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COLOR EXCESSES AND PERIOD-COLOR RELATION OF CLASSICAL CEPHEIDS

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ABSTRACT

Color excesses of classical Cepheids in the *uvby* color system are estimated for the calibration stars with distances from the literature that are measured independently. Intrinsic photometric indices for these stars are calculated and a calibrated empirical relation between $(b-y)_0$, period, $[c_1]$, and $[m_1]$ is derived through a linear fit. This relation is used to determine color excesses E(b–y) for 59 Cepheids. We also examine the period-color [log $P:(b-y)_0$] relation, and find no signs of nonlinearity. We estimate the effective temperature and surface gravity of several Cepheids using both Kurucz and MARCS/SSG grids for $[Fe/H]$=0.0. We confirm that both temperature and surface gravity are higher, by about 150K and 0.4 respectively, when the MARCS/SSG atmospheric grids are used.

Key words : stars: Cepheids — stars: temperature — stars: gravity — stars: color excess

1. INTRODUCTION

The Cepheid period-luminosity (P–L) relationship is crucial in determining extragalactic distances. Without estimating the reddening caused by interstellar dust we cannot reliably measure the luminosity of Cepheids. This is the reason why so many different methods for determining color excesses of classical Cepheids have been developed (see Kim 2008; Kiss and Szatmary 1998; Fernie 1994, and references therein).

A variety of observational procedures have been employed for determining color excesses, but each represents one of the two basic approaches: photometric (Kron and Svolopolus 1959) or spectroscopic (Kraft 1961). Color excesses determined by these two methods show significant discrepancies (Kraft 1961). Furthermore, even when similar photometric or spectroscopic methods are used, investigators have derived color excess values that differ by a greater degree than would be expected from random observational errors. These aspects drew our attention to the problem of homogeneous determination of Cepheid color excess values using the *uvby* system.

It is true that at the present time most Cepheid observation employs the BVRIJHK color system, as opposed to the *uvby* system. However, as an intermediate-band system, *uvby* system has some advantages; in particular, the effects of atmospheric extinction and interstellar reddening are smaller than in a wide-band system like UBVRI. Therefore, more reliable distance estimation of Cepheids can be expected with *uvby* system.

Moreover, the *uvby* system has shown advantages in the estimation of fundamental physical parameters of Cepheids; these include effective temperature, surface gravity, and metallicity. In order to understand the physical processes in Cepheids, these parameters should be estimated as accurately as possible. We estimated these parameters using the Kurucz and MARCS/SSG model atmospheric grids for the *uvby* system.

2. DETERMINING COLOR EXCESSES FOR THE CALIBRATION STARS

We have recently devised a new method, using the *uvby* photometric system, to determine the color excesses of fundamental-mode classical Cepheids (see Kim 2008, hereafter K08). In this method, 50 Cepheids with distance modulus (DM) data compiled by Negeow and Kanbur (2004, hereafter NK) were selected as calibration stars. NK selected only independent distance measurements from open clusters, Barnes-Evans surface brightness method, interferometry, and Hubble Space Telescope astrometry techniques. They did not include the distances from Hipparcos because of the large errors in these data.

For these Cepheids, absolute magnitude (Mv) was determined using the Period-Luminosity-Color (PLC) relation (see Eq. 2), and Av was calculated using DM and Mv for calibration stars. Using the absorption-

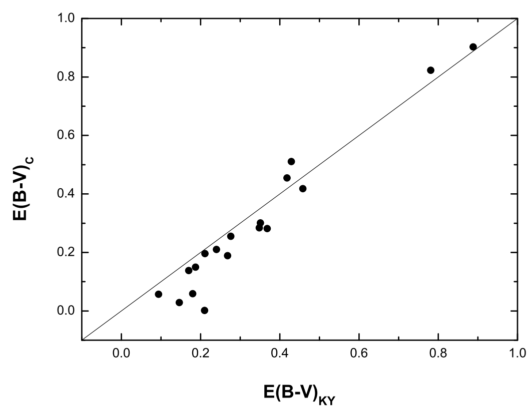

Fig. 1.— E(B–V) values from KY were compared with calculations from the present study

