1977

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Edward G. Schmidt
University of Nebraska at Lincoln, eschmidt1@unl.edu

PUBLICATIONS OF THE ASTRONOMICAL SOCIETY OF THE PACIFIC
89:546–549, August 1977

FOUR-COLOR AND Hβ PHOTOMETRY OF STARS IN NGC 7654 AND M25

EDWARD G. SCHMIDT
Behlen Observatory, University of Nebraska, Lincoln

Received 1977 March 10

Four-color and Hβ photometry has been obtained of stars in the galactic clusters NGC 7654 and M25. An analysis of these data shows variable extinction in both clusters. The distance modulus of NGC 7654 is found to be 10ᵐ99 ± 0.2 and that of M25 is 8ᵐ68 ± 0.1.

Key words: photometry—star clusters—cepheids

I. Introduction

There exist a number of galactic clusters which have yellow giant or cepheid members. These clusters are of interest in connection with the intrinsic colors, temperatures, absolute magnitudes, and evolutionary status of such stars. As a step toward securing a better understanding of these stars, a program of *uvbyβ* photometry in such clusters has been undertaken. Results for one cluster, NGC 6633, were previously presented (Schmidt 1976) and the present paper contains information on two further clusters. NGC 7654 (= M52) contains the F7 I*b* star BD +60°2532 which may be a nonvariable located within the cepheid strip (Schmidt 1972). M52 (= IC 4725) contains the cepheid U Sagittarii. This cluster was included, in spite of its location and the consequent complications to the photometry, due to the fact that it is the nearest and brightest of the clusters known to contain cepheids.

II. The Observations

The stars observed in these two clusters are listed in Tables I and II. The first columns of each of the tables contain the designations of the stars from various previous authors followed by information from the literature regarding the membership of the individual stars and their spectral types. The remainder of each of the tables contains the results of the present investigation.

The observations were made between June 1975 and August 1976. Except during August 1976 the methods and equipment used were identical with those described previously (Schmidt 1976). In August 1976, the photometer at Behlen Observatory was automated to allow sky chopping and rapid filter cycling. This system is described elsewhere (Taylor 1977). The quality of the observations with the automatic photometer is somewhat higher than before and it is possible to use nights of lower quality but otherwise the later observations are completely consistent with the earlier ones.

In each cluster a regional standard was chosen and all the observations were corrected using it. For NGC 7654 the adopted values for the regional standard, star 646, are simply the averages from all the nights of photometric quality. However, because M25 is located so far south, it is never seen through less than two air masses from Behlen Observatory. Thus, special care was taken to establish the standard values in this case. Two methods were used. The first was simply to use the ordinary standard stars for each night (normally observed at small air mass) together with the extinction coefficients determined from an extinction star. Data from seven nights were used. The second method was to observe standard stars near two air masses. This was done on three nights. The results for the regional standard in M25, star 6, are presented in Table III. It is clear that the results of the two methods are entirely consistent and the adopted standard values should be trustworthy.

The internal errors of the photometry were calculated from the data for stars which were observed more than once. This was done after correction with the regional standard. The standard deviations for single measurements are tabulated in Table IV. In NGC 7654 enough observations were obtained to make most of the standard errors of the indices near 0ᵐ01. In M25 the standard deviations of single observations are larger than usual for stars as bright as these. This arises from the large air mass through which this cluster is observed. For most of the stars enough observations were obtained to reduce the standard errors of the $(b-y)$ and β indices to about 0ᵐ01 but the standard errors of m_1 and c_1 are somewhat larger.

