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THIRTEEN-COLOR PHOTOMETRY, SAN PEDRO MARTIR II. 1980-1983

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RESUMEN

Se dan y se discuten datos de extinción atmosférica, coeficientes de color para los juegos de filtros originales y nuevos, y residuos de la transformación para 98 noches de fotometría de 13-colores observadas en el Observatorio de San Pedro Mártir en Baja California. Se analizan los residuos de la transformación para el juego de filtros No. 1 en términos de parámetros físicos de las atmósferas estelares tales como temperatura efectiva, gravedad superficial y composición química. Se hace énfasis en las estrellas tipo B y tipo F y G. Se muestra un cambio no neutral en la extinción atmosférica para 1982, debido a la erupción volcánica de El Chichón.

ABSTRACT

Atmospheric extinction data, color coefficients for the original and new filter sets, and transformation residuals are given and discussed for 98 nights of 13-color photometry observed at the San Pedro Mártir Observatory in Baja California. The transformation residuals of filter set No. 1 are analyzed in terms of the physical parameters of the stellar atmospheres such as effective temperature, surface gravity and chemical composition. B-type stars and F and G-type stars are emphasized. A non-neutral change in the atmospheric extinction is shown for 1982, due to the volcanic eruption of El Chichón.

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

I. INTRODUCTION

In Schuster (1982) we discussed atmospheric extinction data, probable errors of observation, standard star lists, observing procedures, and reduction equations for 225 nights of 13-color photometry observed at the San Pedro Martir Observatory in Baja California. For these nights the atmospheric extinction was not unusual; variations as large as 0.15 magnitude/air mass occasionally occurred for the extinction in the visual magnitudes (*52* and *58*), but the color extinctions remained nearly constant. Also, transformations of our data onto the standard 13-color system were made linearly and without difficulty since the original filters and photomultipliers were in use.

However, from 1980 to 1983, 98 nights of additional 13-color photometry have been observed and reduced, and two significant changes occurred leading to the complications that will be analyzed in this paper. First, the volcano El Chichón erupted in the state of Chiapas during March and April 1982, and in less than three months important changes in both the magnitude and color extinctions were observed at San Pedro Martir. Second, due to the deterioration of the original 13C filters, we started observing in March 1981 with filter set No. 1 of four new sets that arrived in 1980; all the new filters are interference filters. For some colors, particularly (*37–52*), the natural photometric system of the new filters does not transform linearly onto the standard 13C system. For our preliminary reductions of the data we used the same techniques as in Paper I (Schuster 1982), but for stars with spectral types near AOV residuals of 0.03 to 0.05 were noted in (*37–52*) and for F and G-type stars residuals of 0.02 to 0.03 in (*35–52*) and (*37–52*).

This paper will be concerned primarily with the unusual atmospheric extinction curve of 1982 and with the transformations and corrections of data taken with the new 13C filters. Transformations for B stars of luminosity classes V-III and for F and G stars of classes VI-III will be emphasized, but other possible problem areas will be mentioned. Also, tables of data useful to other 13C observers –yearly average extinction values and yearly average color coefficients for the old and new filters– are given.

II. OBSERVATIONS

The 13C photometric system is described in detail in the papers of Johnson, Mitchell and Latham (1967), Mitchell and Johnson (1969), Johnson and Mitchell (1975) and Schuster (1982). All of the observations discussed here were made with the original two photometers and photomultipliers; only the filters were changed in March 1981. The 8C photometer was used for the filters 33 through 63, and the 6RC photometer for filters 58 through 110. 57 nights were observed on the 1.5-m telescope, 34 nights on the 2.12-m, and 7 nights on the 84-cm. Nearly the same observing techniques as those discussed by Schuster (1982) were used, the only difference being that more primary standard stars, 15 to 25, were observed on most nights when the new filters were used.

During two the nights only primary and secondary 13C standards were observed with the new filters in order to improve our understanding of the transformations. The primary standards were those of Table 1 of Schuster (1982), and 33 secondary standards were selected from Table 7 of Johnson and Mitchell (1975), and from Schuster (1976, 1979*a* and 1984*b*. The secondary standards include A-type stars, supergiants, solar-type stars, and subdwarf and high-velocity stars, and all had been well observed previously with the original filters. The secondary standard stars, plus the primary standards, were chosen to span the spectral and luminosity classes of our principle photometric observing programs —classical Be stars, solar-type stars, and G-type high-velocity stars. Also, 27 Be stars, including those having both strong and weak emission lines and showing both photometric variability and non-variability (Schuster and Alvarez 1983), were re-observed with the new 13C filters.

III. ATMOSPHERIC EXTINCTION

In Table 1 are given the yearly average extinction values for 1980 through 1983, the mean extinction for the four years, and the mean extinction for all years since 1973. The 6RC extinction for 1980 has been normalized to the 8C value at filter 58 for the reasons given in Schuster (1982). In general the 6RC color extinctions are well determined, but the magnitude extinction (filter *58*) is much less precise than the values for 8C photometry.

In Figure 1 are graphed the mean extinction values for 1973-1983 and the mean extinctions for the two years following the Mexican volcano El Chichón. The eleven-year values show the typical shape of the extinction curve for San Pedro Mártir. The extinction rises sharply in the ultraviolet due to Rayleigh scattering and ozone absorption. A plateau occurs near 6000 Å due probably to stratospheric ozone, and for $\lambda > 8000$ Å the extinction is nearly constant and due to aerosols.

The mean extinction curve for 1982 is different in several aspect from the typical curve. The level of extinction is much higher, approximately 0.15 magnitude/air mass in the visible. The extinction form 8000 Å to 1.1 μ is not constant but decreases with increasing wavelength. The hump at 6000 Å is not apparent but one at the 37 filter is.

The extinction data for 1982 was determined during three nights of 8C photometry in June, and for 6RC photometry six nights in June, two nights in September and two nights in November. Most of the 1982 data was taken less than three months after the El Chichón volcano. During each of the three nights of 8C observing, an air mass range greater than 1.5 was obtained for the standard stars used to determine the extinction. The values are well determined and the features or lack thereof at 3750 Å and 6000 Å are real, repeating for each of the three nights of 8C photometry.

