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FOUR-COLOR AND Hβ PHOTOMETRY OF THE GALACTIC CLUSTER M25

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ABSTRACT

Four-color and Hβ photometry has been obtained for 39 stars in the field of the galactic cluster M25. The membership of the individual stars is discussed. From 27 stars which are considered likely members we obtain a mean distance modulus of 8.76 and a mean color excess of $E(b-y) = 0.341$.

I. INTRODUCTION

Galactic clusters with Cepheid members are basic to the calibration of the luminosities of these stars. For reasons discussed in the first paper of this series (Schmidt 1980a), it is desirable to obtain new independent distance moduli for such clusters. A program is under way to do this using *uvby*, β photometry. This paper discusses the cluster M25, which contains the Cepheid U Sgr.

There have been a number of previous studies of M25. Sandage (1960), Johnson (1960), Wampler, Pesch, Hiltner, and Kraft (1961), Landolt (1964), and van den Bergh (1978) have all obtained *UBV* data for stars in this cluster. Graham (1967) obtained measurements of the Hβ index and Schmidt (1977) obtained four-color and Hβ photometry of stars in the field of the cluster. Spectral types have been published for many stars in M25 by Feast (1957), Wallerstein (1957, 1960), and Wampler *et al.* Additionally, Feast and Wallerstein both obtained radial velocities and Landolt discussed the proper motions in the cluster field in order to detect nonmembers. Serkowski (1965) measured the polarization of 82 stars in the region of M25.

In addition to U Sgr, M25 contains several other potentially interesting stars. Four stars in the cluster region, CPD $-$ 19°6921 (G3II), CPD $-$ 19°6915 (G6II), CPD $-$ 19°6883 (M2III), and CPD $-$ 19°6923 (M3III), are yellow and red giants which could be cluster members based on their locations. However, the radial velocities indicate that the two M stars are nonmembers (Wallerstein 1960). Additionally, one of the yellow giants, CPD $-$ 19°6921, is metal poor (Wallerstein and Conti 1964) and the luminosity inferred from its Hα core is wrong for cluster membership (Kraft, Preston, and Wolff 1964). Efremov (1964) has suggested that an additional Cepheid, Y Sgr, may be in the halo of the cluster. One of the B stars in the cluster, CPD $-$ 19°6881, has shown temporal emission in its hydrogen lines and has varied somewhat in brightness over a period of several years (Feast and Evans 1967).

Sandage and Tammann (1969) derived a distance modulus for M25 of 8.98 from the *UBV* data. This might be increased to about 9.25 to take into account the increased distance modulus for the Hyades (Hanson 1980). On the other hand, the four-color and Hβ photometry indicated a smaller distance, $V_0 - M_V = 8.68$ (Schmidt 1977). Van den Bergh (1978) attempted to improve this situation by observing fainter stars to better define the main sequence. Unfortunately, among the fainter stars contamination by field stars is serious and causes considerable ambiguity. The resulting distance modulus, 9.0 ± 0.3, is uncertain enough to allow either of the above values.

The previous *uvby*, β photometry was obtained through about two air masses and the quality suffered accordingly. Additionally, only eight cluster members were observed. It was therefore felt that it would be worthwhile to reobserve this cluster from the southern hemisphere where it could be done at small air mass. This paper reports the results of this new study.

II. THE OBSERVATIONS

Photometric observations of stars in M25 were obtained at Cerro Tololo Inter-American Observatory during July 1978, April 1979, and May 1981 with the 0.6-, 0.9-, and 1.5-m telescopes. The list of stars observed was taken from the study of Wampler, Pesch, Hiltner, and Kraft (1961) and all the stars on their list brighter than $V = 11$ were included with two exceptions. The two stars omitted were CPD $-$ 19°6883 and CPD $-$ 19°6915, which are much too red to be B stars and which are known to have late-type spectra. Six fainter stars were also observed. Stars with $V = 11$ in this cluster will have absolute magnitudes of about $M_V = 0.8$ and will be nearly on the zero-age main sequence (see Fig. 2 of Wampler *et al.*).

