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RESEARCH NOTE: ABSOLUTE *UBV* PHOTOMETRY AT THE ZACATECAS OBSERVATORY

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RESUMEN

Se dan datos de extinción atmosférica, coeficientes de color, errores de observación y una lista de estrellas estándar y de comparación para fotometría *UBV* en el Observatorio Astronómico en Zacatecas. Se discuten brevemente nuestros procedimientos de observación y reducción, y se comparan nuestros coeficientes de extinción y errores de observación con valores previos. Se mencionan los usos de estos resultados.

ABSTRACT

Atmospheric extinction data, color coefficients, errors of observation and a list of standard and comparison stars are given for *UBV* photometry at the Astronomical Observatory in Zacatecas. Our observing and reduction procedures are discussed briefly, and our extinction coefficients and observing errors compared with previous values. The uses of these results are mentioned.

Key words: **PHOTOMETRY – STARS-STANDARDS**

In previous papers (Jarzębowski *et al.* 1980, 1981; González-Bedolla 1981*a*, *b*; Peña and González B. 1981; Ríos Herrera *et al.* 1984) differential photometry taken at the astronomical observatory at Cerro de la Virgen in Zacatecas has been published. Natural *UBV* photometry with a mean error between $\pm 0.003^m$ and $\pm 0.005^m$ for one observation was obtained in the *B* filter. We present here results concerning the precision and transformation of absolute *UBV* photometry taken at the same observatory with the same equipment.

The data for the present study were taken during normal observations from 1977 to 1983 and during four special nights of very good photometric quality in October 1982. These special nights have been used to determine precisely the color coefficients of the Zacatecas filter set. During the first three nights 39, 37 and 54 observations, respectively, were made of 34 *UBV* standard stars. Seven stars were primary standard stars from Johnson *et al.* (1966) and 27 were secondary standards selected by Harmanec *et al.* (1981) for use as comparison, check and red standard stars in the international photometric observing campaign of bright Be stars (Harmanec *et al.* 1980, 1981; Harmanec 1983). These 34 stars are indicated by an asterisk in Table 1, where standard and comparison stars that have been or will be observed at Zacatecas are listed. The secondary standards in the second part of Table 1 are those from 14 of Harmanec *et al.*'s groups: Phi Per, 13 Tau, HR 1761, 44 Gem, HR 3135, HR 4123, Kappa Dra, 48 Lib, Nu 2 Boo, Chi Oph, HR 6971, 25 Cyg, HR 7983 and EW Lac. Be stars in these groups are being studied. The comparison stars in the third part of Table 1 were, or are being, used in other programs, such as for BW Vul and 17 Com; *UBV* values for these stars come mainly from Hoffleit and Jaschek (1982).

During October 1982 some stars were measured more than once each night for the determination of the extinction coefficients. The observing pattern was "type A" of Harmanec *et al.* (1977): *UBV* for the star, then *VBU* for the sky measures, and finally *VBU* for the star again. A 1-mm diaphragm was employed, corresponding to 27.5 arc seconds for the 50-cm telescope. The fourth night in October 1982 was used for the calibration of the D.C. amplifier by repeatedly observing stars near the zenith.

The data have been reduced using the HEC9 program of Harmanec (Harmanec *et al.* 1977) and using the standard *UBV* values of Johnson *et al.* (1966). For the October 1982 data the program was first used to calculate the zero, color and extinction coefficients for each

TABLE 1

STANDARD STARS FOR ZACATECAS

Primary Standards

HR	HD	Sp	V	B−V	U−B	Comments
45	1013	M2 + III	4.80	+ 1.57	+ 1.93	*
718	15318	B9 III	4.29	− 0.06	− 0.12	*
753	16160	K3 V	5.82	+ 0.97	+ 0.80	*
875	18331	A1 Vn	5.17	+ 0.08	+ 0.05	*
1084	22049	K2 V	3.73	+ 0.88	+ 0.58	*
8622	214680	O9 V	4.88	− 0.20	− 1.04	*
8832	219134	K3 V	5.57	+ 1.00	+ 0.88	*