The mean extinction curve for 1982 has been com-

TABLE 1

AVERAGE EXTINCTION – YEARLY VALUES

Year	*33*	*35*	*37*	*40*	*45*	*52*	*58*	*63*	No. Nights
1980	0.616	0.493	0.396	0.295	0.197	0.137	0.120	0.079	5
1981	0.665	0.533	0.449	0.335	0.227	0.168	0.146	0.122	27
1982	0.807	0.673	0.607	0.469	0.370	0.315	0.276	0.250	3
1983	0.693	0.580	0.488	0.394	0.288	0.235	0.222	0.202	7
Mean	0.674	0.546	0.461	0.350	0.244	0.186	0.165	0.140	42
Mean 1973-83	0.647	0.523	0.424	0.320	0.214	0.159	0.144	0.107	161

Year	*58*	*72*	*80*	*86*	*99*	*110*	No. Nights	
1980	0.120	0.062	0.043	0.027	0.029	0.010	11	Normalized to 8C
1981	0.147	0.088	0.074	0.061	0.061	0.042	16	
1982	0.197	0.128	0.103	0.093	0.075	0.047	10	
1983	0.246	0.171	0.165	0.157	0.160	0.150	3	
Mean	0.160	0.097	0.079	0.067	0.063	0.042	40	
Mean 1973-83	0.135	0.073	0.056	0.045	0.049	0.040	133	

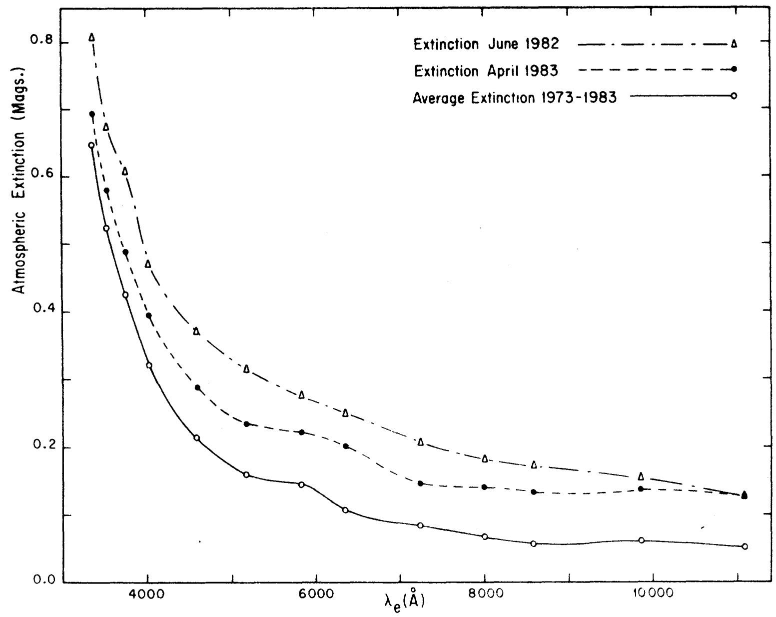

Fig. 1. Atmospheric extinction versus the effective wavelengths of the 13C filters. Circles represent the average values for the years 1973 to 1983, including 161 nights of 8C photometry and 133 nights of 6 RC photometry. Triangles show the average values from 1982 (mostly June) and filled circles 1983 (April).

pared to curves for nights with particularly high extinction from the years 1974, 1975, 1977 and 1981. Some nights such as 15/16 and 16/17 June 1974 have extinction values even higher than the mean of 1982, but at 3750 Å and 6000 Å and for $\lambda > 8000$ Å all of these selected nights appear typical, unlike 1982. In Figure 1 the average curve for 1983 is higher than the eleven-year average, but the shape has nearly returned to normal; perhaps the plateau at 6000 Å is somewhat broader than usual.

The higher overall extinction for 1982 was caused partially by the fine ash and dust injected into the stratosphere by the volcano El Chichón. Even more important, the gas content of the eruption produced an extensive aerosol cloud that increased stratospheric absorption (Rampino and Self 1984). This increased concentration of the stratospheric dust and aerosols also probably masked the absorption component of the stratospheric ozone that normally increases the extinction near 6000 Å.

Rampino and Self (1984), Hofmann and Rosen (1983), Oberbeck *et al.* (1983) and Knollenberg and Huffman (1983) showed that the aerosol size distribution in the El Chichón cloud was definitely bi-modal with sizes both larger and smaller than the typical pre-eruption size. The smaller particles with radii near 0.02 μm were newly formed condensation nuclei while the larger particles (radii near 0.7 μm) formed from the original aerosols by accreting sulfuric acid vapor. According to Mie scattering theory a change in the aerosol size distribution will affect the wavelength dependence of the optical depth and explains the change in our extinction curve for $\lambda > 8000$ Å.

Krueger (1983) showed that the initial gas cloud of El Chichón contained much SO_2, and the results of Hofmann and Rosen (1983) indicated that the formation of condensation nuclei continued into late June 1982. In Okabe (1978) we see that the SO_2 molecule absorbs in the 3400 to 3900 Å region with one of the peaks in the absorption centered on our *37* filter. Had 8C observations been made in 1982 after July the hump in the extinction curve at the *37* filter would probably not have been present.

IV TRANSFORMATIONS TO THE STANDARD 13C PHOTOMETRIC SYSTEM

In Table 2 are shown the average yearly color coefficients for the transformations to the standard 13C system from data taken with the original filter set. These filters were used until February 1981, and we include in Table 2 average values from three previous years from Schuster (1982) to show the continuity in our reductions. These filters were used to create the 13C system, and so no transformation problems have been encountered. Coefficients for the color transformations are approximately 1.0000 and for the magnitudes near 0.0000, and the residuals of the transformations, the difference between the standard photometric values and the calculated values, are generally small. Due to deterioration, the original *35* filter occasionally gave large (*35–52*) residuals for red standard stars.