to-reddening coefficients (Rv) derived by Tammann et al. (2003, hereafter TSR), E(B–V) was calculated for each Cepheid. This E(B–V) value was converted to E(b–y) using the relation between E(B–V) and E(b–y). Finally, using these E(b–y) values, a calibrated empirical relationship between $(b-y)_0$, period, $[c_1]$, and $[m_1]$ was derived by a linear fit using the following equation:

$$(b-y)_0 \quad = A + B \log P + C\ [m_1] + D\ [c_1] \qquad (1)$$

With the aid of this relationship, E(b–y) values were determined for all Cepheids for which *uvby* data were available. Our efforts to collect all the known *uvby* data for classical Cepheids led to the discovery that the *uvby* system has rarely been used for observations of individual Cepheids. Specifically, the *uvby* system was used primarily by three investigators for long-term surveys of a large number of Cepheids. Feltz and McNamara (1980, hereafter FM), Eggen (1983 and 1985, both hereafter EG), and Arellano Ferro et al. (1998, hereafter AF) published *uvby* data for 41, 65, and 138 Cepheids, respectively.

Although EG had the largest number of observations for each Cepheid, the AF data were of higher quality owing to the use of a six-channel photometric instrument. However, the number of observations performed by AF for each Cepheid was small except in several cases. Although K08 adopted the data from EG for their investigation, we did not include EG since the Stromgren and Eggen *uvby* systems are not identical (Eggen 1982); in particular, the y filter's width is different. Among NK's 50 Cepheids, *uvby* data were available for 16 in the observations made by FM and AF.

We attempted to estimate E(b–y) for Cepheids using the method devised by K08 but with a different E(B–V) data source. Fernie (1994) and Fernie, et al.(1995) compiled the color excesses for 505 Cepheids constituting the largest body of E(B–V) values. Later, TSR corrected a systematic scale error in this source, and K08 used these E(B–V) data to derive an empirical relation presented in Eq. (1) through a linear fit. In this paper, we adopted another E(B–V) data source compiled by Kim and Yushchenko (2005, hereafter KY). They collected the color excesses of 323 fundamental-mode Cepheids from the literature and transformed them to yield a single homogeneous system.

Fernie (1994, 1995) argued that his results can be compared to those determined through multi-color observations, and that these results were similar to those obtained for cluster Cepheids. However, his main purpose was to include many faint Cepheids observed with the BV photometric system, which is in much wider use than other systems. Although Fernies method increased the number of Cepheids whose color excess E(B–V) could be determined, this method can only be applied to the BV system, excluding color excess values determined with other photometric systems since the mid-1990's.

KY tried to re-derive the intrinsic colors of individual Cepheids by adopting the Feltz and McNamara (1976, 1980, unpublished, hereafter FM) color excess values, and compiled into a single list for all color excess values currently available in the literature. KY reported that their reddening values are somewhat smaller than those of TSR (see Fig. 2 in KY). Table 1 presents the results of analysis for Cepheids used for calibration. In this table, log P, $< V >$, $E(B-V)_{KY}$ were from KY, but DM was from NK. The absolute magnitude (Mv) was calculated via the PLC relation below, which was derived by KY using NKs distance modulus and TSRs $(B-V)_0$ values. Because the intrinsic scatter of a PLC relationship in the UBV system is smaller than that of a PL relationship, a PLC relationship was used for the determination of Mv, as follows:

$$\begin{aligned} \mathrm{M_v} &= -3.203(0.020) \log P \qquad (2)\\ &\quad + 0.498(0.436)\ (B-V)_0 - 1.149(0.180). \end{aligned}$$

The absorption-to-reddening coefficients (R_v) for individual Cepheids from TSR were used.