There has been some previous photometry of these clusters which can be compared with the present results. Pesch (1960) has observed stars in NGC 7654 and a comparison with the present photometry gives V(S) − V(P) = 0ᵐ017 ± 0ᵐ014 (standard deviation for a single star). In this case one star, number 735, has been omitted from the comparison because it deviates by a large amount. In the case of M25 there has been some difficulty in reconciling photometry from different ob-

TABLE I

DATA FOR NGC 7654

Star Number		Membership		Spectral								
Lundby[1]	Hoag et al[2]	Lundby[1]	Ebbighausen[3]	Type[4]	V	b-y	m_1	c_1	β	n	E_{b-y}	V_o-M_V
646	3	No		F2IV	9.06	0.214	0.181	0.875	2.768	*	0.053	7.32
735	5	Yes	Yes	B6V	10.83	0.454	-0.043	0.562	2.681	7	0.526	10.10
759	7	No	Yes	B8V	11.35	0.437	-0.070	0.527	2.683	5	0.512	10.63
769		Yes	Yes		11.09	0.368	-0.026	0.472	2.670	7	0.447	10.93
813	9	Yes	Yes	B6V	11.46	0.438	-0.050	0.483	2.690	5	0.517	10.58
820	8	Yes	Yes	B6V	11.36	0.385	-0.032	0.549	2.653	5	0.457	11.63
867	6	Yes	Yes	B8V	10.81	0.430	-0.037	0.688	2.642	5	0.489	11.25
930		Yes	Yes		11.60	0.403	-0.039	0.561	2.654	6	0.474	11.77
	4		No		10.53	0.415	-0.027	0.567	2.640	6	0.485	11.02

Footnotes:

[1] Lundby (1946) Proper motion study.

[2] Hoag et al. (1961).

[3] Ebbighausen (1942) Proper motion study.

[4] Mermilliod (1976).

*Regional standard. The tabulated values are based on 7 nights' observations. The standard errors of the mean values are V: $0^{m}.011$, b-y: $0^{m}.002$, m_1: $0^{m}.004$, c_1: $0^{m}.007$, β: $0^{m}.007$.

TABLE II

DATA FOR M 25

Star		Membership[3]	Spectral								
Wampler et al[1]	Johnson[2]		Type[4]	V	b-y	m_1	c_1	β	n	E_{b-y}	V_o-M_V
6	91	Yes	B6II-III, B6III, B9V	8.09	0.270	-0.002	0.594	2.696	*	0.335	7.81
14	97	Yes	B5IV, B7V	8.81	0.320	-0.004	0.527	2.582	6	0.392	12.26
15	98	Yes	B7III-IV, B9V	10.24	0.349	-0.016	0.651	2.764	1	0.410	8.42
36	106			11.26	0.348	0.044	0.836	2.822	1	0.390	8.78
58	111		A1V, A8V	9.01	0.253	0.165	0.692	2.741	5	0.056	6.02
63	102	Yes	B6IV, B6V, B8V	9.13	0.394	-0.025	0.484	2.665	5	0.472	9.00
64	101	Yes	B8V	10.34:	0.389	-0.011	0.591	2.833	1	0.457	7.49
99	51	Yes	B7.5IV-V, B9.5V, A0V	9.23	0.290	0.017	0.534	2.660	6	0.361	9.65
124	153			9.37	0.234	0.071	0.419	2.734	3	0.315	8.41
6881	50	Yes	B5III, B6V, B7III	7.95	0.279	0.007	0.539	2.667	6	0.349	8.26

Footnotes:

[1] Wampler et al. (1961).

[2] Johnson (1960).

[3] Feast (1957) Radial velocity study.

[4] Mermilliod (1976).

*Regional standard. The derivation of the values for this star are described in the text.

TABLE III

STANDARDIZATION OF STAR 6 IN M 25

	V	b-y	m_1	c_1	β	n
Ordinary Standards	8.104	0.275	-0.007	0.589	2.697	7
Two Air Mass Standards	8.079	0.266	0.001	0.599	2.694	3
Adopted	8.092	0.270	-0.002	0.594	2.696	

TABLE IV

STANDARD DEVIATIONS FOR SINGLE MEASUREMENTS

Magnitude Range	V	b-y	m_1	c_1	Hβ
		NGC 7654			
10-11	0.023	0.014	0.020	0.027	0.035
11-11.5	0.040	0.018	0.028	0.054	0.041
		M 25			
8-9.4	0.028	0.020	0.028	0.043	0.018

servers due to the problem of observing it from northern latitudes. In comparing the present photometry to previous work we find an average difference of $V(S) - V(WPHK) = 0.006 \pm 0.032$ (again omitting one deviant star) from the photometry of Wampler et al. (1961) and $V(S) - V(J) = 0.024 \pm 0.029$ from the photometry of Johnson (1960). The above differences are relatively small and give confidence that the V magnitudes obtained using the present filter system are reasonably well standardized. Graham (1967) has published β indices for stars in M25. There are eight stars in common with the present observations and the mean difference is $\beta(S) - \beta(G) = -0^{m}.005 \pm 0.034$. Although the scatter is rather large, the systematic agreement is good.