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TABLE 2

AVERAGE COLOR COEFICIENTS – ORIGINAL FILTER SET

Year	*52*	*33–52*	*35–52*	*37–52*	*40–52*	*45–52*	*52–58*	*52–63*	*58*	No. Nights
1977	0.0039	1.0049	1.0268	0.9882	1.0256	0.9944	0.9906	1.0043	0.0236	34
1978	0.0046	1.0078	1.0311	0.9899	1.0252	0.9917	0.9941	1.0025	0.0280	9
1979	0.0040	1.0149	1.0231	0.9934	1.0362	1.0030	0.9947	1.0035	0.0188	5
1980	0.0032	1.0015	1.0161	0.9867	1.0259	0.9941	0.9795	1.0116	0.0185	5
Mean	0.0040	1.0058	1.0262	0.9888	1.0266	0.9947	0.9905	1.0046	0.0234	53

Year	*58*	*58–72*	*58–80*	*58–86*	*58–99*	*58–110*	*58*	No. Nights
1977	+ 0.0305	1.0519	1.0314	1.0251	1.0192	1.0170	+ 0.0440	15
1978	+ 0.0415	1.0430	1.0242	1.0203	1.0135	1.0119	+ 0.0590	15
1979	+ 0.0126	1.0515	1.0348	1.0261	1.0220	1.0250	+ 0.0183	5
1980	+ 0.0291	1.0460	1.0296	1.0230	1.0141	1.0168	+ 0.0420	10
1981	+ 0.0500	1.0502	1.0298	1.0265	1.0218	1.0197	+ 0.0709	4
Mean	+ 0.0333	1.0478	1.0290	1.0234	1.0169	1.0164	+ 0.0478	49

In Table 3 are given the average yearly color coefficients from data taken with the new filter set No. 1. For 8C photometry we have always operated the 1P21 photomultiplier at 700 VDC, but for 6RC photometry due to the brightness of some of the red standard stars and due to the use of the 2.12-m telescope we have had to use several voltages in order to maintain a linear signal from the 7102 phototube. During 1981 we used mostly a high voltage of 850 VDC, during 1982 voltages from 750 to 900 VDC, and during 1983 strictly 900 V. The color coefficients do depend slightly on the high voltage applied, and in the last part of Table 3 are given values for our two most common voltages. During one night, 10/11 May 1981, we observed a significant number of stars at both these voltages.

Except for the colors (*52–58*) and (*52-63*), the values of Table 3 are approximately 1.0000 for the color transformations and approximately 0.0000 for the magni-

TABLE 3

AVERAGE COLOR COEFFICIENTS – NEW FILTER SET NUMBER 1

Year	*52*	*33–52*	*35–52*	*37–52*	*40–52*	*45–52*	*52–58*	*52–63*	*58*	No. Nights
1981	– 0.0064	1.0164	0.9984	1.0184	1.0580	0.9902	0.9265	1.1122	+ 0.0464	34
1982	– 0.0075	1.0155	0.9985	1.0194	1.0628	0.9894	0.9235	1.1144	+ 0.0365	3
1983	– 0.0030	1.0152	1.0120	1.0114	1.0497	0.9839	0.9363	1.1300	+ 0.0492	7
Mean	– 0.0059	1.0162	1.0007	1.0173	1.0570	0.9892	0.9279	1.1152	+ 0.0461	44

Year	*58*	*58–72*	*58–80*	*58–86*	*58–99*	*58–110*	*58*	No. Nights
1981	+ 0.0387	1.0334	1.0293	1.0103	1.0158	1.0283	+ 0.0553	13
1982	+ 0.0344	1.0295	1.0245	1.0043	1.0064	1.0160	+ 0.0493	11
1983	+ 0.0491	1.0454	1.0345	1.0143	1.0160	1.0318	+ 0.0694	3
Mean	+ 0.0381	1.0331	1.0279	1.0083	1.0120	1.0237	+ 0.0544	27

High Voltaje	*58*	*58–72*	*58–80*	*58–86*	*58–99*	*58–110*	*58*	No. Nights
850 VDC	+ 0.0381	1.033	1.0288	1.0097	1.0147	1.0256	+ 0.0545	19
900 VDC	+ 0.0334	1.0439	1.0347	1.0157	1.0173	1.0295	+ 0.0479	9

tudes. The original *63* filter is a long-pass glass filter, and the long wavelength side of the filter-detector response function is defined strictly by the falling sensitivity of the 1P21 detector. The new *63* filter is an interference filter which cuts more sharply on the long wavelength side. The effective wavelength of the new *63* filter is less than that of the original, and so the color coefficient is greater than 1.0000 for (*52–63*). [The opposite is true for the new filter *58* and for the color (*52–58*)]. Our reddest standard star BS 45 (Sp = M2III) has shown very obvious evidence of a non-linear transformation for the (*52–63*) color, and since this star is much redder than any of our program stars, it has been removed from our standard star lists for most of our reductions and re-reductions.

The color coefficients for (*33–52*), (*35–52*), (*37–52*) and (*40–52*) in Table 3 are slightly different from the values of Table 2, and these differences, although small, are important in the discussions to follow. The new *37* filter, for example, is closer in wavelength to its *52* filter than the original *37* filter. The bandwidths of filters *33, 35* and *37* are approximately 100 Å.

The preliminary reductions showed that primary standard stars with spectral types near A0V had residuals in (*37–52*) of about -0.04, and the metal-poor 13C standard BS 4550 residuals in (*35–52*) and (*37–52*) of approximately + 0.03. The residuals are the difference between the standard 13C value and the value calculated from the linear least-squares solution for the zero point, color coefficient and correction to the mean extinction. Also, the value of the color coefficient for (*37–52*) would depend on the subset of primary standards used for the reduction of a given night; nights when the extinction pair containing BS 6629 (Sp = A0V) was often observed, for example, gave values different from nights when BS 3454 (Sp = B3V) was used to measure the extinction. For these reasons all of our nights were re-reduced using the mean color coefficients of Table 3.

For 8C photometry the three-year averages of Table 3 were forced in the least-squares solution of the re-reduction, and the standard stars were used to re-calculate only the zero points of the transformation and the corrections to the mean extinction. For 6RC photometry the mean color coefficients corresponding to the high voltage of the program stars were forced. Only standard stars observed at the same high voltage as the program stars were used to calculate the zero points, and the extinction was forced either to the mean annual values or to the values of the first reduction. For 1981 and 1983 all nights were re-reduced using the yearly mean extinction since for 6RC photometry the extinction values were quite constant for these two years. For 1982 the 6RC extinction was more variable, due probably to El Chicón, and most nights were re-reduced using the extinction values of the first reduction. By these techniques all primary standard stars of a given night or of a given period were used to calculate the extinction, but only the standards observed with the same high voltage as the program stars were used for the color coefficients. Re-reduction with the average color coefficients gives us a fixed transformation scale for the study of the residuals.