$$\begin{aligned} \mathrm{R_v} &= +3.17 + 0.44[(B-V)_0 - 0.78] \qquad (3)\\ &\quad + 0.05[E(B-V) - 0.42]. \end{aligned}$$

3. DETERMINING COLOR EXCESSES FOR THE CEPHEIDS

In Table 1, $E(B-V)_C$ is the result of the calculation, and ΔE(B-V) is the difference between $E(B-V)_{KY}$ and $E(B-C)_C$. In Fig. 1, $E(B-V)_{KY}$ was compared

Table 1.
Calculated color excesses of the candidates of calibration Cepheids

Cepheid	log P	$< V >$	$E(B-V)_{KY}$	DM	M_V	R_V	$E(B-V)_c$	Δ E(B–V)	$E(b-y)_c$	$E(b-y)_3$
η AQL	0.856	3.898	0.187	7.025	-3.590	3.080	0.150	-0.037	0.120	0.109
RX AUR	1.065	7.673	0.276	11.101	-4.223	3.117	0.255	-0.021	0.206	0.178
δ CEP	0.730	3.957	0.146	7.100	-3.232	3.039	0.029	-0.117	0.021	0.068
X CYG	1.215	6.392	0.268	10.395	-4.608	3.201	0.189	-0.079	0.152	0.222
SU CYG	0.585	6.863	0.210	9.700	-2.843	2.975	0.002	-0.208	0.001	0.044
ζ GEM	1.006	3.898	0.094	7.732	-4.012	3.128	0.057	-0.037	0.043	0.024
Z LAC	1.037	8.416	0.368	11.637	-4.108	3.145	0.282	-0.086	0.228	0.308
T MON	1.432	6.125	0.240	10.721	-5.274	3.226	0.210	-0.030	0.169	0.128
CV Mon	0.731	10.304	0.781	11.003	-3.230	3.075	0.823	0.042	0.672	0.556
BF Oph	0.610	7.340	0.351	9.271	-2.849	3.048	0.301	-0.050	0.244	0.241
U SGR	0.829	6.695	0.458	8.881	-3.486	3.110	0.418	-0.040	0.340	0.324
W Sgr	0.881	4.670	0.170	7.933	-3.685	3.067	0.138	-0.032	0.110	0.056
X Sgr	0.846	4.562	0.211	7.553	-3.590	3.054	0.196	-0.015	0.158	0.125
WZ Sgr	1.339	8.027	0.429	11.316	-4.954	3.255	0.511	0.082	0.416	0.360
BB SGR	0.822	6.934	0.348	9.518	-3.464	3.104	0.284	-0.064	0.230	0.228
RU SCT	1.294	9.463	0.888	11.480	-4.903	3.195	0.903	0.015	0.737	0.723
T VUL	0.647	5.753	0.180	8.920	-2.990	3.019	-0.059	-0.239	0.000	0.058
SV VUL	1.653	7.209	0.418	11.636	-5.924	3.286	0.455	0.037	0.370	0.383

with our $E(B-V)_C$. Although the scattering did not appear large, $E(B-V)_{KY}$ is larger than $E(B-V)_C$ for smaller values of $E(B-V)_C$. Then $E(B-V)_C$ was converted to $E(b-y)_C$, using the relation of E(b–y)=0.78 E(B–V) due to Bell and Parsons (1974) for the first iteration. For the second iteration, we derived equation (4) with σ=0.030 below, and adopted the resulting values as the standard reddening values in the following procedure.

$$E(b-y)_C = -0.003(\pm0.008) + 0.820(\pm0.017)\ E(B-V)_{TSR} \quad (4)$$

For all observations of each calibration Cepheid, we calculated reddening-free indices $[c_1]$ and $[m_1]$ using the relations $[c_1]=(c_1)_{obs}-0.16$ E(b–y) and $[m_1] = (m_1)_{obs}$ + 0.33 E(b–y) adopted by Arellano, Ferro, and Mantegazza (1996). We assumed that the intrinsic linear relation between $(b-y)_0$ and the pulsating and photometric indices log P, $[m_1]$, and $[c_1]$ presented in Eq. (1) exists.

