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The Reddening of the Bright G and K Stars*

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ABSTRACT

We analyzed the reddening of 873 bright G and K stars from the DDO photometry in combination with MK spectral classes and $(B-V)$ colors. About a quarter of the sample stars have DDO indices beyond the limits of DDO calibrations. To extend the reddening determination to all stars, we applied a scheme for reddening determination of field G and K stars by using the DDO calibrations (Janes 1977, 1979b) and MK-$(B-V)$ relation of FitzGerald (1970).

I. INTRODUCTION

Since McClure and van den Bergh (1968) developed the David Dunlap Observatory (DDO) photometric system to observe the evolved late type stars, cluster giants, (Osborn 1971, 1973; Janes 1979a), field giants (Janes 1975; Hartkopf and Yoss 1982), and the integrated light of external galaxies (McClure and van den Bergh 1968; Faber 1973) have been observed by the DDO photometry. Along with these observations, much effort has been made to calibrate the DDO indices in terms of astrophysical parameters of late type stars (Osborn 1973, 1975; Janes 1975, 1977, 1979b).

For further accurate determinations of astrophysical parameters such as M_V, T_{eff}, and [Fe/H], the observed DDO indices should be corrected for the effects of interstellar reddening. McClure and Racine (1969) developed a method to determine reddening of giant stars by making use of DDO C(45-48) and C(42-45) in combination with $(B-V)$. Janes (1977, 1979b) has constructed two tables which give the unreddened $(B-V)$ colors of population I giants in the C(42-45)-C(45-48) plane, and those of population II giants in the C(42-45)-[Fe/H] plane, respectively. The reddenings of G and K stars can be also determined from the intrinsic relation between MK spectral class and unreddened $(B-V)$ color. In case of population II stars, however, it is difficult to derive their reddenings due to lack of a reliable [MK, $(B-V)$]-relation.

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In the present study we examined all the methods for reddening determinations of G and K stars to single out the best one by comparing their reddenings each other. The observational data for this study are presented in section II and the reddening determination is described in section III. Discussions on the derived reddenings of G and K stars are given in section IV.

II. OBSERVATIONAL DATA

From "A Catalogue of Homogeneous Photometry of Bright Stars on the DDO System" by McClure and Forrester (1981), we obtained DDO photometry of 873 G and K stars (114 dwarfs and 759 giants) whose UBV photometry and MK spectral type are known from the Bright Star Catalogue (BSC: Hoffleit 1982). In order to check the derived reddening of each star we confined our sample stars to the stars whose parallax are listed in the BSC.

Figure 1 shows the C(45-48) versus C(42-45) for our sample stars. C(45-48) is a continuum index, which is known to be sensitive to the surface gravity and temperature of late type stars, while C(42-45) measures the break in the continuum at the G-band and it is found to be a strong function of effective temperature. In this figure the dwarf and giant sequences are easily differentiated.

The equivalent diagram in the C(41-42)-C(42-45) plane is given in Figure 2. C(41-42) index measures the strength of the blue cyanogen band and it is known to be sensitive to luminosity and to heavy element abundance of late type stars. Figure 3 is a plot of C(42-45) versus $(B-V)$. Both of C(42-45) and $(B-V)$ indices are color indices, primarily sensitive to the effective temperature in UBV and DDO photometric systems. However, we