III. Discussion

A variety of calibrations have been made of the four-color and Hβ indices in terms of intrinsic color and absolute magnitude. In the present paper we have used the calibrations of the intrinsic colors from Crawford (1970). The absolute magnitudes were calculated using the calibrations of Crawford (1973). The separation of B stars from the later stars was accomplished in several ways. Many of the stars have spectral types and these are listed in Tables I and II. In NGC 7654 the reddest B star with a spectral type, star 735, has a $(b-y)$ color index of $0^{m}.454$. This is redder than any of the three stars without spectral types. Thus, it is likely, unless the reddening is very nonuniform, that the stars without spectral types are all B stars. Finally, Strömgren (1966) has shown that it is possible to separate B stars from later types by using the diagram of $[c_1]$ and $[m_1]$. When this test was applied, all of the stars in both clusters which are without spectral types were found to be in the B-star region of the diagram.

The last two columns of Table I give the color excesses and true distance modulii of the stars in NGC 7654. Star 646 has a distance modulus and color excess which are considerably below those of the other stars and is obviously a nonmember. The remainder appear to be members on photometric grounds and this agrees quite well with the results of the proper motion studies. The average color excess of the cluster members is $E(b-y) = 0^{m}.488$ which corresponds to $E(B-V) = 0^{m}.66$. However, there is a range of the measured color excess from $0^{m}.447$ to $0^{m}.526$. This scatter is larger than what would be expected from the photometric errors and agrees with the finding of Pesch (1960) that the reddening in NGC 7654 is nonuniform. Pesch found a larger range in $E(B-V)$ than was found here but this is apparently due to his larger sample. Individual measurements agree reasonably well. The true distance modulii have an average value of $10^{m}.99 \pm 0^{m}.20$ (standard error of the mean) and the scatter of individual stars is characterized by a standard deviation of $0^{m}.56$. The average standard error of the Hβ values given for this cluster is $0^{m}.016$. Carrying this uncertinty through the calibration gives an error of $0^{m}.45$ in the absolute magnitude which is reasonably close to the observed scatter in the distance modulus. Pesch gave a distance modulus of $11^{m}.1$ for this cluster which agrees very well with the present value.

The last two columns of Table II give the color excesses and distance modulii of the individual stars in M25. Star 58 appears to deviate from the others and is clearly a foreground star. Star 14 has a color excess which is reasonable for this cluster but has a distance modulus which is too high. Furthermore, the absolute magnitude $M_V = -5$, is clearly too bright for the spectral type given in the fourth column of the table. Since the absolute magnitude was obtained from the Hβ index, the individual measurements were examined. It was found that they are reasonably consistent and there is no indication of any problem. The present result agrees well with Graham's (1967) β measurement. Therefore, it is uncertain whether this is a background star of high luminosity as the photometry would seem to indicate or whether it is a main-sequence cluster star as the spectral type would seem to indicate. In either event, the inclusion of the distance modulus given in Table II would significantly alter the modulus of the cluster and is unjustified either because the star is not in the cluster or because the photometric luminosity is wrong. Therefore, star 14 has been omitted from the following analysis.

The color excess for M25 is very nonuniform as was previously known from *UBV* photometry. The current values range from $0^{m}\!.315$ to $0^{m}\!.472$. The situation is particularly bad in the region near the cepheid U Sgr. Stars 63 and 64 on one side of the cepheid have a mean value of $0^{m}\!.465$ while star 36, approximately the same distance away on the other side, has a color excess of $0^{m}\!.390$. Because the extinction is irregular it is not possible to determine where the color excess of U Sgr lies between these extremes.