The four constants in this relationship were determined using a total of 536 observations corresponding to all different phases through a least-squares fit. Bad observations, i.e., those which differed significantly from the overall light curve pattern, were excluded and a least-squares fit was performed. Then the residual for each observation was determined, and each observation with $\sigma > 0.05$ was discarded for the second run to increase the accuracy. For 340 observations, a second linear fit process was followed, and the derived equation with four constants and with σ=7.592×10^{-4} was

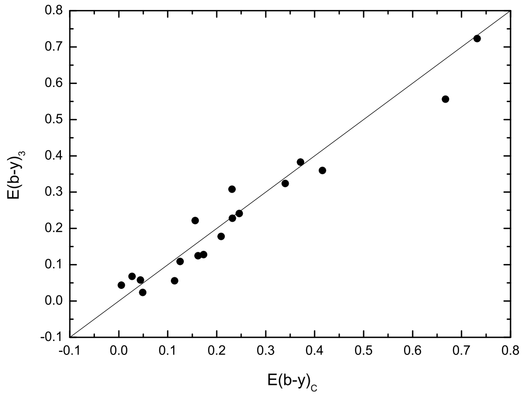

Fig. 2.— $E(b-y)_c$ values in Table 1 were compared with those obtained by using Eq. (6) for calibration Cepheids

$$(b-y)_0 = 0.062(.015) + 0.165(.006)\ \log P - 0.033(.026)\ [m_1] - 0.048(.013)\ [c_1], \quad (5)$$

In the above equation, the σ values are remarkably small, which we believe this reflects the reliability of our E(b–y) values for the calibration Cepheids. Our value of 7.592×10^{-4}, compared with 2.136×10^{-3} in KY, shows that the use of the linear fit resulted in significant improvement in a linear-fit. Table 2 presents the final E(b–y) values determined for 59 fundamental-mode Cepheids. In this table, log P and V were taken from Berdnikov et al., $(b-y)_0$ is the reddening free color index determined using Eq. (5), and E(b–y) is the color excess determined from $(b-y)_{obs}$–$(b-y)_0$. The

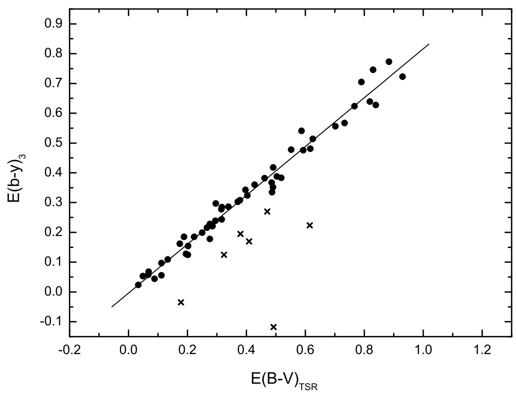

Fig. 3.— Our $E(b-y)_3$ values were compared with $E(B-V)_{TSR}$ to derive a conversion relation between E(B–V) and E(b–y). The solid line corresponds to a liner-fit, excluding the values marked with crosses.

reddening-free indices $[m_1]$ and $[c_1]$ were determined from E(b–y).

The quantities in parentheses given with $(b-y)_0$, $[m_1]$ and $[c_1]$ indicate the standard deviations; all values are in thousandths of a magnitude. N is the total number of observations, and $(b-y)_0$, $[m_1]$, and $[c_1]$ are averaged over N in the table. S is the source of the observations. When data from both investigators were available for the same Cepheids, first priority was given to FM. Fig. 2 shows a plot of the $E(b-y)_c$ values from Table 1 versus the $E(b-y)_3$ values determined using Eq. (5) for calibration Cepheids; no systematic difference is apparent.