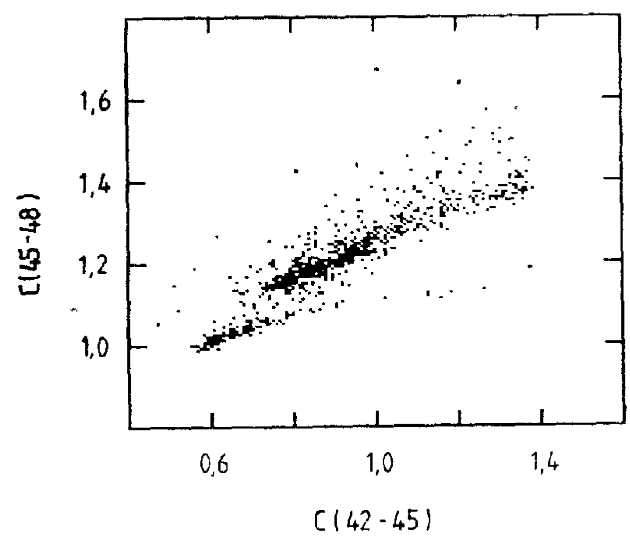

FIG. 1—Distribution of stars in C(45-48)-C(42-45) plane. The dwarf and giant sequences are well defined. Most of our sample stars lie on the giant sequence

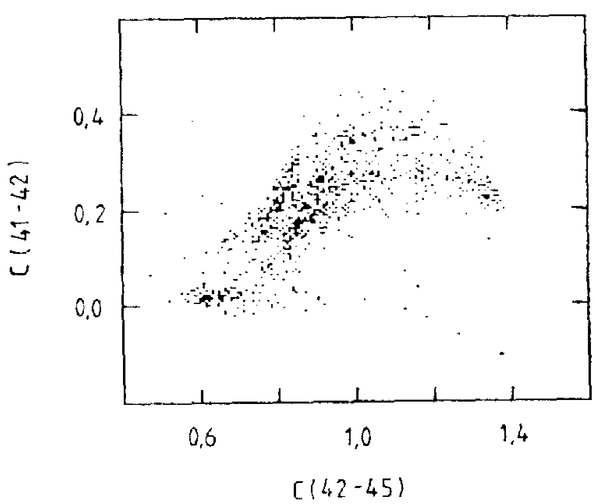

FIG. 2—Distribution of stars in C(41-42)-C(42-45) plane.

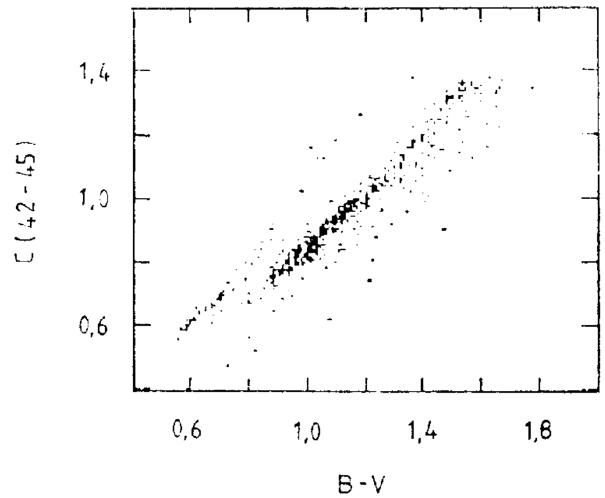

FIG. 3—Distribution of stars in C(42-45)-$(B-V)$ plane. Both axes are of quantities primarily sensitive to surface temperature of late type stars. There seems clear separation between dwarf and giant sequences.

can see from the figure that there is some dependence of the surface gravity on $(B-V)$ indices. The dwarf and giant sequences are well separated in this figure.

III. REDDENING DETERMINATION

A simple method for reddening determination is to use the intrinsic relation between MK spectral class and unreddened $(B-V)$ colors. Although this method is widely used for field stars, the uncertainty involved in the derived $E(B-V)$ is somewhat large, because MK spectral class itself has some uncertainty amounting to subclass 2. McClure and Racine (1969) and Janes (1977, 1979b) have shown that the reddening $E(B-V)$ of G,K giants of population I and II can be derived by the DDO photometry when $(B-V)$ color is known. The McClure and Racine's method is useful only for giants near luminosity class III, and in the Janes' method the preliminary knowledge of the stellar population is required. In the following, we will examine all the methods for the reddening determination to obtain the most reliable method for field G and K stars.

