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A METHOD OF COLOR EXCESS DETERMINATION FOR HIGH AMPLITUDE δ SCUTI STARS

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ABSTRACT

In order to determine color excess in the $uvby\beta$ color system for high amplitude δ Scuti stars, reddening free $[m_1]$, $[c_1]$, and β indices data were obtained from the existing literature for 21 stars. Then, the three intrinsic relations of $(b-y)_0-[m_1]$, $(b-y)_0-[c_1]$, and $(b-y)_0-\beta$ were investigated. Among these, it was shown that the $(b-y)_0-[c_1]$ relation is the most useful. By establishing intrinsic $(b-y)_0-[c_1]$ relations for six reddening calibration stars, color excesses of other stars were determined.

Key words : variable star– high amplitude δ Scuti star– color excess– $uvby\beta$ system

I. INTRODUCTION

Unlike classical cepheids, the investigation of High Amplitude δ Scuti Stars (HADS) has been concentrated on the study of pulsation characteristics and stellar evolution. It is true that HADS are not as important as the classical cepheids. Although the PL relation was derived for HADS already, their role as a distant indicator has been limited due to their low luminosity and low amplitude. There is, however, a possibility that they could be used to determine the distance of extragalaxies if big telescopes can be used to observe HADS in the future. To be used as a distant indicator, it is absolutely necessary to determine their reliable color excesses.

If color excess cannot be determined accurately, we cannot reliably determine distances even though the PL relation is well established. Therefore, a reliable estimation of color excess is as important as the determination of a reliable PL relation. This is the reason why many different methods have been developed to estimate color excess using various photometric systems for classical cepheids. Also, various spectroscopic methods were devised too (see Kim 1987, 2008; references therein) for a long time. However, color excesses derived from these different methods show significant discrepancies. In addition, with poorly determined color excess, reliable atmospheric parameters such as effective temperature, surface gravity, and metallicity cannot be estimated accurately.

Unfortunately, color excess of HADS has not been widely investigated. For HADS, in most cases, intrinsic $(b-y)_0$ values in observation using the uvby color system have been calculated with the aid of the Crawford (1975, 1979) calibration of A- and F- type stars. The $uvby\beta$ color system is almost the only one that makes it possible to determine color excess of HADS. Hence, we tried to examine a different method which is independent of Crawford calibration. Our method is based on the method which was devised to determine E(b–y) of classical cepheids (Kim 1987; Feltz & McNamara 1976, 1980).

II. METHOD

In order to extend our knowledge of space-reddening to HADS, it is necessary to obtain a viable correlation between photometric indices and the intrinsic colors $(b-y)_0$ of the variables. Implicit in this requirement is the assumption that there is sufficient similarity among the HADS so that general calibration schemes can be developed and applied to the entire group.

For the establishment of the intrinsic relations, we begin by assuming that similarities of HADS extend to their photometric behavior during declining light at a given period. This implies that it should be possible to predict intrinsic color indices such as $(b-y)_0$ from reddening-free indices like $[m_1]$, $[c_1]$, and β.

Through an internet search, we selected a total number of 20 HADS from the literature, where the uvbyβ system was adopted for photometric observations. Table 1 presents the list of these stars. In this table, however, six stars were not included due to a reason which will be explained in the last part of this section. We also obtained normal points of $(b-y)$, c_1, m_1, and β for each star from the literature. For those stars where normal points were not available, we obtained them using the Fourier fitting procedure.