In Fig. 3, in order to derive the conversion relation between E(b–y) and E(B–V), we compared our $E(b-y)_3$ values in Table 3 with the data of TSR. The scattering is large for the seven outliers (indicated with crosses), but no systematic difference between the two methods is apparent. The result of a least-squares fit for 59 Cepheids with σ=0.030 is presented in Eq. (6); this equation was used to convert $E(B-V)_C$ to $E(b-y)_C$ for the calibration Cepheids. The solid line in Fig. 3 indicates the result of the linear least-squares fit from Eq. (6). The slope in the above relation is different from that determined by Bell and Parsons (1974), namely E(b–y)=0.78E(B–V). Seven outliers corresponding to WZ Pup, WX Pup, AA Gem, X Pup, RZ CMa, TX Mon, and VZ Cyg were not included in the linear fit.

$$E(b-y)_3 = -0.003(\pm 0.008) + 0.820(\pm 0.017)\ E(B-V)_{TSR} \quad (6)$$

4. PERIOD-COLOR RELATION

Nonlinear Period-Luminosity (PL) and Period-Color (PC) relations for classical Cepheids have been found, in LMC Cepheids in the optical band, but Ngeow and Kanbur (2006) argued that the LMC PL relation in the K band is apparently linear. Moreover, for Galaxy and LMC Cepheids, it has been unclear whether the PC relationship for (B–V) and (V–I) color indices is linear or nonlinear. Thus the investigation of the linearity of PC and PL relations in different passbands for Cepheids in different galaxies is a subject of considerable interest.

We attempted to derive the PC relationship for (b–y) color indices; Fig. 4 gives a plot of period versus $(b-y)_0$. Due to scattering, any nonlinearity is essentially negligible, and we derived the PC relation given in Eq. (7). Five outliers corresponding to CM Sct, RZ CMa, AP Sgr, TX Mon, and SV Vul were not included in the linear fit.

$$(b-y)_0 = 0.102(0.02) + 0.364(0.018) \log P \quad (7)$$

This result can be compared with,

$$(b-y)_0 = 0.173(0.099) + 0.317(0.021) \log P \quad (8)$$

from K08. The errors for the slope and constant are smaller in our result, but sigma value of 0.032 is same for both cases. In both cases, non-linearity can be hardly confirmed.

5. ATMOSPHERIC PARAMETERS

Because reliable photometric indices of $(b-y)_0$ and $[c_1]$ were determined using our new color excess values, we attempted to estimate the effective temperature (Te) and surface gravity (log g).

New grids of theoretical color indices for the *uvby* photometric system were derived by Clem et al. (2004) using MARCS model atmospheres and SSG codes (Bell, Paltoglu, and Tripicco 1994). Their results represent a considerable improvement over currently available color-Te relations for the Stromgren photometric system, and have led in turn to important refinements in the understanding of stars and stellar populations.

Given that the photometric estimation of Te and log g for evolved stars like Cepehids is difficult, we would like to point out that our main purpose is not the determination of accurate Te and log g values for supergiants. Because the MARCS/SSG model is not in wide use, we tried to determine Te and log g using this model for eight Cepheids with different period for $[Fe/H]$=0.0, and to compare the results with those determined by the Kurucz model (Lester et al. 1986).

These results are presented in Table 3. For long period Cepheids, i.e., those with $P > 10$ days, $(b-y)_0$