In Figure 4, the reddenings $E(B-V)_{SP}$, determined from the relation between MK spectral class and intrinsic $(B-V)$ colors for population I stars, are plotted against distance (log R) for all the sample stars whose MK spectral classes are listed in the BSC. The rather large dispersion in $E(B-V)_{SP}$ in Figure 4 is mostly due to errors in MK spectral classes. Also the application of FitzGerald's (1970) relation to population II stars, although there are a small portion of our sample, is responsible in part for the dispersion of the reddening in Figure 4.

Figure 5 shows the distribution of reddening $E(B-V)_{MR}$ of giants, determined by the McClure and Racine's (1969) method. As compared with Figure 4, the dispersion of $E(B-V)_{MR}$ in Figure 5 is quite small. However, it is still somewhat large when we consider the typical errors are $0\overset{m}{.}01$ and $0\overset{m}{.}02$ in the DDO and UBV photometry, respectively. A better calibration for the reddening determination of giants was developed by Janes (1977). It can be applied to population I stars of all luminosity classes. We derived reddenings

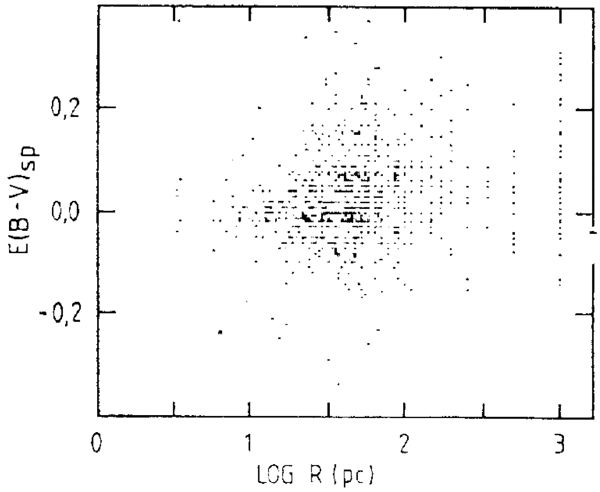

FIG. 4—$E(B-V)_{SP}$ versus log R for all the G and K stars with MK spectral class. $E(B-V)_{SP}$ were derived from the intrinsic colors by FitzGerald (1970). The stars with negative parallax were plotted at log $R=3$.

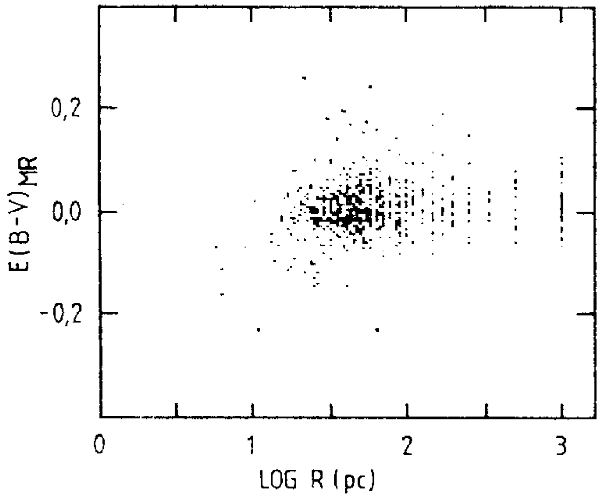

FIG. 5—$E(B-V)_{MR}$ versus log R for the G and K giants in our sample. $E(B-V)_{MR}$ were determined from the calibration of McClure and Racine (1969). The stars with negative parallax were plotted at log $R=3$.