For the primary and secondary standards average residuals were calculated for each star. For the secondary standards all residuals were used, where the residual is the old color, observed with the original filters, minus the new color. Many of the primary standard stars were observed at large air masses for determining the extinction, but only residuals observed at small to moderate air masses were used in the averages; increasing the air mass increases the observational errors but does not affect the transformation residuals. Generally, for the primary standards only residuals corresponding to the air masses 1.0 to 1.5 were used in the averages. If the minimum air mass of a primary standard for a given night fell between 1.5 and 2.0, the corresponding residuals were used. No residuals for observations made at two or more air masses were included in the averages.

In Tables 4, 5, and 6 are presented the average transformation residuals for each star used in these analyses. In the first two columns of these tables are given the Bright stars numbers and spectral types from Hoffleit and Jaschek (1982). Six subdwarf stars are found at the end of Table 6, and their spectral types were taken from various sources. The last columns of Tables 4, 5, and 6 give the number of new observations that were averaged to obtain the residuals. These residuals can be subtracted from the published 13-color photometry of each star to retrieve the new data, which are not exactly on the standard 13-color system but on a system as close to the standard one as possible by transforming linearly the natural system of the new filters.

In Table 7 are presented the average transformation residuals for a number of spectral groups and individual stars. Many of the residuals, or lack thereof, are statistically significant with a large number of independent measurements. However, the three lines with some of the largest residuals (A0 to A2, Ib; BS 45, M2III, 8C and 6RC) are the least significant statistically, and these residuals might be explained by photometric variability. No observing programs concerning M stars are now under way at our observatory and so little emphasis has been placed in understanding the residuals of BS 45. To better transform the 13C data for A supergiants, more secondary standards of this type from Johnson and Mitchell (1975) or from Schuster (1984*b*) should be observed. For the following analyses only the residuals of Table 7 larger than about 1.5σ are considered worrisome and due to transformation problems; σ is the standard deviation of a single observation from Schuster (1982). In any case, for the early-type stars the residuals of (*33–52*), (*35–52*), (*37–52*) and (*40–52*) are tested due to the narrowness of the band-passes and due to the possible affects of the Balmer lines in the *40* filter. The new (*37–52*) colors are obviously influenced by a shift

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TABLE 4

TRANSFORMATION RESIDUALS PRIMARY STANDARS – 8C PHOTOMETRY

BS	Sp	Res(*52*)	Res(*33–52*)	Res(*35–52*)	Res(*37–52*)	Res(*40–52*)	Res(*45–52*)	Res(*52–58*)	Res(*52–63*)	Res(*58*)	N
45	M2 III	-0.0175	0.0204	0.0793	0.0167	-0.0383	0.0247	-0.0070	0.1242	-0.0119	2
617	K2 III	0.0179	-0.0131	-0.0014	0.0099	-0.0022	-0.0096	-0.0009	-0.0030	0.0184	13
718	B9 III	0.0169	-0.0079	0.0095	-0.0353	0.0196	0.0002	0.0047	-0.0017	0.0069	13
875	A1 Vn	0.0166	-0.0027	0.0160	-0.0397	0.0176	-0.0052	-0.0069	-0.0072	0.0183	3
1084	K2 V	-0.0208	-0.0119	-0.0080	0.0137	-0.0052	-0.0010	-0.0055	-0.0184	-0.0115	3
1855	B0 V	-0.0182	0.0155	-0.0116	0.0308	-0.0065	-0.0091	0.0025	-0.0004	-0.0189	3
2852	F0 V	0.0184	0.0038	0.0125	0.0048	0.0028	-0.0003	0.0118	0.0128	0.0060	5
2890	A2 Vm	0.0143	-0.0163	-0.0117	-0.0515	0.0126	0.0047	0.0000	-0.0004	0.0108	7
2990	K0 III	0.0302	-0.0256	-0.0135	0.0070	0.0003	-0.0124	0.0201	0.0329	0.0094	1
3249	K4 III	-0.0010	0.0159	0.0423	-0.0053	-0.0230	0.0026	0.0141	0.0261	-0.0155	16
3454	B3 V	-0.0109	0.0217	-0.0013	0.0289	0.0035	0.0023	0.0153	0.0180	-0.0265	18
4456	B4 V	-0.0004	0.0032	-0.0027	0.0202	-0.0130	-0.0045	-0.0049	-0.0036	0.0057	21
4534	A3 V	-0.0105	-0.0118	0.0000	-0.0405	0.0232	0.0188	0.0024	0.0107	-0.0166	18
4550	G8Vp(VI)	0.0020	0.0242	0.0350	0.0357	0.0042	0.0030	0.0015	-0.0021	0.0055	13
5634	F5 V	-0.0118	-0.0079	0.0177	0.0110	0.0030	0.0037	-0.0078	-0.0012	-0.0019	4
5685	B8 V	0.0050	-0.0039	0.0022	0.0208	-0.0051	-0.0054	-0.0037	-0.0064	0.0076	24
5854	K2 III	0.0037	-0.0086	-0.0226	0.0005	-0.0055	-0.0072	0.0004	-0.0105	0.0042	29
5947	K2 III	0.0036	-0.0066	0.0089	0.0055	-0.0007	-0.0029	-0.0009	0.0028	0.0054	22
6092	B5 IV	0.0202	-0.0057	-0.0130	0.0036	-0.0088	-0.0045	0.0005	0.0012	0.0185	22
6603	K2 III	-0.0045	-0.0018	-0.0181	0.0042	0.0018	-0.0043	-0.0055	-0.0033	0.0023	36
6629	A0 V	0.0020	-0.0107	0.0088	-0.0519	0.0071	-0.0007	-0.0018	-0.0086	-0.0005	36
8622	O9 V	-0.0093	0.0105	-0.0051	0.0301	-0.0226	-0.0079	-0.0004	0.0066	-0.0070	18
8832	K3 V	-0.0230	0.0192	0.0027	0.0044	0.0195	0.0224	-0.0022	-0.0143	-0.0164	22