Table 2.
Color excesses of Cepheids

Cepheid	log P	ΔV	$E(B-V)_{TSR}$	$E(b-y)_3$	$(b-y)_0$	$[c_1]$	$[m_1]$	N	S
U AQL	0.846	0.76	0.371	0.303(32)	0.372(69)	0.221(68)	0.783(159)	37	FM
η AQL	0.856	0.79	0.133	0.109(20)	0.405(67)	0.357(64)	0.676(153)	43	FM
SZ AQL	1.234	1.23	0.552	0.478(63)	0.497(120)	0.306(157)	0.656(279)	31	FM
TT AQL	1.139	1.10	0.462	0.382(32)	0.455(117)	0.309(149)	0.703(270)	32	FM
FM AQL	0.786	0.73	0.617	0.481(28)	0.391(83)	0.180(85)	0.747(193)	34	FM
FN AQL	0.977	0.57	0.490	0.352(44)	0.457(52)	0.286(72)	0.640(120)	36	FM
RT AUR	0.572	0.78	0.049	0.053(18)	0.349(62)	0.338(54)	0.698(143)	24	FM
RX AUR	1.065	0.67	0.276	0.178(25)	0.427(54)	0.311(65)	0.711(127)	21	FM
δ CEP	0.730	0.83	0.068	0.068(19)	0.372(88)	0.364(72)	0.700(202)	44	FM
X CYG	1.215	1.00	0.284	0.222(43)	0.549(88)	0.484(134)	0.485(200)	53	FM
SU CYG	0.585	0.76	0.088	0.044(25)	0.306(75)	0.252(44)	0.802(173)	26	FM
VZ CYG	0.687	0.67	0.615	0.224(25)	0.354(73)	0.272(68)	0.752(168)	30	FM
ζ GEM	1.006	0.49	0.033	0.024(16)	0.534(20)	0.552(40)	0.415(47)	7	FM
W GEM	0.898	0.80	0.266	0.216(24)	0.389(87)	0.290(91)	0.745(202)	22	FM
X LAC	0.736	0.40	0.339	0.286(25)	0.340(45)	0.218(45)	0.814(103)	23	FM
Y LAC	0.635	0.70	0.202	0.154(27)	0.342(64)	0.252(43)	0.754(146)	20	FM
Z LAC	1.037	0.96	0.378	0.308(27)	0.464(94)	0.338(103)	0.635(217)	25	FM
BG LAC	0.727	0.60	0.316	0.244(27)	0.376(68)	0.283(78)	0.719(159)	26	FM
T MON	1.432	0.99	0.195	0.128(46)	0.644(100)	0.627(152)	0.325(228)	21	FM
AW PER	0.810	0.82	0.487	0.335(30)	0.398(73)	0.151(74)	0.722(171)	23	FM
S SGE	0.923	0.71	0.112	0.097(26)	0.401(73)	0.363(69)	0.706(167)	34	FM
U SGR	0.829	0.74	0.403	0.324(37)	0.410(79)	0.312(86)	0.689(184)	34	AF
Y SGR	0.761	0.71	0.188	0.185(23)	0.356(74)	0.311(79)	0.767(172)	33	FM
YZ SGR	0.980	0.69	0.285	0.221(39)	0.441(75)	0.353(83)	0.653(174)	36	FM
BB SGR	0.822	0.61	0.276	0.228(43)	0.425(56)	0.342(78)	0.636(130)	28	FM
350 SGR	0.712	0.71	0.295	0.239(43)	0.354(76)	0.263(64)	0.764(175)	35	FM
SS SCT	0.565	0.51	0.317	0.285(33)	0.351(51)	0.244(59)	0.729(119)	29	FM
T VUL	0.647	0.64	0.067	0.058(16)	0.337(66)	0.321(59)	0.752(152)	34	FM
U VUL	0.903	0.71	0.593	0.476(33)	0.413(80)	0.216(90)	0.735(185)	34	FM