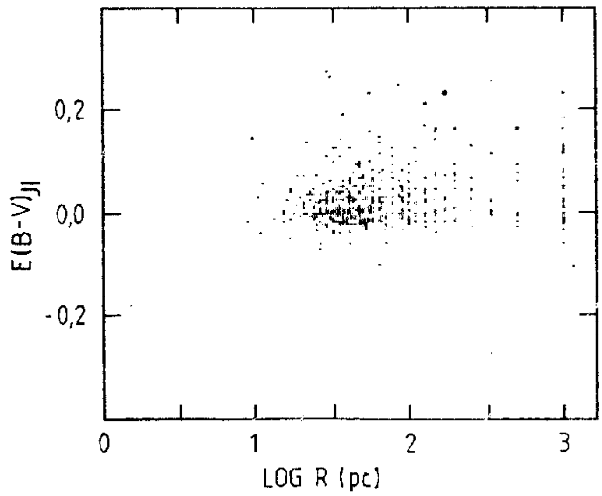

FIG. 6—$E(B-V)_{JI}$ versus log R for the stars with DDO indices within the calibration limit by Janes (1977). $E(B-V)_{JI}$ were determined from the table of Janes (1977). The stars with negative parallax were plotted at log $R=3$.

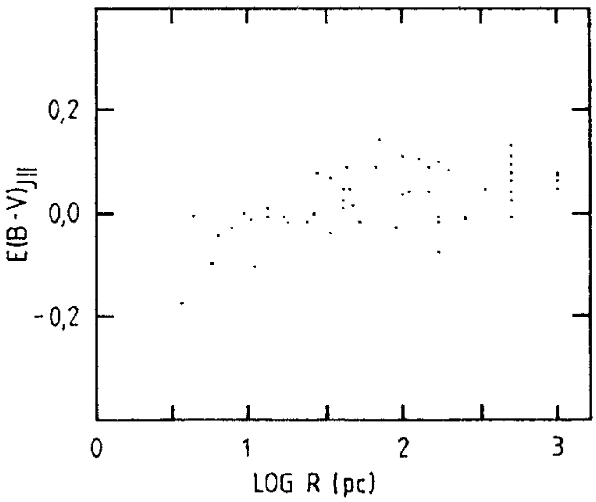

FIG. 7—$E(B-V)_{JII}$ versus log R for the stars with kinematic properties of halo stars. The stars with negative parallax were plotted at log $R=3$.

$E(B-V)_{JI}$ from the calibration of Janes (1977) by assuming that all the stars in our sample are population I stars. They are plotted in Figure 6. As expected, the most of dwarfs (108 among 114 dwarfs) and many G giants have DDO indices beyond the calibration limit of Janes. However, as compared with Figures 4 and 5, the smaller dispersion of $E(B-V)_{JI}$ along log R in Figure 6 indicates that Janes' method is better than any other methods when we take into account the distances ($R\lesssim 100$pc) of our sample stars near the

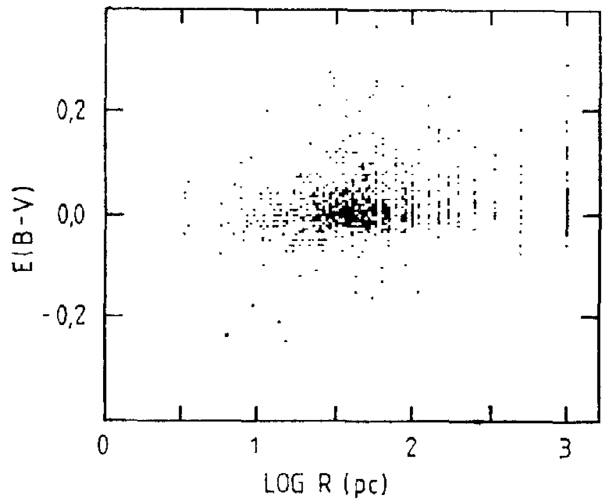

FIG. 8—$E(B-V)$ verus log R for all the G and K stars with parallax. $E(B-V)$ were determined by the combined scheme described in the text.

sun. According to Eggen's (1979) kinematic criteria for halo stars ($e>0.42$ or $W<60$ km/s) there are 55 stars of halo population in our sample. For these stars the reddening $E(B-V)_{JII}$ was determined by using Table II of Janes (1979b) with the uncertainty of $0^m_.08$ in $E(B-V)$. They are shown in Figure 7. Despite of a small number of population II stars, the dispersion in $E(B-V)_{JII}$ is rather large.