Secondary Standards

HR	HD	Sp	*V*	*B−V*	*U−B*	Comments[a]
113	2626	B9 IIIn	5.94	+ 0.01	− 0.36	* C
189	4142	B5 V	5.68	− 0.13	− 0.56	* C
253	5234	K2 III	4.84	+ 1.22	+ 1.27	* RS
464	9927	K3 III	3.57	+ 1.28	+ 1.44	* RS
536	11291	B9 IIIp	5.79	− 0.06	− 0.30	Ch
590	12303	B8 III	5.04	− 0.08	− 0.32	* C
879	18411	A2 Vn	4.70	+ 0.06	+ 0.12	* C
882	18449	K2 III	4.92	+ 1.25	+ 1.28	* RS
947	19656	K1 III	4.64	+ 1.11	+ 1.02	* RS
1034	21278	B5 V	4.98	− 0.10	− 0.56	* C
1037	21362	B6 Vn	5 58	− 0.04	− 0.44	* Ch
1074	21856	B1 V	5.90	− 0.06	− 0.86	* C
1140	23288	B7 IV	5.46	− 0.04	− 0.33	Ch?
1144	23324	B8 V	5.65	− 0.07	− 0.36	* C
1151	23432	B8 V	5.76	− 0.04	− 0.23	* Ch?
1210	24546	F5 IV	5.28	+ 0.41	0.00	* RS
1242	25291	F0 II	5.08	+ 0.50	+ 0.49	* RS
1256	25604	K0 III	4.37	+ 1.07	+ 0.95	* RS
1551	30834	K2.5 IIIb	4.77	+ 1.41	+ 1.58	* RS
1620	32301	A7 V	4.64	+ 0.16	+ 0.15	* C
1676	33276	F2 IV	4.82	+ 0.32	+ 0.19	* RS
1689	33641	A4 m	4.88	+ 0.18	+ 0.10	* C
1833	36166	B2 V	5.78	− 0.20	− 0.84	* C
1861	36591	B1 IV	5.35	− 0.19	− 0.93	Ch 2
1871	36741	B2 V	6.58	− 0.16	− 0.80	* Ch
1907	37160	K0 IIIb	4.09	+ 0.95	+ 0.66	* RS
1920	37320	B8 III	5.88	− 0.07	− 0.37	* Ch
1946	37711	B3 IV	4.86	− 0.12	− 0.64	* Ch
1963	37984	K1 III	4.90	+ 1.17	+ 1.06	* RS
2248	43526	B 7 III	6.57	− 0.13	− 0.51	* Ch
2820	58187	A5 IV	5.38	+ 0.12	+ 0.11	C
2828	58367	G6.5 IIb	4.99	+ 1.01	+ 0.78	RS
2858	59059	B9 IV	6.18	− 0.03	− 0.08	Ch
3059	63975	B8 II	5.14	− 0.11	− 0.49	C
3145	66141	K2 III	4.38	+ 1.25	+ 1.28	RS
3314	71155	A0 V	3.90	− 0.02	− 0.02	Ch
3988	88182	A5 m	6.24	+ 0.18	+ 0.15	C
4094	90432	K4.5 III	3.79	+ 1.48	+ 1.81	RS
4172	92245	A0 Vn	6.04	0.00	...	Ch
...	104316	A0	...	...	...	Ch1
4795	109551	K2 III	4.94	+ 1.31	...	RS
4833	110462	A2 III	6.02	...	...	Ch 2
5018	115612	B9.5 V	6.20	− 0.06	− 0.16	C
5718	136849	B9 Vn	5.37	− 0.07	− 0.21	Ch 3
5760	138341	A4 IV	6.46	+ 0.19	+ 0.14	Ch 2
5908	142198	G8.5 IIIb	4.16	+ 1.01	+ 0.82	RS
5927	142640	F7 V:	6.33	+ 0.46	+ 0.08	Ch Haupt
5930	142703	A2 III	6.13	+ 0.23	...	Ch

TABLE 1 (CONTINUED)