X VUL	0.801	0.77	0.790	0.705(63)	0.377(70)	0.104(74)	0.818(163)	19	FM
SV VUL	1.653	1.03	0.518	0.383(39)	0.554(119)	0.389(155)	0.653(274)	39	FM
336 AQL	0.863	0.72	0.625	0.514(22)	0.431(75)	0.284(82)	0.680(172)	19	AF
600 AQL	0.860	0.65	0.819	0.639(29)	0.444(63)	0.259(67)	0.670(145)	16	AF
RY CMa	0.670	0.73	0.223	0.185(22)	0.346(80)	0.313(59)	0.758(184)	8	AF
RZ CMa	0.628	0.60	0.471	0.270(47)	0.438(31)	0.294(35)	0.549(68)	6	AF
SZ CYG	1.179	0.88	0.587	0.541(149)	0.596(114)	0.610(108)	0.404(270)	9	AF
VX CYG	1.304	0.95	0.830	0.746(146)	0.602(98)	0.569(78)	0.463(235)	5	AF
BZ CYG	1.006	0.50	0.839	0.628(112)	0.468(98)	0.247(58)	0.667(234)	6	AF
CD CYG	1.232	1.18	0.486	0.367(40)	0.564(140)	0.549(189)	0.473(326)	11	AF
386 CYG	0.721	0.69	0.884	0.773(40)	0.353(81)	0.183(64)	0.849(189)	5	AF
402 CYG	0.639	0.57	0.397	0.343(81)	0.337(60)	0.281(51)	0.791(143)	5	AF
RZ GEM	0.743	0.94	0.503	0.388(34)	0.381(104)	0.220(62)	0.739(240)	8	AF
AA GEM	1.053	0.65	0.380	0.195(23)	0.518(74)	0.444(99)	0.497(174)	10	AF
V LAC	0.697	0.92	0.315	0.278(40)	0.357(123)	0.283(100)	0.756(285)	9	AF
RR LAC	0.808	0.78	0.296	0.297(9)	0.342(91)	0.279(75)	0.831(210)	5	AF
SV MON	1.183	1.07	0.250	0.199(31)	0.546(96)	0.515(111)	0.475(219)	8	AF
TX MON	0.940	0.62	0.492	-0.118(27)	0.264(16)	0.167(28)	1.001(40)	7	AF
CV MON	0.731	0.73	0.702	0.556(47)	0.372(107)	0.195(74)	0.779(250)	6	AF
X PUPp	1.414	1.26	0.409	0.170(103)	0.629(105)	0.457(108)	0.369(246)	6	AF
WX PUP	0.951	0.69	0.324	0.125(82)	0.506(108)	0.376(69)	0.485(255)	6	AF
WZ PUP	1.365	0.78	0.178	-0.035(97)	0.519(97)	0.375(62)	0.575(230)	5	AF
W SGR	0.881	0.79	0.112	0.056(31)	0.437(76)	0.392(79)	0.605(175)	30	AF
X SGR	0.846	0.60	0.201	0.125(27)	0.376(69)	0.307(56)	0.744(159)	23	AF
WZ SGR	1.339	1.09	0.428	0.360(52)	0.632(122)	0.586(198)	0.355(282)	27	AF
AP SGR	0.704	0.83	0.174	0.162(25)	0.414(72)	0.375(63)	0.609(165)	24	AF
Y SCT	1.015	0.79	0.767	0.624(33)	0.511(91)	0.344(113)	0.566(213)	28	AF
Z SCT	1.111	0.99	0.491	0.418(27)	0.492(96)	0.383(122)	0.609(225)	28	AF
RU SCT	1.294	1.08	0.930	0.723(49)	0.594(102)	0.445(135)	0.482(237)	27	AF
CM SCT	0.593	0.59	0.733	0.567(36)	0.417(55)	0.284(55)	0.627(129)	15	AF