The stars which were observed are listed in Table I. The designations are from Wampler *et al.*, while the spectral types are from Wampler *et al.*, Feast (1957), and Wallerstein (1957). The *V* magnitudes are means (weighted by the number of observations) of the values from Sandage (1960), Johnson (1960), Wampler *et al.*, and the present photometry. The photometric indices and the number of nights on which they were observed

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TABLE I. Photometric data for stars in M25.

Star (1)	Spectral type: Wampler *et al.* (2)	Feast (3)	Wallerstein (4)	V (5)	$b-y$ (6)	m_1 (7)	c_1 (8)	n (9)	β (10)	n (11)	$E(b-y)$ (12)	V_0-M_V (13)	Sp (14)	Footnotes (15)
4				12.17	0.355	0.102	0.908	1	2.892	1	0.289	7.83	A	a
6	B6III	B6V	B6II–III	8.08	0.264	0.013	0.620	14	2.701	15	0.317	7.90	B	
9				11.21	0.303	0.046	0.907	2	2.852	3	0.339	8.62	B	
12		B8V		10.38	0.287	0.035	0.723	2	2.786	3	0.331	8.34	B	
13	B7IV	B8V		9.69	0.264	0.022	0.642	3	2.715	4	0.314	9.16	B	
14	B5IV	B7V	B7III–IV	8.77	0.311	0.000	0.534	3	2.617	5	0.375	11.63	B	d
15	B7III–IV	B9V		10.19	0.321	0.037	0.581	2	2.758	3	0.380	8.14	B	
17	B7.5IV–V	B8V		10.07	0.310	0.032	0.630	2	2.711	2	0.363	9.40	B	
18	B6.5III–IV	B8V		9.87	0.294	0.035	0.573	3	2.738	5	0.354	8.39	B	
32		A1V:		10.09	0.289	0.066	0.821	4	2.813	4	0.329	7.87	B	
36				11.22	0.365	0.038	0.908	3	2.843	4	0.402	8.45	B	
43		A0V		10.42	0.319	0.050	0.661	3	2.764	3	0.368	8.49	B	
45	B7.5IV	B6V		10.20	0.302	0.017	0.587	3	2.735	3	0.360	8.80	B	c:
49				11.03	0.368	0.014	0.879	2	2.795	2	0.407	8.94	B	
50				11.57	0.386	0.062	0.996	2	2.878	2	0.319	7.95	A	
54				11.49	—	—	—	—	2.878	1	—	—	—	
58		A1V	A8V	8.99	0.278	0.130:	0.729	2	2.766:	2	0.098	5.69	A	a, c, d
60		B8V		10.55	0.310	0.037	0.755	2	2.750	2	0.353	9.24	B	
62				10.67	0.354	0.036	0.606	2	2.723:	2	0.411	9.37	B	
63	B6IV	B6V	B8V	9.26	0.382	0.006	0.462	3	2.634	5	0.456	10.68	B	d
64		B8V	B8.5V	10.28	0.341	0.022	0.727	2	2.793	3	0.386	7.86	B	
67		B8V		10.52	0.323	0.034	0.791	2	2.771:	2	0.364	8.81	B	
81				11.82	0.337	0.077	1.037	3	2.906	2	0.346	8.81	A0	
84	B6III			8.96	0.257	0.042	0.481	2	2.670	2	0.325	9.48	B	
88	B5III	B8V		9.81	0.243	0.053	0.517	2	2.712	2	0.307	9.10	B	
89		A1I		9.64	0.305	0.023	1.090	3	2.693	3	0.322	11.24	B	a, b, c, d
92	B7Ven	B5V:		10.18	0.341	0.005	0.467	3	2.536:	3	—	—	B	a, c:
93		B9V		10.42	0.304	0.024	0.730	3	2.737	3	0.348	9.37	B	
99	B7.5IV–V	A0V:	B9.5V	9.22	0.285	0.029	0.592	3	2.647	4	0.342	10.87	B	c, d
100				10.61	0.236	0.050	0.894	2	2.794	2	0.272	9.30	B	
103	B8IV	B7V	B9V	10.44	0.226	0.043	0.696	3	2.768:	3	0.271	8.98	B	
106		A1V		10.72	0.257	0.076	0.944	3	2.852	3	0.290	8.55	B	
109		A9V		9.00	0.301	0.135	0.646	2	2.706	2	0.070	6.24	F	c, d
118				10.51	0.279	0.042	0.765	3	2.751	3	0.321	9.36	B	
124				9.42	0.262	0.036	0.480	3	2.704	3	0.331	8.76	B	
144	B3IV	B2V:		9.69	0.292	0.011	0.270	2	2.648	2	0.388	10.11	B	a, b, c, d
190	B7IV	B9V		10.21	0.262	0.025	0.745	2	2.754:	2	0.305	9.01	B	
6881	B5III	B6V	B7III	7.93	0.281	0.012	0.571	2	2.665	3	0.341	8.79	B	
6917	B3III + B1V	B5V	B7Vnn	8.83	0.226:	0.025	0.162	3	2.616	3	0.332	10.76	B	a, b, c:, d