From Figures 4 through 7 it is apparent that the Janes' (1977) DDO calibration for population I giants provides the most accurate reddening $E(B-V)$. The reddening of G and K dwarf stars can be determined from the FitzGerald intrinsic colors and MK spectral classes with less accuracy. The reason for the poor accuracy in the $E(B-V)_{SP}$ is the large error involved in the classification of a spectral type and the neglect of different stellar populations.

Therefore if we want to determine the reddenings of all the G and K stars in our sample, the [MK, $(B-V)$]-relation of FitzGerald (1970) and the calibration for population II stars by Janes (1979b) should be supplimented to the DDO calibration (Janes 1977) for population I giants. In the case that we deal with much large sample of stars with or without space motion data, it is necessary to use a chemical composition criterion in order to segregate populations of stars. For this purpose we can use Eggen's (1979) definition, $[Fe/H]<-0.60$ for population II stars.

With this criterion for population II stars we determined the reddenings of all the stars in our sample, using the DDO calibration of Janes (1977, 1979b) in combination with the [MK, $(B-V)$]-relation of FitzGerald (1970). The derived $E(B-V)$ were plotted in Figure 8, which shows the better determination of $E(B-V)$ for all the G,K stars (see compare them with the cases in Figs. 4-7).

IV. DISCUSSIONS

Figure 9 presents a histogram for all the stars of known parallax as a function of

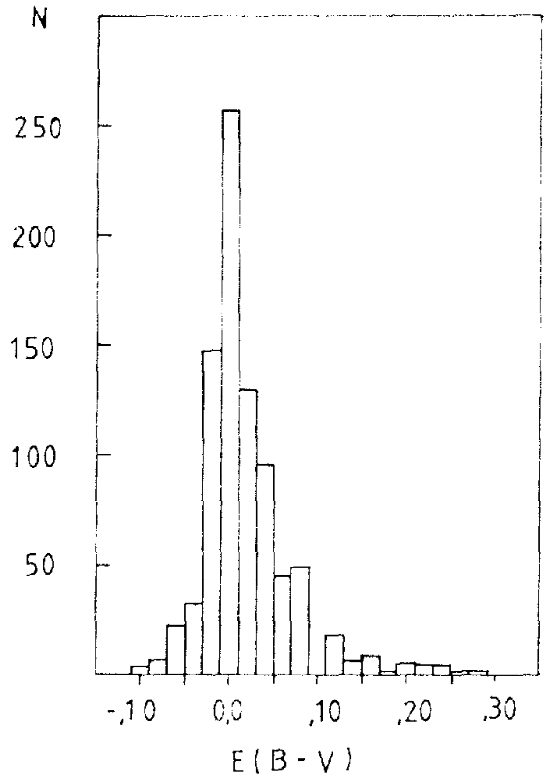

FIG. 9 Historam of $E(B-V)$ of the bright G and K stars with parallax. Most of the stars have parallaxes larger than 0.01.

$E(B-V)$. The histogram shows a peak around zero reddening. Because most of the stars in our sample are within or near 100 pc from the sun, they are unreddened stars. When we consider an admixture of some reddened stars such as supergiants and bright giants, the distribution of $E(B-V)$ similar to Figure 9 is expected. In this regard, the combined method seems to be better than the other methods for reddening determination for all G and K stars.

TABLE 1 List of Stars with Large Color Excesses.