Table 3.
Te and log g from Kurucz and MARCS models

Cepheid	log P	Kurucz Te	MARCS Te	ΔTe	Kurucz log g	MARCS log g	$\Delta log\ g$
SS Sct	0.565	5832	6031	199	2.22	2.73	0.51
RT Aur	0.572	5847	6056	209	2.37	2.85	0.48
SU Cyg	0.585	6135	6294	159	2.35	2.79	0.45
δ Cep	0.730	5704	5917	213	2.15	2.70	0.55
CV Mon	0.731	5710	5903	193	1.78	2.40	0.45
η Aql	0.856	5505	5732	227	1.95	2.58	0.37
S SGE	0.923	5535	5750	215	1.82	2.48	0.66
TX Mon	0.940	6389	6523	134	2.06	2.46	0.40

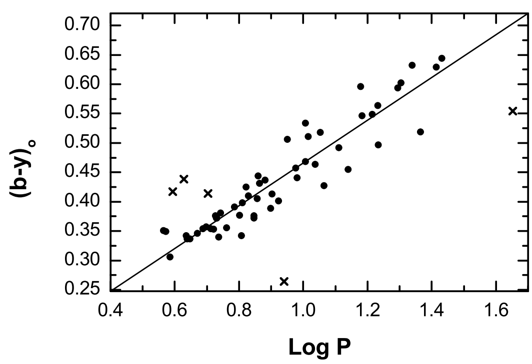

Fig. 4.— The period–color relation. The solid line corresponds to a linear fit. Crosses were not included in a linear-fit.

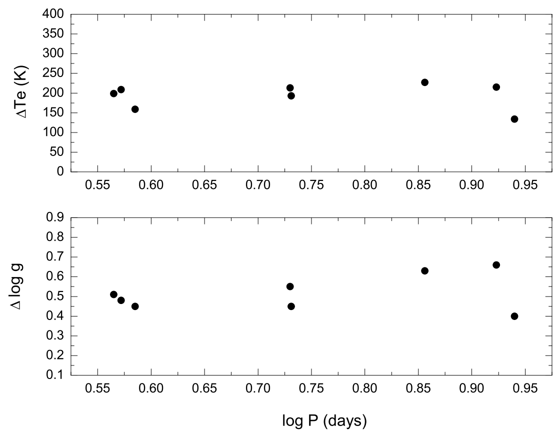

Fig. 5.— The difference of Te and log g from the Kurucz and MARCS/SSG model atmospherric grids.

values were outside the range of Kurucz grids. Thus only Cepheids with $P < 10$ days are included in Table 3. In Fig. 5 the differences of Te and log g appear to be unrelated to period, but we can see that both the Te and log g values from the MARCS/SSG model (about 193K and 0.48 respectively) are higher than those from the Kurucz model.

6. CONCLUSION

We attempted to determine reliable values for the color excess of fundamental mode classical Cepheids, in order to investigate linear or nonlinear period-color relations in the *uvby* photometric system. By adopting the DM and PLC relation with light curve parameters taken from the literature, we derived an intrinsic relationship between $(b - y)_0$ and period, amplitude, $[c_1]$, and $[m_1]$. In this relationship, the period term is related to the effect of pulsation, while $[c_1]$ and $[m_1]$ reflect the photometric characteristics of Cepheids as pulsating variables. We then investigated the PC relation and estimated Te and log g using the Kurucz and MARCS/SSG grids.

Due to high levels of scattering in the data points, we were unable to confirm any nonlinearity in the PC relationship. It is true that nonlinearity is not supported by any observational results, but this does not guarantee non-linearity. Even though non-linerity exists, there is a possibility that inaccurate colors caused by uncertain color excess values can make detection of this impossible.

It seems that, even using the majority of color excess values for different bands obtained from a basic database through a certain calibration process, insufficient evidence was available to test for linearity. Inaccurate mean colors, conversion relations between different color systems, absorption-to-reddening coefficients, etc., provide other sources of significant scattering in the PC relationships. To confirm nonlinearity, we may have to wait for the elimination of these sources of uncertainty in the estimation of un-reddened colors.

On the other hand, it was confirmed that Te and log g are different for the different atmospheric grid models developed by Kurucz and MARCS/SSG. The differences of about 200K and 0.5 in Te and log g, respectively are nonnegligible. At the time of this writing, it is uncertain whether this phenomenon occurs only in Cepheids. In any case, it is beyond the scope of this paper to investigate the reasons underlying these differences.

Since reliable values for Te and log g are essential in the study of stellar evolution, the fact that different grids devised by different people produce different results for same atmospheric parameter values may be problematic. Hence it is crucial to investigate the causes underlying the different results obtained with different grids for normal stars, variable stars, and cluster stars separately. Otherwise, researchers will be forced to use a single model.

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