[a]Unlikely member based on its location in the c_1-V diagram.
[b]Unlikely member based on its location in the c_1-β diagram.
[c]Unlikely member based on its spectral type.
[d]Unlikely member based on its color excess or distance modulus.

are listed in columns (6)–(11) of the table.

Standard four-color and Hβ filters were used for the observations. The indices were placed on the standard system by observations of equatorial secondary standards which were in turn referred to the primary four-color and Hβ standards (Crawford and Mander 1966; Crawford and Barnes 1970). A complete discussion of these secondary standards is in preparation and will be published elsewhere. In the reductions of the Hβ index, color terms were included as discussed by Schmidt and Taylor (1979). Different Hβ filters were used during the three observing seasons. There were no significant differences among the indices from the various years and we conclude that the color terms have adequately accounted for any color effects.

A further check on the standardization of the β indices can be made by comparing our results with those obtained by Graham (1967) which were on the same system. There are 16 stars in common between the two sets of data and the mean difference (Graham − present indices) is 0.002 ± 0.026 (standard deviation for a single star). Thus the scale of the indices agrees very well although there is rather large scatter.

The internal errors of the indices are as follows: $b-y$, 0.010 mag; m_1, 0.012 mag; c_1, 0.017 mag; β, 0.009 mag. These values are the standard deviations for a single observation.

In order to apply the proper calibration for each star it is necessary to estimate the spectral type. This was done using the location in the $[m_1]$-$[c_1]$ diagram (Schmidt 1980a,b, 1981) and the Hβ index. Column (14) in Table I indicates the inferred spectral type. It can be seen that these types agree well with the MK types for almost all the stars. For the stars classed as B, A, or F, the calibrations of Crawford (1975, 1978, 1979) were applied to derive the color excesses and distance moduli. Star 81 falls too near the maximum of the hydrogen line strength for these calibrations and the calibration of Claria (1974, cited by Eggen 1980) was used for it. In these calculations the ratio of total to selective absorption was assumed to be $A(V)/E(b-y) = 4.28$ as determined by Crawford and Mandwewala (1976).

III. CLUSTER MEMBERSHIP AND THE DISTANCE MODULUS

Although there have been studies of the motions of the M25 stars, it is not possible to use them in determining which stars of our sample are genuine members. The proper motions (discussed by Landolt 1964) are not accurate enough to discriminate against any but the most deviant stars. The radial velocities of the main-sequence B stars are difficult to measure owing to the small number of broad lines, and Feast (1957) was only able to use them to obtain the mean cluster velocity. Since *UBV* data were used in selecting stars for the present program, they cannot be used at this point to eliminate nonmembers. Thus, we will use the present photometric data to remove nonmembers from the sample. The relevant diagrams for this purpose are shown in Figs. 1–4. Figure 1, the c_1-V diagram, allows us to discriminate against stars which differ in distance modulus from the remainder of the stars, while the c_1-β diagram (Fig. 2) distinguishes stars which are in an evolutionary state which is inconsistent with the bulk of the cluster stars. In these two figures the majority of the stars fall along the zero-age main sequence with the brightest stars somewhat above it as expected. Stars which seem to deviate are labeled in the diagrams and are indicated by footnotes in column (15) of Table I. Figure 3, a plot of the magnitudes and colors against the spectral types, gives us similar information to that in Fig. 1, but there are several stars which stand out better as nonmembers. Finally, Fig. 4 is a plot of color excess against distance modulus. In this diagram there is a clustering of stars between $V_0 - M_V = 7.8$ and 9.4. Two stars are closer and considerably less reddened and are presumably foreground stars. There are six stars which are more distant and we will consider them to be background stars. Of these eight stars, six are apparent nonmembers on other grounds. The remaining two, stars 14 and 63, fall in the region of the evolved main-sequence stars in Figs. 1–3 and are therefore not easy to distinguish as nonmembers. However, the fact that they fall well away from the remainder of the cluster stars in Fig. 4 indicates either that they are background stars or that they are photometrically peculiar in some way. In either event, they should not be included in calculating average distance moduli.