HR	HD	Sp	*V*	*B–V*	*U–B*	Comments
			Secondary Standards			
5936	142908	F0 IV	5.45	+ 0.33	+ 0.03	RS
5954	143333	F8 V	5.48	+ 0.52	+ 0.02	C
...	143418	A3 IV	7.47	+ 0.17	+ 0.10	Ch 1
5982	144206	B9 III	4.76	– 0.11	– 0.32	C
5993	144470	B1 V	3.97	– 0.05	– 0.82	C
6104	147700	K0 II-III	4.50	+ 1.03	+ 0.84	RS
6141	148605	B2 V	4.79	– 0.07	– 0.79	Ch
7098	174567	A0 Vs	...	+ 0.02	– 0.10	Ch
7178	176437	B9 III	3.24	– 0.05	– 0.08	C
7237	177808	M0 III	5.54	+ 1.54	+ 1.90	RS
7613	188892	B5 IV	4.95	– 0.09	– 0.52	C
7689	191026	K0 IV	5.33	+ 0.85	+ 0.54	RS
7769	193369	A2 V	5.57	+ 0.07	0.00	Ch
...	199311	A2 V	6.68	+ 0.06	+ 0.09	C
...	199479	B9 V	6.80	– 0.04	– 0.21	Ch
8255	205512	K0.5 III	4.91	+ 1.08	+ 1.01	RS
8800	218407	B2 V	6.66	– 0.05	– 0.68	Ch
8804	218452	K5 III	5.33	+ 1.41	+ 1.72	RS
8805	218470	F5 V	5.69	+ 0.43	+ 0.01	C

HR	HD	Sp	*V*	*B–V*	*U–B*	Program Stars
			Comparison Stars			
...	32488	F5	∿ 8.1	...	...	HD 32633
1639	32608	A5 V	6.49	...	...	HD 32633
2240	43384	B3 Ib	6.25	+ 0.45	– 0.38	HD 43818
...	43753	B0.5 III	7.91	+ 0.30	– 0.64	HD 43818
3045	63700	G3 Ib	3.34	+ 1.24	+ 1.16	HR 3185
...	108100	F2	7.15	+ 0.37	+ 0.04	4 CVn
4738	108382	A4 V	5.00	+ 0.08	+ 0.13	17 Com
4753	108722	F5 III	5.48	+ 0.43	+ 0.09	17 and 21 Com
4780	109307	A4 Vm	6.29	+ 0.11	+ 0.10	21 Com
4843	110834	F6 IV	6.33	+ 0.43	...	4 CVn
5004	115271	A7 V	5.79	+ 0.19	+ 0.12	20 CVn
5032	116010	K1 III	5.60	+ 1.20	...	20 CVn
5858	140729	A0 V	6.14	+ 0.00	–0.03	HD 140160
...	141458	A0	6.81	+ 0.03	0.00	HD 140160
...	153809	F5 IV	∿ 7.2	...	...	HR 6326
6341	154228	A1 V	5.93	+ 0.00	– 0.04	HR 6326
6464	157325	M0 III	5.59	+ 1.57	+ 1.86	HR 6588
6574	160290	gK1	5.37	+ 1.15	+ 1.16	HR 6588
...	198527	B9	∿ 7.0	...	...	BW Vul
...	199102	B9	∿ 7.6	...	...	BW Vul

a. Where C = Comparison, RS = Red Standard and Ch = Check.

night separately, and then all of the data was iterated together to give precise, mean values for the color coefficients. The three nights were then re-reduced separately using the mean color coefficients. The main results of this note are given in Tables 2, 3 and 4.

Of the 130 observations made during the three special nights, 8 were removed from the final results for various instrumental problems. The first four stars of 24/25 October 1982 were centered differently from the rest; the field lens of the photometer is adequate but the signal is less sensitive to tracking errors when the star is offset slightly from the reticle's center.

In Table 2 the atmospheric extinction of October 1982 is compared to that of other years and months. The values for the years 1977-78 are from Jarzębowski *et al.* (1980, 1981), and only nights with the better extinction solutions are included in the averages. During some nights observations were made in only one or two filters leading to the variable number of nights for some lines of Table 2. The October 1982 values are very well

TABLE 2

ATMOSPHERIC EXTINCTION IN *UBV* AT THE ZACATECAS OBSERVATORY

	k_V	k_B	k_U	k_{B-V}	k_{U-B}	No. Nights
Yearly Values						
1977-78	0.14	0.25	0.49	0.11	0.24	≥ 3
1979	0.14	0.25	0.49	0.11	0.24	$\gtrsim$5-6
1980	0.14	0.25	0.53	0.11	0.28	2-4
1982	0.27	0.37	0.62	0.10	0.25	3
1983	0.20	0.30	0.52	0.10	0.22	1
Pre-1982 Average	0.14	0.25	0.50	0.11	0.25	10-13
Monthly Averages						
February	...	...	...	0.10	0.22	1
May-June	0.13	0.25	0.57	0.12	0.32	2-4
September	0.13	0.22	0.46	0.09	0.24	3
October	0.17	0.30	0.52	0.11	0.24	2-5
December	0.10	0.21	0.44	0.11	0.23	2