For these raw normal points, reddening-free values

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Table 1.
Color Excesses of Selected HADS

STAR	P	$E(b-y)_1$	$E(b-y)_2$	$E(b-y)_3$	$E(b-y)_4$	$< E(b-y) >$	$E(b-y)$	Δ
GD 428	0.039	0.028	0.250	0.186	0.216	0.238± 0.034	0.238	0.022
SX Phe	0.055	0.002	-0.056		-0.053	-0.036± 0.033	0.000	0.036
KZ Hya	0.059	0.038	-0.007	0.040	-0.014	0.014± 0.029	0.032	0.018
CY Aqr	0.061	0.076	0.033	0.084	0.024	0.054± 0.030	0.059	0.005
ZZ Mic	0.065	-0.009	-0.032	0.003	-0.050	-0.022± 0.024	0.000	0.022
GP And	0.078	0.046	-0.003	0.049	-0.006	0.022± 0.030	0.021	-0.001
V1162 Ori	0.078	0.039	-0.007	0.042	-0.012	0.015± 0.029	0.021	0.005
EH Lib	0.084	0.052	0.008	0.056	0.005	0.030± 0.028	0.041	0.011
AE UMa	0.086	0.034	-0.010	0.035	-0.014	0.011± 0.027	0.015	0.004
RV Ari	0.093	0.133	0.089	0.137	0.081	0.110± 0.029	0.101	-0.009
AN Lyn	0.098	0.043	-0.101	0.046	-0.008	-0.005± 0.069	0.002	0.007
YZ Boo	0.104		-0.004	0.038	-0.010	0.008± 0.026	0.018	0.010
BP Peg	0.109	0.094	0.050	0.096	0.047	0.072± 0.027	0.067	-0.005
XX Cyg	0.135	0.101	0.059	0.101	0.053	0.079± 0.026	0.057	-0.022
RS Gru	0.147	0.043	0.001	0.043	-0.005	0.020± 0.026	0.010	-0.010
DY Her	0.148	0.074	0.028	0.078	0.022	0.051± 0.030	0.045	-0.005
V567 Oph	0.149	0.339	0.481	0.343	0.382	0.386± 0.066	0.285	-0.101
V798 Cyg	0.195	0.167	0.127	0.175	0.120	0.147± 0.028	0.117	-0.030
BS Aqr	0.197	0.059		0.060	0.012	0.044± 0.027	0.008	-0.036
RY Lep	0.225	0.075	0.032	0.075		0.061± 0.025	0.013	-0.048
DE Lac	0.253	0.164	0.077	0.159	0.110	0.127± 0.042	0.087	-0.041

Notes: $E(b-y)_1$, $E(b-y)_2$, $E(b-y)_3$, and $E(b-y)_4$ are from the calibration stars of YZ Boo, BS Aqr, SX Phe, and RY Lep respectively.

were calculated by adopting the reddening value in the literature, $E(b-y)$ using $[m_1] = m_1 + 0.3E(b-y)$ and $[c_1] = c_1 - 0.2E(b-y)$ (Crawford 1975). In order to examine any possible intrinsic relation, reddening-free normal points corresponding to the descending branch region for all stars were plotted on three planes of $(b-y)_0 - [m_1]$, $(b-y)_0 - [c_1]$, and $(b-y)_0 - \beta$. For double mode stars like SX Phe, only the case of first oscillation mode was considered.

These are presented in Fig.1 for the (b–y)–c_1 plane, and we can see that normal points show almost a linear distribution with parallel displacement from one star to the other. However, the distribution does not show a systematic trend on the $(b-y)_0 - [m_1]$ plane. On the other hand, the distribution on the $(b-y)_0 - \beta$ plane also shows a similar pattern, but not as good as in the $(b-y)_0 - [c_1]$ plane. We also wish to point out that β system has not been so widely adopted compared to the *uvby* system, so, in many cases, β data is not available. Therefore, we adopted only the $(b-y)_0 - [c_1]$ plot for further analysis.