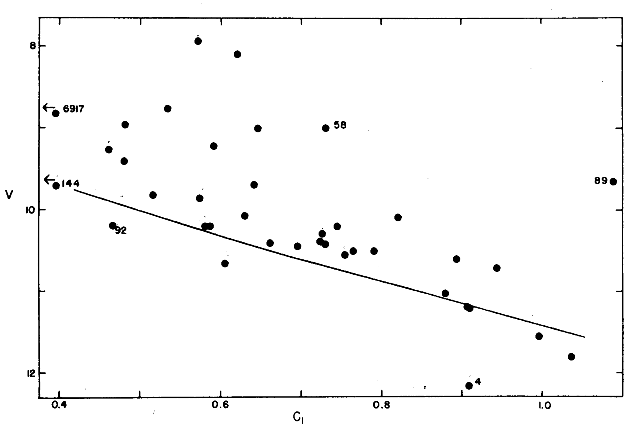

FIG. 1. The V-c_1 diagram for the stars from Table I. The solid line is the zero-age main sequence from Crawford (1978) adjusted for a color excess of $E(b-y) = 0.34$ and a true distance modulus of $V_0 - M_V = 8.7$. Stars which seem to deviate from the majority are numbered.

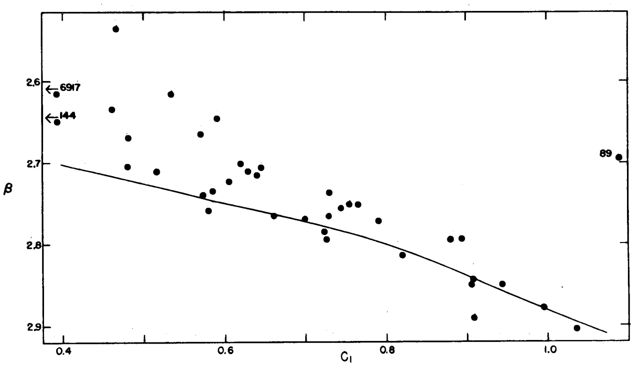

FIG. 2. The β-c_1 diagram. The zero-age main sequence adjusted for a reddening of $E(b-y) = 0.34$, which corresponds to $E(c_1) = 0.07$, is shown.

The inclusion of star CPD − 19°6881 in our discussion might be regarded as unwise because Feast and Evans (1967) have reported indications of photometric variability as well as Hβ emission. Its distance modulus in Table I seems to be in agreement with the cluster so we have retained this star. In any event, its rejection would not alter the mean distance modulus.

The use of these diagrams might cause us to reject some stars which are in fact cluster members. This can happen in the case of blue stragglers and stars which have photometric peculiarities of some sort. However, it is clear that the rejection of a few genuine cluster members will have a much smaller effect on the mean distance modulus of the cluster than the inclusion of a few nonmembers. For that reason we have chosen to reject the dubious cases such as stars 14 and 63. An accurate proper motion study of this cluster is needed to clarify the membership of several stars.