determined; for each of the three nights the observations were made over an air mass range of at least 1.6 with at least four stars observed at air masses greater than 2.0. In Table 2 we see a large increase in the k_V, k_B and k_U extinction coefficients in 1982 due to the injection of fine ash, dust and gas into the stratosphere by the volcano El Chichón, as discussed by Schuster and Guichard (1985). In late 1982 the absorption of this stratospheric material is still large but neutral with wavelength in agreement with the results of Schuster and Guichard; the k_V, k_B and k_U coefficients in October 1982 are 0.12 or 0.13 magnitude/air mass larger than pre-eruption values while k_{B-V} and k_{U-B} are nearly unchanged. By early 1983 the effects of the eruption have already decreased significantly. For the monthly averages of Table 2 only pre-eruption values have been used for k_V, k_B and k_U.

The good observing season at Zacatecas runs from September through March. In the monthly averages of Table 2 we see some indication that the *U–B* atmospheric extinction, k_{U-B}, may be atypical during the rainy season.

The color coefficients of Table 3 are defined by equations (1) of Harmanec *et al.* (1977). The standard stars used to measure these coefficents range in spectral type from M2 to O9, in *B–V* from + 1.57 to –0.20 and in luminosity class from main sequence stars to giants. Different subsets of standard stars were used for each of the three nights, and yet the individually determined values for A_1, A_4, A_7 and A_{10} are in good agreement. With 122 observations the combined solution for the color coefficients carries considerable weight. Since A_1 is small and A_4 nearly 1 000, we conclude that the *BV* response functions of the Zacatecas filters are close to those of the standard *BV* system. Since the σ_{U-B} values of Table 4 are small we see that the natural *U–B* values of Zacatecas transform well onto the standard *U–B* system, but the *U* filter is not a close match to the original since A_{10} is significantly different from zero and A_7 is not close to 1.000.

TABLE 3

COLOR COEFFICIENTS FOR THE ZACATECAS *UBV* FILTERS

Date	A_1	A_4	A_7	A_{10}	Number of Obser-vations
24/25 October 1982	– 0.06981	0.99451	0.89498	0.21709	35
25/26 October 1982	– 0.06036	0.99123	0.88497	0.23039	35
26/27 October 1982	– 0.05894	0.99325	0.88996	0.23340	52
Combined	– 0.06291	0.99309	0.88849	0.22926	122

The standard deviations of Table 4 are based on the subset of 122 observations; 35, 35 and 52 for the three nights, respectively. Due to the instrumental problems, eight observations with large residuals ($\gtrsim$0.10 mag.) were removed from the data. Also, the three nights had very favorable observing conditions with good seeing and uniform, photometric skies. So, the values of Table 4 represent the optimum performance of the *UBV* photometer at Zacatecas using the simplest configuration of data acquisition and the most elementary type of gain calibration. The σ's of Table 4 include both extinction and transformation errors and compare quite favorably

TABLE 4

STANDARD DEVIATIONS OF A SINGLE OBSERVATION FOR THE ABSOLUTE *UBV* PHOTOMETRY

Date	σ_V	σ_{B-V}	σ_{U-B}	Average Air Mass
24/25 October 1982	0.022	0.023	0.022	1.297
25/26 October 1982	0.018	0.018	0.017	1.394
26/27 October 1982	0.029	0.017	0.021	1.363
Combined	0.024	0.019	0.020	1.353
Johnson *et al.* 1966	0.022	0.016	0.024	1.000

with the values given by Johnson *et al.* (1966) for a large quantity of homogeneous, high quality *UBV* photometry. In fact, the Zacatecas σ_{U-B} is slightly smaller due in part to the second color term in the transformation of $U-B$ (see Harmanec *et al.* 1977; equations (1)).

In conclusion, precise, absolute *UBV* photometry can be taken at the Zacatecas Observatory using the simplest techniques.

The color coefficients of Table 3 can be used to transform precisely any natural *UBV* photometry taken at Zacatecas during the 1982-83 observing season and to transform approximately for other years, such as the data of Jarzębowski *et al.* (1980, 1981). In Table 2 we have a good estimate for k_V (before the eruption of El Chichón) and very good values for k_{U-B} and k_{B-V}, which can be used in future data reductions. As at any observing site, the color extinctions should remain nearly constant (except perhaps during the rainy season), and the magnitude extinctions will be more variable.

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