Color excesses of $E(b-y)$ can now be found for all HADS by plotting observational data in the diagram depicted in Figure 2. Among all stars, we selected four stars whose linearity appeared relatively good. These were SX Phe, BS Aqr, RY Lep and YZ Boo, and they were used as reddening standard calibration stars. This also implies that we assumed that their reddening values of $E(b-y)$ from the literature are reliable. Each curve on the $(b-y) - [c_1]$ plane of the calibration star was used to determine the color excess of other stars. For example, in the case of BS Aqr, an intrinsic relation corresponding to this star on the $(b-y)_0 - [c_1]$ plane was presented with the thick curve in Figure 2. The color excesses of $E(b-y)$ for other stars are found by sliding their curves back along the $(b-y)$ axis to the intrinsic relations.

This procedure was repeated four times by changing the calibration star each time. Finally, the mean value was calculated for each star. In many cases, the shape of the intrinsic relation for the calibration star and the target HADS were not similar, so we drew four to five lines parallel to the X-axes with approximately equal separation, as shown in Figure 2. The distance along the X-axes between the points corresponding to the intrinsic relation and that of the target star was measured. Then, the reddening value of the target star was $E(b-y)_* =$ E(b–y) + ∇ E(b–y). Here, E(b–y) is the color excess of the calibration star, and ∇ E(b–y) is the distance between two points on the diagram. So, for each object, four or five measurements were secured, and the mean value of these was the $< E(b-y) >$ value of that star corresponding to a certain calibration star. Finally, the mean value for all calibration stars was calculated.

Table 1 presents the results. In this table, the names of calibration stars and their periods (days) are in the first and second column. First column is the name of HADS stars, the calculated radddening values corresponding to four calibration stars are in the column

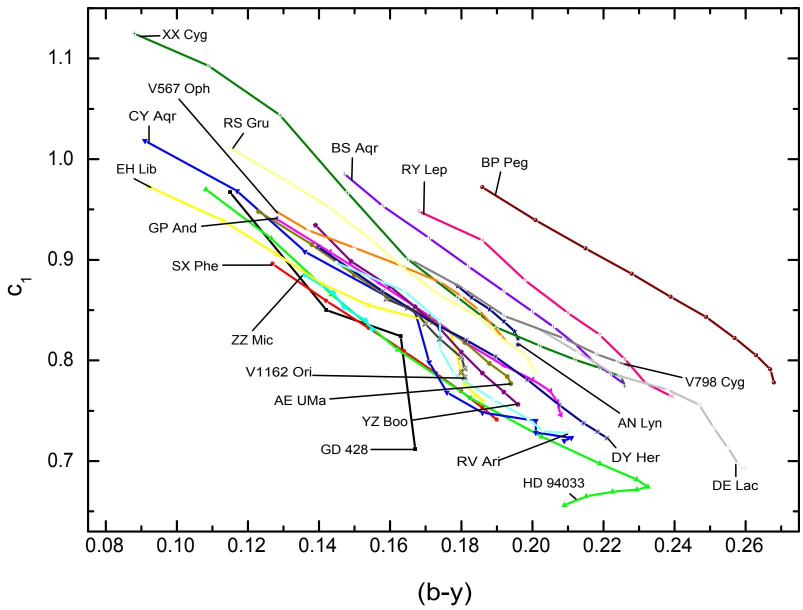

Fig. 1.— Normal points distribution for all selected HADS on the (b-y)-c_1 plane. Note that the (b-y) and c_1 indices are not de-reddened.