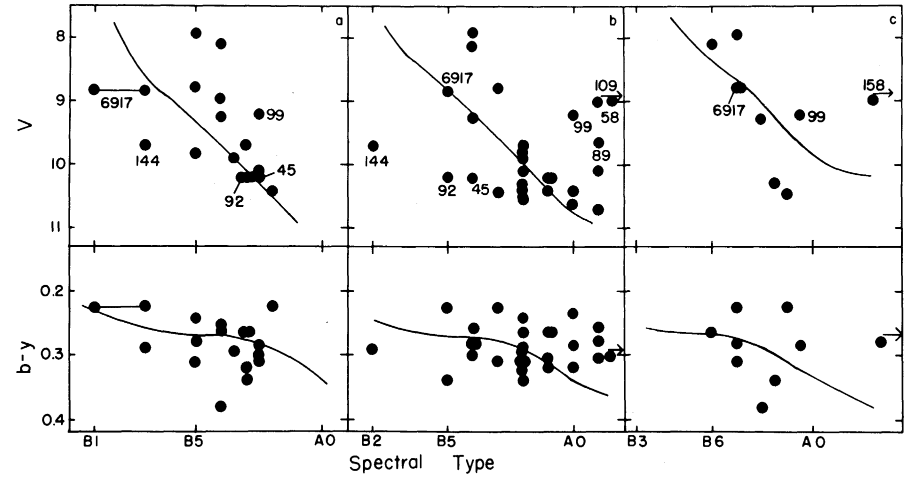

FIG. 3. Plots of the V magnitudes and colors against spectral type for stars from Table I. The zero-age main sequence is shown for a distance modulus of $V_0 - M_V = 8.7$ and a color excess of $E(b-y) = 0.34$. Panel (a) shows the spectral types from Wampler *et al.*, panel (b) shows those from Feast, and panel (c) shows those from Wallerstein.

The mean distance modulus for the 27 stars in Table I for which no reasons were found to doubt membership is 8.76 ± 0.10 (standard error of the mean). The mean color excess of these same stars is $E(b-y) = 0.341$ but varies from 0.271 to 0.411. The largest absorption tends to be in the center of the cluster near U Sgr, while the lowest absorption is towards the northeast of the cluster center.

IV. DISCUSSION

We can use the present data to estimate the color excess in the region of the Cepheid U Sgr. Stars 14, 15, 17, 18, 36, 63, and 64 are all near the Cepheid. However, 14 and 63 are likely to be background to the cluster so we will not use them. Interpolating among the five remaining stars yields a mean color excess of $E(b-y) = 0.395$ at the location of U Sgr. The five stars in question have a range in color excess of 0.05 mag and scatter around the interpolating line by ± 0.015 mag. Thus, the excess for U Sgr should be accurate to perhaps ± 0.02 mag. This value of color excess corresponds to $E(B-V) = 0.53$, which agrees well with the value of 0.55 derived by Sandage and Tammann (1969) from *UBV* data.

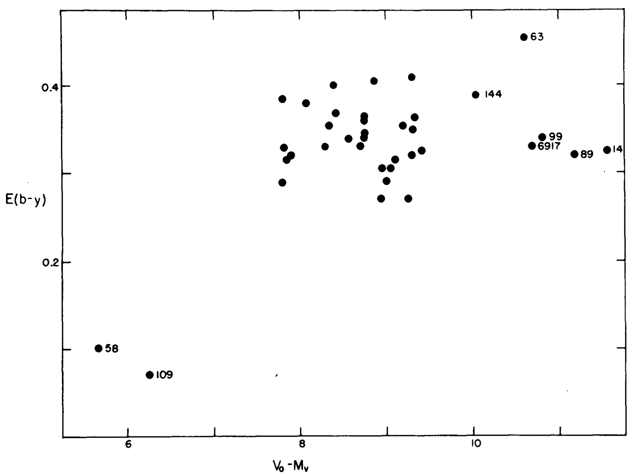

FIG. 4. The color excess plotted against the true distance modulus.

In many recent discussions of pulsation theory and the cosmic distance scale it has been usual to use the distance modulus derived by Sandage and Tammann (1969) for M25 increased by about 0.26 mag to account for the increased distance modulus now adopted for the Hyades (see Cox 1979 for references to work on pulsation theory and de Vaucouleurs 1978 for a discussion of the distance scale). The resulting modulus for M25, 9.24, is 0.48 mag larger than our adopted value. However, our value agrees with van den Bergh's (1978) recent determination, 9.0 ± 0.3, to within the errors.

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