HD	V	B-V	Sp	C(45-48)	C(42-45)	C(41-42)	P	E(B-V)	R*
13445	6.12	0.82	G1V	1.085	0.527	0.012	0.014	0.19	N
32147	6.22	1.06	K3V	1.122	1.129	0.070	0.110	0.11	S
38529	5.95	0.78	G4V	1.059	0.736	0.093	0.027	0.12	N
64572	5.43	1.16	K0III	1.252	0.906	0.358	0.035	0.13	N
108309	6.26	0.68	G3III	1.032	0.668	0.055	0.040	0.21	N
112987	4.90	1.17	G9III	1.245	0.890	0.254	0.016	0.16	D
119971	5.45	1.36	K2III	1.313	1.095	0.182	0.013	0.15	N
120933	4.74	1.66	K5III	1.403	1.351	0.135	0.026	0.15	V
127243	5.59	0.86	G3IV	1.136	0.748	0.043	0.022	0.20	N
136442	6.35	1.06	K0V	1.173	0.994	0.231	0.033	0.25	N
145897	5.22	1.42	K3III	1.332	1.140	0.271	0.029	0.13	R
167818	4.65	1.66	K5II	1.480	1.232	0.371	0.033	0.26	N
173764	4.22	1.10	G5II	1.237	0.801	0.259	0.019	0.18	V
210745	3.35	1.57	K1I	1.503	1.131	0.442	0.017	0.36	DR

* Stellar peculiarities such as binarity and variability. Notations were described in the note of Table. 2.

TABLE 2 List of Stars with Large Negative Color Excesses.

HD	V	B-V	Sp	C(45-48)	C(42-45)	C(41-42)	P	E(B-V)	R
166	6.13	0.75	K4V	1.056	0.753	0.025	0.067	-0.25	DV
20794	4.27	0.71	G8III	1.062	0.718	-0.011	0.162	-0.24	N
55865	0.91	0.60	K0III	1.189	0.859	0.165	0.016	-0.10	VS
74006	3.97	0.94	G7I	1.159	0.757	0.194	0.018	-0.16	DS
82210	4.56	0.77	G4III	1.096	0.706	0.066	0.042	-0.11	V
82885	5.41	0.77	G8III	1.054	0.772	0.070	0.109	-0.18	VS
99491	6.50	0.79	K0IV	1.063	0.790	0.087	0.054	-0.12	VS
102350	4.11	0.90	G5I	1.137	0.735	0.182	0.011	-0.10	DV
115310	5.10	0.96	K1III	1.165	1.812	0.198	0.016	-0.13	R
149661	5.75	0.82	K2V	1.080	0.845	0.036	0.093	-0.10	R
155974	6.12	0.48	G0IV	0.961	0.304	0.043	0.023	-0.15	D
173540	5.24	0.78	G5III	1.103	0.673	0.089	0.023	-0.12	R
211088	4.79	0.80	G8III	1.099	0.686	0.153	0.009	-0.15	S
217014	5.49	0.67	G2I	1.025	0.675	0.034	0.074	-0.21	V

Note N: Normal star
D: Double star
V: Variable star
S: Spectroscopic binary
R: Stars with variable radial velocity
DV: Double and variable star
DS: Double and spectroscopic binary
DR: Double star with variable radial velocity
VS: Variable and spectroscopic binary

In our reddening determination, some stars within 100 pc from the sun show too large color excesses, whereas some other stars have large negative color excesses. We present the list of these stars in Tables 1 and 2. Most of the large negative color excesses are supposed to be due to stellar duplicity and/or varbility as indicated from the last column of Table 2. The fact that more than half of the stars with large color excesses are normal stars implies that the large reddenings of these stars may be real and related to the inhomogeneous distribution of the interstellar medium in the vicinity of the sun.

Detailed examinations of the peculiarity of stars, such as duplicity, variability in luminosity, etc., shows that stellar peculiarity may affect the observed DDO indices. A high fraction of variable double stars with variable radial velocity, variable double stars of spectroscopic binary, and variable stars with variable radial velocity have DDO indices, which lie beyond calibration of Janes (1977, 1979b).

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