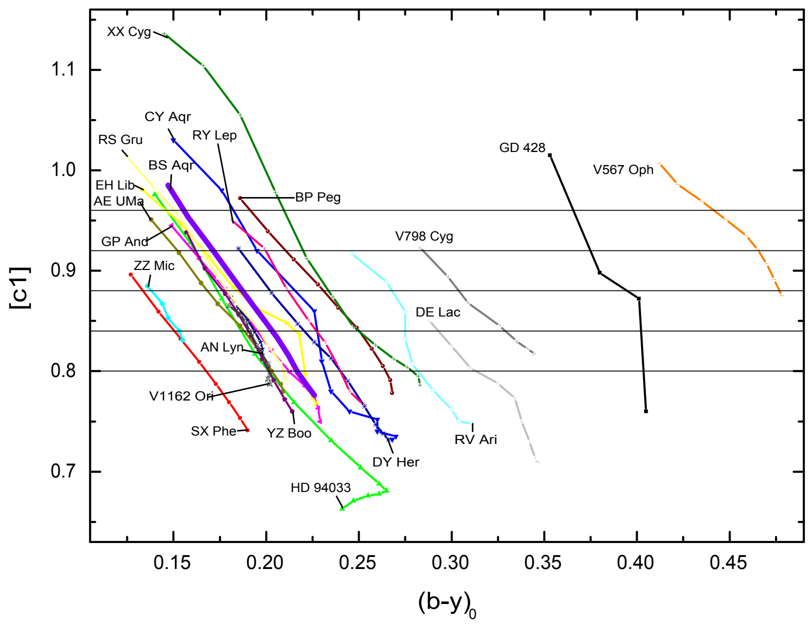

Fig. 2.— Intrinsic relation $(b-y)-[c_1]$ defined by the calibration of HADS BS Aqr as an example. The color excess $E(b-y)$ was found by sliding the data back along $(b-y)$-axis and fitting it to the intrinsic relation determined by the calibration star.

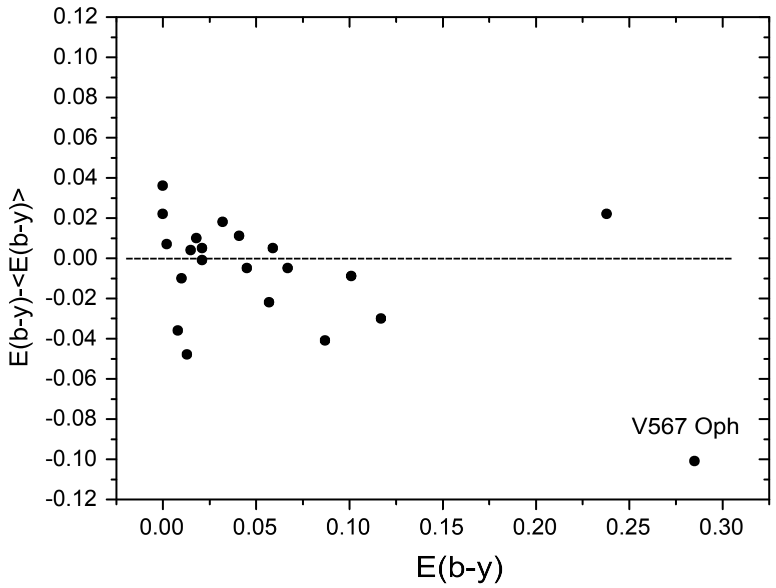

Fig. 3.— Deviation between the mean $< E(b-y) >$, from our method, and $E(b-y)$, from the literature, determined using the photometric calibration for A and F.

