) yields a significant slope in a $(b-y)_{\rm phot}$ vs. $c_{1,\rm phot}$-$c_{1,\rm spec}$ plot, indicating that it is not an accurate representation of the published photometry.

- I have used a χ^2 minimization algorithm to calculate a new Strömgren u sensitivity curve (Figure 2). The new curve is quite similar to the Matsushima (1969) one but has a short-wavelength edge which is redder by ≈ 35 Å. The likely culprit for the difference between the two is a difference in atmospheric transmission or in the reduction process to extrapolate to zero air mass. The new sensitivity curve yields a much better fit to the data.

- The new ZPs are given in Table 1. Their precisions are similar to those for Tycho-2.

- I show in Table 3 the typical uncertainties for individual Strömgren photometric entries in the GCPD, as measured by comparing them with the corresponding spectrophotometric values. Little variation is observed as a function of magnitude or the number of measurements per entry, so those values can be applied to the full GCPD once the outliers (which comprise 2-6% of the entries) are eliminated. In all three cases ($b-y$, m_1, and c_1) the uncertainties are several times larger than the ZP precisions, so the data can be directly compared with synthetic photometry results.

4. Johnson *UBV*

- I have collected V, $B-V$, and $U-B$ data from the GCPD. After the selection and filtering process, I ended up with a total of 108, 111, and 101 stars, respectively.

- The data are consistent with the Vega V magnitude of 0.026 ± 0.008 derived by Bohlin & Gilliland (2004b), which can be used as ZP_V.

- The B and V sensitivity curves of Bessell (1990) are accurate.

- Both of the U sensitivity curves of Buser & Kurucz (1978) and Bessell (1990) are inconsistent with the observed $U-B$ photometry.

- I have derived a new Johnson U sensitivity curve (Figure 3). The new curve has a plateau in the 3200-3500 Å region that is likely caused by an averaging over different effective sensitivities used under different conditions. The fit to the $U-B$ data using the new U sensitivity curve is better than using the previous two, but the residuals are larger than for other colors and indices.

- The new ZPs are given in Table 1. The precision for ZP_{B-V} is similar to the previous ones but the one for ZP_{U-B} is considerably worse. Therefore, it is not possible to eliminate systematic errors beyond 0.01 magnitudes for archival $U-B$ photometry.
- I show in Table 3 the typical uncertainties for individual Johnson photometric entries in the GCPD. As in the Strömgren case, little variation is observed as a function of magnitude and the outliers comprise 2-6% of the entries. The random uncertainties for Johnson photometry are found to be larger than for the Strömgren case.

Table 1: Color/index zero points and associated uncertainties/errors.

	Tycho-2	Strömgren			Johnson	
	$B_\mathrm{T}-V_\mathrm{T}$	$b-y$	m_1	c_1	$B-V$	$U-B$
zero point	0.033	0.007	0.154	1.092	0.010	0.020
random	0.001	0.001	0.001	0.002	0.001	0.006
systematic	0.005	0.003	0.003	0.004	0.004	0.014

Table 2: Magnitude zero points and associated uncertainties.

	Tycho-2	Johnson
	V_T	V
zero point	0.034	0.026
uncertainty	0.006	0.008

Table 3: Random uncertainties for individual entries in the GCPD.

Strömgren			Johnson	
$b-y$	m_1	c_1	$B-V$	$U-B$
0.013	0.014	0.018	0.020	0.028

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