TABLE 5

TRANSFORMATION RESIDUALS PRIMARY STANDARDS – 6RC PHOTOMETRY

BS	Sp	Res(*58*)	Res(*58–72*)	Res(*58–80*)	Res(*58–86*)	Res(*58–99*)	Res(*58–110*)	N
45	M2 III	-0.0566	0.0226	0.0268	0.0224	0.0210	0.0106	3
617	K2 III	0.0739	0.0030	-0.0019	0.0062	-0.0087	0.0242	3
718	B9 III	0.0370	-0.0006	-0.0033	-0.0070	-0.0173	-0.0198	9
753	K3 V	0.0310	-0.0020	-0.0072	0.0066	-0.0093	0.0161	7
875	A1 Vn	0.0317	-0.0006	0.0037	0.0036	-0.0170	-0.0057	5
1084	K2 V	0.0112	0.0130	0.0088	0.0133	-0.0025	0.0084	4
1855	B0 V	-0.0128	0.0153	-0.0004	0.0047	0.0107	0.0099	4
2852	F0 V	0.0037	-0.0101	-0.0013	-0.0033	-0.0089	-0.0043	1
3249	K4 III	0.0112	-0.0088	-0.0060	-0.0004	-0.0013	0.0101	12
3454	B3 V	0.0074	-0.0161	-0.0156	-0.0119	-0.0086	-0.0100	8
4456	B4 V	-0.0140	0.0013	0.0030	0.0008	0.0082	-0.0029	12
4534	A3 V	-0.0010	-0.0158	-0.0114	-0.0076	-0.0143	-0.0160	11
4550	G8Vp(VI)	-0.0030	0.0004	0.0012	0.0023	-0.0021	-0.0056	10
5634	F5 V	-0.0340	0.0085	0.0017	0.0118	0.0078	-0.0134	3
5685	B8 V	0.0207	0.0090	0.0052	0.0009	-0.0061	0.0076	13
5854	K2 III	0.0212	-0.0098	-0.0079	-0.0104	-0.0002	-0.0067	13
5947	K2 III	0.0137	0.0021	-0.0022	-0.0003	0.0019	-0.0077	18
6092	B5 IV	-0.0044	-0.0082	-0.0059	-0.0060	-0.0032	0.0008	19
6603	K2 III	0.0220	0.0010	-0.0022	-0.0043	-0.0076	-0.0264	17
6629	A0 V	0.0042	0.0008	-0.0004	-0.0005	-0.0086	-0.0182	26
7906	B9 IV	0.0095	0.0219	0.0144	0.0158	-0.0053	0.0023	2
8622	O9 V	-0.0394	-0.0066	-0.0009	0.0017	0.0121	0.0194	19
8832	K3 V	-0.0662	0.0029	0.0113	0.0007	0.0127	0.0367	19

TABLE 6

TRANSFORMATION RESIDUALS SECONDARY STANDARS – 8C PHOTOMETRY

BS/DM	Sp	Res(*52*)	Res(*33–52*)	Res(*35–52*)	Res(*37–52*)	Res(*40–52*)	Res(*45–52*)	Res(*52–58*)	Res(*52–63*)	Res(*58*)	N
2831	A2 Ib	-0.0184	0.0110	0.0055	0.0420	0.0220	0.0000	0.0235	0.0185	0.0045	2
2874	A5 Ib	-0.0095	-0.0260	-0.0410	0.0185	0.0365	0.0020	0.0150	0.0195	-0.0310	2
3309	G5 V	-0.0150	0.0045	0.0245	-0.0060	0.0055	-0.0005	0.0025	0.0020	-0.0180	2
3569	A7 IV	0.0465	0.0005	0.0060	-0.0160	0.0255	-0.0005	0.0105	0.0150	0.0335	2
3662	A5 V	0.0175	-0.0135	0.0105	-0.0265	0.0130	-0.0025	-0.0100	-0.0145	0.0190	2
3706	G8 III	-0.0200	-0.0125	0.0095	0.0530	0.0200	-0.0100	0.0085	-0.0075	-0.0280	2
3974	A7 V	-0.0240	0.0165	0.0510	-0.0060	0.0385	0.0105	-0.0295	-0.0450	0.0030	2
3975	A0 Ib	0.0180	-0.0010	-0.0300	0.0590	-0.0120	-0.0080	0.0240	0.0190	-0.0090	1
3981	A0 III	-0.0140	-0.0040	0.0190	-0.0240	0.0370	0.0200	-0.0160	-0.0530	-0.0020	1
3982	B7 V	0.0520	-0.0350	-0.0500	-0.0090	-0.0120	-0.0100	-0.0080	-0.0150	0.0580	1
4030	G2 IV	0.0010	0.0120	0.0220	0.0780	0.0160	0.0200	-0.0450	-0.0500	0.0480	1
4033	A2 IV	0.0180	0.0060	-0.0100	-0.0500	0.0310	0.0000	-0.0150	-0.0100	0.0280	1
4132	A7 IV	0.0150	-0.0260	0.0200	-0.0280	0.0320	0.0200	-0.0030	-0.0050	0.0160	1
4357	A4 V	0.0430	-0.0090	-0.0010	-0.0310	0.0210	-0.0010	-0.0030	-0.0170	0.0420	1
4496	G8 V	0.0103	-0.0400	0.0013	0.0187	-0.0073	-0.0007	0.0350	0.0357	-0.0210	1
4789	A0 IV	0.0130	-0.0200	-0.0130	-0.0360	0.0140	-0.0020	-0.0070	-0.0280	0.0150	1
5019	G6 V	-0.0030	0.0080	0.0120	0.0440	0.0150	0.0000	0.0010	-0.0170	-0.0010	1
5127	A7 III	-0.0270	-0.0100	-0.0090	-0.0270	0.0010	0.0020	-0.0160	-0.0160	-0.0140	1
5148	F7-9V	0.0150	-0.0160	0.0190	0.0200	-0.0190	-0.0080	-0.0070	-0.0200	0.0240	1
5235	G0 IV	0.0050	-0.0130	0.0410	0.0290	0.0190	-0.0110	-0.0030	-0.0040	0.0000	1
5435	A7 III	0.0300	-0.0140	0.0110	0.0040	0.0220	0.0080	-0.0330	-0.0460	0.0300	1
5659	G5 V	0.0140	-0.0220	0.0110	0.0500	0.0010	-0.0040	0.0130	-0.0010	0.0030	1
5968	G2 V	0.0100	-0.0080	0.0370	0.0420	-0.0080	0.0050	0.0120	0.0000	0.0010	1
5996	G4 IV-V	-0.0420	-0.0020	0.0090	0.0310	-0.0140	-0.0100	0.0150	0.0140	-0.0550	1
6081	A5 II	-0.0470	-0.0820	-0.0100	-0.0190	-0.0200	-0.0070	-0.0280	-0.0190	-0.0200	1
6095	A9 III	0.0320	-0.0480	-0.0060	-0.0100	-0.0140	-0.0170	-0.0150	-0.0300	-0.0450	1
6144	A7 Ib	-0.0250	-0.0270	-0.0200	0.0000	0.0010	-0.0100	-0.0190	-0.0210	-0.0100	1
+23°3344	sd A2	0.0270	-0.0270	-0.0150	-0.0310	-0.0160	-0.0120	-0.0060	-0.0010	0.0290	2
+25°1981	sd F2	-0.0230	-0.0020	0.0200	0.0080	-0.0130	-0.0020	0.0100	0.0510	-0.0330	2
+21°2247	sd F7-8	0.0995	-0.0270	0.0120	0.0185	-0.0130	-0.0075	0.0220	0.0185	0.0805	2
- 9°3595	K1V(VI)	-0.0205	0.0220	0.0210	0.0435	0.0295	0.0250	-0.0080	-0.0140	-0.0080	2
-10°4149	sd G2	-0.0220	0.0135	0.0740	0.0325	-0.0145	0.0055	-0.0125	-0.0065	-0.0065	2
-21°4009	sd F5-7	-0.0635	0.0280	0.0270	0.0275	0.0085	0.0000	0.0005	-0.0115	-0.0610	2