The mean distance modulus, weighted by the number of observations of each star, was found to be 8.68 ± 0.1 (standard error). The standard error was found from the errors of individual Hβ measurements. This is considerably lower than values indicated by *UBV* photometry. Johnson (1960) gave a distance modulus of $8^{m}\!.95$ and Wampler et al. (1961) gave a value of $9^{m}\!.08$ ± $0^{m}\!.2$. The discrepancy between these values and the present result is larger than the errors would lead one to expect. Furthermore, the absolute magnitude of U Sgr determined using a distance modulus of 8.98 (Sandage and Tammann 1969) agrees to within a few hundredths of a magnitude with the calibration of the period-color-luminosity relation based on 13 cepheids in various clusters. A possible source of systematic error in the present work is the adoption of a value for the Hβ index of the regional standard, star 6. Decreasing the β index for that star by $0^{m}\!.01$ would increase the distance modulus to agree with the other values. However, as explained above, the value obtained for this star was obtained in two ways and it can be seen in Table IV that they agree well. Furthermore the various individual values which went into the averages in that table are in good agreement. We have already noted that the measurements of Graham (1967) give β indices higher by $0^{m}\!.005$ on the average than the present ones. If we corrected the present values by this amount the resulting distance modulus would become less by about $0^{m}\!.15$, aggravating the disagreement. Graham obtained a distance modulus of $8^{m}\!.84$, for M25. While this is in good agreement with the values of Wampler et al. and Johnson, it was based on a preliminary calibration of the $\beta - M_V$ relation. Application of the more recent relation used here would decrease Graham's average distance modulus to about $8^{m}\!.44$. Thus, the low distance modulus obtained here is consistent with the previous Hβ photometry and does not seem affected by serious systematic errors.

It should be noted that the current distance modulus, unlike that determined from the *UBV* photometry, is not based on the Hyades cluster. The Crawford (1973) calibration of the $\beta - M_V$ relation was tied, via the A stars in three clusters, to trigonometric parallaxes. Thus, the controversy surrounding the Hyades distance modulus does not affect the present result.

In view of the importance of U Sgr to the calibration of the period-luminosity-color relation of cepheids, the conflict between the *uvbyβ* and the *UBV* distances of M25 should be investigated further.

REFERENCES

Crawford, D. L. 1970, in *Dark Nebulae, Globules and Protostars*, B. T. Lynds, ed. (Tucson: University of Arizona Press), p. 2.
—— 1973, in *Problems of Calibration of Absolute Magnitudes and Temperatures of Stars, I.A.U. Symposium No. 54*, B. Hauk and B. E. Westerlund, eds. (Dordrecht: D. Reidel Publishing Company), p. 93.
Ebbinghausen, E. G. 1942, *A.J.* **50**, 91.
Feast, M. W. 1957, *M.N.R.A.S.* **117**, 193.
Graham, J. A. 1967, *M.N.R.A.S.* **135**, 377.
Hoag, A. A., Johnson, H. L., Iriarte, B., Mitchell, R. I., Hallam, K. L., Sharpless, S. 1961, *Pub. U.S. Naval Obs.* **17**, Part VII, 349.
Johnson, H. L. 1960, *Ap. J.* **131**, 620.
Lundby, A. 1946, *Upsala Astr. Obs. Ann.* **1**, No. 10.
Mermilliod, J.-C. 1976, *Astr. and Ap. Suppl.* **24**, 159.
Pesch, P. 1960, *Ap. J.* **132**, 689.
Sandage, A., and Tammann, G. A. 1969, *Ap. J.* **157**, 683.
Schmidt, E. G. 1972, *Ap. J.* **174**, 605.
——1976, *Pub. A.S.P.* **88**, 63.
Strömgren, B. 1966, *Ann. Rev. Astr. and Ap.* **4**, 433.
Taylor, D. J. 1977 (in preparation).
Wampler, J., Pesch, P., Hiltner, W. A., and Kraft, R. P. 1961, *Ap. J.* **133**, 895.