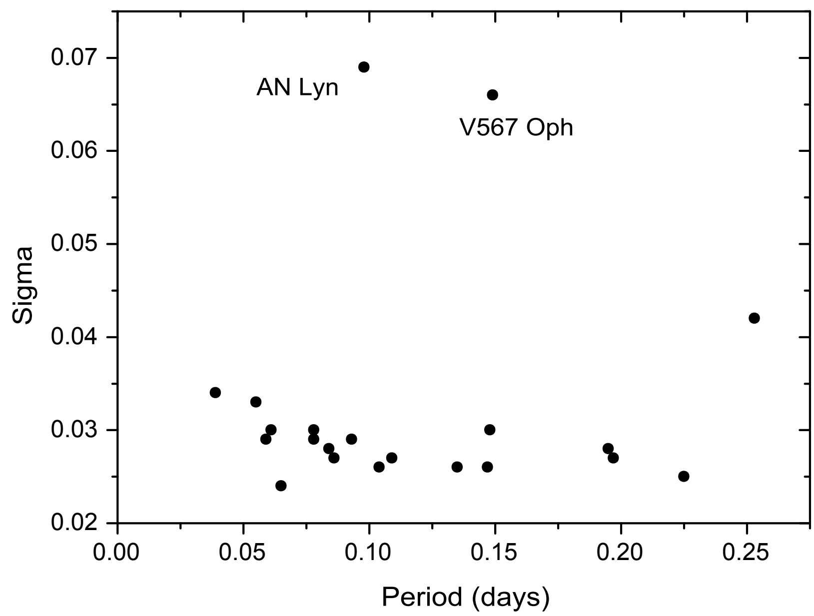

Fig. 4.— Standard deviation of E(b-y) values vs. period.

3-6, and $< E(b-y) >$ in the column 7 are the mean values with the standard deviation. E(b–y) in the column 8 is the reddening value from the literature, and Δ in the column 9 is the difference between E(b–y) and $< E(b-y) >$ in the columns 7 and 8. Actually other HADS stars of AD CMi, BL Cam, IP Vir, and RV Ari were investigated. However these stars were not included in Table 2 because their distribution of the normal points were not smooth enough on the (b–y)–c_1 diagram for the meaningful analysis.

Figure 3 was plotted to see any systematic trends in the differences(Δ) for different stars. The deviation of within around 0.05 is relatively small, except for V567 Oph of which deviation is large of 0.101. Hence, the reddening value of this star in the literature can be doubted. We also plotted the period against the standard deviation (σ) in Figure 4, and the sigma value is around 0.03 for most of HADS stars except two cases of AN Lyn and V567 Oph. For these two stars, reddening values corresponding to BS Aqr are relatively large. Because the number of calibration stars are only four, one large dispcrepancy value from other three values can cause larger sigma value.

III. CONCLUSION

We modified a method which has been developed to determine the color excess of classical cepheids in order to estimate the reliable color excess of HADS. We established an intrinsic relation between $(b-y)_0$ and $[c_1]$. The strong point of our method is that it is not necessary to introduce a reddening line in a color-color diagram. By just examining how far a few normal points of a calibration star are from the intrinsic curve along the (b–y) axis, we can determine $E(b-y)$ directly.

We found that the difference of E(b–y) values determined from our method and those from the literaure are less than around 0.05, and, in adition, sigma values are around 0.03 with no dependency or correlation on period. We believe that these facts support the usefulness of our method for the determination of E(b–y) for HADS. However, there is an inevitable weakness in our method in that the accuracy of reddening values determined by our method is strongly dependent on how we can find the right position of the intrinsic curves for calibration stars on the diagram.

Practically speaking, if $E(b-y)$ of one of the HADS is accurately determined by independent distance measurements, this star can be used as a calibration reddening star. Then, color excesses of all other HADS can be estimated with respect to that of this calibration star using our technique. However, unfortunately, reddening of all HADS had been determined with the Crawford calibration for F- and G- stars, so the weight of the reliability of $E(b-y)$ of all HADS is not so different from one to the other. Rarely, parallax was measured for a few HADS, but their parallax error was too large.

Emphasis should be given to the fact that the intrinsic relation corresponding to a certain period should be applied only to those HADS with the same period, and the intrinsic relation should be different for different periods. This is the very core of our method, which makes it possible to obtain more accurate reddening values. The problem is how to derive each distinct intrinsic relation corresponding to a different period, because the dispersion of photometric data is not small in most cases. In our work, because the period of HADS is not so different from one to the other, unlike the case of classical Cepheids, we did not consider the period effect in our method.

In order to obtain reliable intrinsic relations, which are the essential point in our method, reddening of at least more than a few calibration stars with different periods should be determined using more accurate methods than photometric calibration for A- and F-stars, such as parallax, etc. Then we can expect to determine more accurate color excess values for other HADS.

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