of bandwidth change in the *37* filter with respect to the hydrogen lines.

In Tables 5 and 7 from O9 to K4, luminosity classes VI to III, no problems with the 6RC transformations are noted. The observations of BS 45 are few and the residuals within 2σ. The remainder of this section will be concerned with only the 8C transformations and residuals.

The areas of prime concern in Table 7 are the (*37–52*) color for early-type stars and (*35–52*) and (*37–52*) for F and G-type stars. The residuals are caused by small changes of bandwidth of shifts in the effective wavelengths of the new filters with respect to the original wavelengths, and the new band-passes include more (or less) of certain spectral features. For the early-type stars the absorption features of the stellar spectra depend to first order on temperature and surface gravity and for F and G-type stars on temperature, composition and surface gravity. The natural photometric systems of some of the new filters depend on these physical parameters in a way that cannot be related linearly to the dependence of the original 13C filters, at least not over a wide range in spectral type. The residuals of Table 7 are studied here as a function of these physical parameters for limited ranges of spectral type and luminosity class.

For the early-type stars (O9-A9) the equation $\overline{\mathrm{Res}} = a\ell + b\tau + c$ has been solved by least-squares, where $\overline{\mathrm{Res}}$ are the average residuals of Tables 4 and 6, and $\ell = (37-45) - .467(40-58)$ and $\tau = (35-40) - .304(40-58)$ are the reddening-free luminosity (surface gravity) and temperature indices of Schuster (1984*a*), respectively. For the F and G stars $T = (45-63)$ has been used as the temperature index. $C = (37-45) - .544(45-63)$ for composition and $G = (35-52) - (37-45) - 0.627(45-63)$ for gravity. The sensitivity of these indices to the physical parameters has been discussed by Schuster (1979*a*), and C and G are the same indices as used by Schuster but

TABLE 7

AVERAGE RESIDUALS

Spectral Group or Star	$\overline{\text{Res}}$ (*52*)	$\overline{\text{Res}}$ (*33–52*)	$\overline{\text{Res}}$ (*35–52*)	$\overline{\text{Res}}$ (*37–52*)	$\overline{\text{Res}}$ (*40–52*)	$\overline{\text{Res}}$ (*45–52*)	$\overline{\text{Res}}$ (*52–58*)	$\overline{\text{Res}}$ (*52–63*)	$\overline{\text{Res}}$ (*58*)	No. Stars	No. Measures
O9V to B3V	– 0.013	+ 0.016	– 0.006	+ 0.030	– 0.009	– 0.002	+ 0.006	+ 0.008	– 0.017	3	39
B8 to A3, V to III	+ 0.007	– 0.008	+ 0.002	– 0.034	+ 0.017	+ 0.003	– 0.005	– 0.012	+ 0.008	9	104
A4 to A9, V to III	+ 0.017	– 0.011	+ 0.011	– 0.015	+ 0.016	+ 0.002	– 0.010	– 0.016	+ 0.010	9	16
A0 to A2, Ib	0.000	+ 0.005	– 0.012	+ 0.050	+ 0.005	– 0.004	+ 0.024	+ 0.019	– 0.002	2	3
F2 to K1, VI (subdwarfs)	– 0.005	+ 0.010	+ 0.032	+ 0.028	0.000	+ 0.004	+ 0.002	+ 0.006	– 0.004	6	22
F9 to G8, V and IV	– 0.001	– 0.008	+ 0.020	+ 0.034	+ 0.001	– 0.001	+ 0.003	– 0.004	– 0.002	9	12
K2V and K3V	– 0.022	+ 0.004	– 0.003	+ 0.009	+ 0.007	+ 0.011	– 0.004	– 0.016	– 0.014	2	25
G8III to K4III	+ 0.004	– 0.007	+ 0.001	+ 0.011	– 0.001	– 0.006	+ 0.005	+ 0.005	– 0.001	7	119
BS3249, K4III	– 0.001	+ 0.016	+ 0.042	– 0.005	– 0.023	+ 0.003	+ 0.014	+ 0.026	– 0.016	1	16
BS45, M2III	– 0.018	+ 0.020	+ 0.079	+ 0.017	– 0.038	+ 0.025	– 0.007	+ 0.124	– 0.012	1	2

Spectral Group or Star	$\overline{\text{Res}}$ (*58*)	$\overline{\text{Res}}$ (*58–72*)	$\overline{\text{Res}}$ (*58–80*)	$\overline{\text{Res}}$ (*58–86*)	$\overline{\text{Res}}$ (*58–99*)	$\overline{\text{Res}}$ (*58–110*)	No. Stars	No. Measures
O9 to A3, V to III	+ 0.004	0.000	– 0.001	– 0.001	– 0.004	– 0.003	11	128
F0 to K4, VI to III	+ 0.008	0.000	– 0.001	+ 0.002	– 0.002	+ 0.003	11	107
BS45, M2III	– 0.057	+ 0.023	+ 0.027	+ 0.022	+ 0.021	+ 0.011	1	3

corrected for interstellar reddening. T is not corrected but most of the F and G stars used are little reddened. The following three equations were used to solve for the residuals in the spectral range F0 to K4:

$$\overline{\text{Res}} = \text{dC} + \text{eT}$$
$$\overline{\text{Res}} = \text{fG} + \text{gT}$$
$$\overline{\text{Res}} = \text{hC} + \text{JG}.$$

Three equations were included to show more clearly the dependence of the residuals upon temperature, composition and gravity, and a least-squares technique used.

The solutions for the residuals are shown in Table 8 and new residuals corrected by these solutions in Table 9. Columns 2 and 3 of Table 8 indicate the spectral and luminosity ranges of the stars used in each solution, column 4 the photometric indices, columns 5, 6 and 7 the constants of the above equations, and column 9 the correlation coefficients between the observed residuals and the calculated ones.

In Tables 8 and 9 the best solutions for the early-type stars occur when the spectral and luminosity ranges are most limited and when only the temperature index τ is used as the measured variable. Supergiants are best analyzed separate from the luminosity classes V-III, and B stars separate from A stars due to the maximum absorption of the hydrogen Balmer lines around the spectral types A0-A2. The residuals in (*37–52*) are obviously real since they correlate well with the physical parameters of the stellar atmospheres, and so can be corrected. No corrections are needed for (*35–52*). The residuals of (*33–52*) perhaps are physically significant, and the (*40–52*) residuals of luminosity classes V-III correlate well with the stellar temperature.

The use of a temperature term in a photometric transformation is not uncommon. The J(*b–y*) and I(*b–y*) terms of Crawford and Barnes (1970) and of Grønbech, Olsen, and Strönmgren (1976), used respectively in the transformations of the m_1 and c_1 indices of *uvby* photometry, the A_{10} (*B–V*) term used in the transformation of *U–B* by Harmanec *et al.* (1977), and McClure's (1976) K_2 C(*42–45*) term for transforming C(*35–38*) of the DDO system are all examples. The colors (*b–y*), (*B–V*), and C(*42–45*) are all effective temperature indices in their respective systems. In general, such temperature terms are needed to allow for wavelength shifts or bandwidth changes of new filters with respect to the original filters in relation to certain spectral features. For example, the (*b–y*) terms of the m_1 and c_1 transformations correct for changes in the v filter with respect to the Hδ line (Crawford and Barnes 1970).

Also, a separate transformation for supergiants is found in other photometric studies. Grønbech, Olsen, and Strömgren (1976) remove both the supergiants and bright giants (luminosity classes Ib and II) to improve their solutions for m_1 and c_1.

The Vilnius (Straizys 1979) and VILGEN (North,

TABLE 8

SOLUTIONS FOR RESIDUALS

Color	Spectral Classes	Luminosity Classes	Photometric Indices	a,d,f or h	b,e,g or j	c	No. of Stars	Correlation Coefficient	Solution
33–52	O9-A9	V-Ib	ℓ, τ	+ .0061	– .0349	– .0155	29	.59	1
35–52	O9-A9	V-Ib	ℓ, τ	+ .0582	– .0277	+ .0035	29	.51	1
37–52	O9-A9	V-Ib	ℓ, τ	– .1322	+ .0247	– .0309	29	.85	1
40–52	O9-A9	V-Ib	ℓ, τ	+ .0417	– .0064	+ .0165	29	.52	1
33–52	O9-A3	V-Ib	ℓ, τ	– .0237	– .0031	– .0099	17	.55	2
35–52	O9-A3	V-Ib	ℓ, τ	– .0179	+ .0201	– .0030	17	.27	2
37–52	O9-A3	V-Ib	ℓ, τ	– .1043	+ .0080	– .0294	17	.72	2
40–52	O9-A3	V-Ib	ℓ, τ	– .0194	+ .0469	+ .0168	17	.75	2
33–52	O9-A9	V-III	τ	–	– .0247	– .0141	24	.54	3
35–52	O9-A9	V-III	τ	–	+ .0105	+ .0028	24	.21	3
37–52	O9-A9	V-III	τ	–	– .0623	– .0312	24	.83	3
40–52	O9-A9	V-III	τ	–	+ .0275	+ .0161	24	.54	3
33–52	A0-A7	II-Ib	τ	–	– .1084	+ .0008	5	.76	4
35–52	A0-A7	II-Ib	τ	–	– .0012	– .0188	5	.02	4
37–52	A0-A7	II-Ib	τ	–	– .1185	+ .0483	5	.95	4
40–52	A0-A7	II-Ib	τ	–	+ .0054	+ .0042	5	.06	4
33–52	O9-A3	V-III	τ	–	– .0202	– .0110	15	.59	5
35–52	O9-A3	V-III	τ	–	+ .0095	– .0009	15	.25	5
37–52	O9-A3	V-III	τ	–	– .0699	– .0377	15	.90	5
40–52	O9-A3	V-III	τ	–	+ .0328	+ .0178	15	.79	5
35–52	F0-K4	VI to III	C, T	– .0356	+ .0191	–	26	.57	6
37–52	F0-K4	VI to III	C, T	– .0360	+ .0258	–	26	.48	6
35–52	F0-K4	VI to III	G, T	– .0617	– .0142	–	26	.09	7
37–52	F0-K4	VI to III	G, T	– .0795	– .0151	–	26	.11	7
35–52	F0-K4	VI to III	C, G	– .0263	– .0378	–	26	.50	8
37–52	F0-K4	VI to III	C, G	– .0240	– .0531	–	26	.41	8

TABLE 9

AVERAGE CORRECTED RESIDUALS

Spectral Group	$\overline{\text{NRes}}$ (*33–52*)	$\overline{\text{NRes}}$ (*35–52*)	$\overline{\text{NRes}}$ (*37–52*)	$\overline{\text{NRes}}$ (*40–52*)	No. Stars	Solution
O9V to B3V	+ .0003	+ .0031	– .0067	– .0023	3	1
B8 to A3, V to III	+ .0049	– .0013	– .0097	– .0008	9	1
A4 to A9, V to III	– .0020	+ .0036	+ .0092	– .0019	9	1
A0 to A2, Ib	+ .0225	+ .0092	+ .0240	+ .0066	2	1
O9V to B3V	+ .0061	+ .0049	– .0057	+ .0088	3	2
B8 to A3, V to III	+ .0006	+ .0054	– .0100	+ .0020	9	2
A0 to A2, Ib	+ .0104	– .0126	+ .0565	– .0146	2	2
O9V to B3V	+ .0049	+ .0019	– .0022	+ .0033	3	3
B8 to A3, V to III	+ .0049	+ .0001	– .0063	+ .0028	9	3
A4 to A9, V to III	– .0079	+ .0058	+ .0101	– .0014	9	3
A0 to A2, Ib	+ .0020	+ .0065	– .0003	+ .0009	2	4
O9V to B3V	+ .0064	+ .0046	– .0034	+ .0070	3	5
B8 to A3, V to III	+ .0020	+ .0037	– .0002	+ .0013	9	5
F2 to K1, VI (subdwarfs)	–	+ .0043	– .0052	–	6	6
F9 to G8, V and IV	–	– .0006	+ .0081	–	9	6

Hauck, and Straizys 1982) photometric systems have filters very similar to several of the 13-color system. For example, the *35, 37* and *40* filters of the VILGEN system have effective wavelengths nearly identical to those of their namesakes in the 13-color system but have wider band passes (North, Hauck, and Straizys 1982; Johnson and Mitchell 1975). The *52* filters also have nearly identical effective wavelengths, but the VILGEN *52* is slightly narrower. Straizys (1979) discusses the use of interference filters to define such intermediate-band photometric system and concludes that they are not the most suitable since it is difficult to repeat their response curves in new filter sets. Frequently "nonlinear and multivalued" transformations from the interference-filter natural system to the standard photometric system are required (Straizys 1979). These are exactly the sort of effects that we have encountered above. The response curve of the new *37* filters is not sufficiently close to the original, and the converging Balmer lines cause a non-linear transformation for the (*37–52*) color with the deviation from linearity a maximum at approximately the A2V stars and decreasing for earlier and later types.

Since the (*37–52*) color is used to calculate ℓ which is our luminosity index, iterative processes must be used to classify accurately newly observed program stars and to calculate the transformation corrections to (*37–52*) separately for supergiants and classes V-III. The residuals in (*37–52*) are not large ($-0.06 <$ Res (*37–52*) $< +0.06$) and convergence will be rapid.

For the F and G stars the residuals correlate best with the composition; the solution using the indices G and T has small correlation coefficients. From Schuster (1979*a, b*) it is known that the colors (*33–52*), (*35–52*), (*37–52*) and (*37–45*) are all good measures of the atmospheric blanketing and can be calibrated to give (Fe/H) values. The filters *35* and *37* have fairly narrow band-passes ($\sim$ 100 Å) and fall in spectral regions of high blanketing by metallic absorption lines. Small changes in the effective wavelengths of the new filters have caused measurable changes in the sensitivity to metallicity.

V. CONCLUSIONS

Analyses of the transformation residuals have been made for the new 13C filter set No. 1 in use at the San Pedro Mártir Observatory. Particular emphasis has been placed on the transformations for B stars and for F and G stars. For the early-type stars corrections of the form $b\tau + c$ give the best results over a limited temperature and luminosity range. Supergiants should be separated from classes V-III, and B stars from A stars. To extend the range a higher order expansion, quadratic or higher using both ℓ and τ, would have to be used to provide an accurate solution.

A solution of the form dC + eT works best for the spectral types F0 to K4, luminosity classes VI to III when correcting the ultraviolet 13C photometry. The important physical parameter for this solution is the chemical composition; a change in the mean blanketing in filters *35* and *37* has caused the residuals.

The set of primary standard stars for 13C photometry (Table 1, Schuster 1982) is rather small and several spectral-luminosity classes not well represented. There is only one M-type standard star (M2III), one O star (O9V), one supergiant (F5Ib), no bright giants, no A, F or G giants, only one subgiant (B5IV), and no F subdwarfs. When observing program stars in one subgiant (B5IV), and no F subdwarfs. When observing program stars in one of these groups, an observer should select several (more than 20) secondary standards from Johnson and Mitchell (1975) or from one of the other sources of 13C data listed by Schuster (1982). The secondary standards should span the expected spectral types and luminosity classes of the program stars. The first order reductions should be carried out using a wide range of primary standard stars and using the techniques described in Schuster (1982), and then second order corrections applied using observations of the secondary standards, as done in this paper. By this procedure precise, smooth transformations will be obtained.

In Table 7 particularly large residuals for (*35–52*) and (*52–63*) are noted for the M standard star BS 45 indicating rather severe for BS 3249 (Sp = K4III). To study M-type stars with the new filters as many secondary M-type standards as possible should be observed. Also, the red leaks of filters *33, 35* and *37* should be checked; the filters were ordered with 10^{-5} blocking out to 1.3μ, but such a leak would explain the positive residual in (*35–52*). A molecular band absorption might also be the cause. The large positive residual in (*52–63*) is due to the sharp long-side drop in the response function of the new *63* interference filter as compared to the original long-pass glass filter. For very red stars the gradual drop in the 1P21 response function for $\lambda > 6400$ Å measures much more energy for M-type stars than does the new *63* filter, and the relation between the two natural photometric systems (the original and the new) becomes non-linear for Sp $\gtrsim$ K4.

Finally, the unusual atmospheric extinction for the year 1982 was caused by dust and gases thrown into the stratosphere by the El Chichón volcano. The extinction increase was *non-neutral*. The variable extinction from 8000 Å to 1.1 μ resulted from aerosol concentrations and size distributions different from the usual ones; many particles both larger and smaller than the normal mean radius of 0.08 μm (Hofmann and Rosen 1983) formed during the months following the eruption. The extinction bump at the *37* filter was caused by absorptions of the SO_2 molecule which has an absorption peak at about 3750 Å.

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