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Four-Color and Hβ Photometry of Stars in the Galactic Cluster NGC 6087

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FOUR-COLOR AND Hβ PHOTOMETRY OF STARS IN THE GALACTIC CLUSTER NGC 6087

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ABSTRACT

Four-color and Hβ photometry has been obtained for 16 stars in the open cluster NGC 6087. Based on this photometry the membership of these stars in the cluster is discussed. Using stars which appear to be members a color excess of $E(b-y) = 0^m.123$ and a distance modulus of $(V_0 - M_v) = 9^m.60$ are derived. This distance modulus is about $0^m.4$ less than previous values and indicates a lower luminosity for the Cepheid member, S Nor, than is currently accepted.

I. INTRODUCTION

There are a number of galactic clusters which have Cepheid members. These clusters are of interest in connection with the intrinsic colors, temperatures, absolute magnitudes, evolutionary status, and pulsational properties of such stars. The distance moduli have been determined by main sequence fitting with UBV data. However, this method suffers from contamination by nonmembers in crowded fields (see, for example, van den Bergh 1978), the possibility that clusters with different metal abundances than the Hyades will have different main sequences (van den Bergh 1977), and difficulties with evolutionary effects among the brightest and therefore most easily observed stars. Because of these problems it was felt that it would be useful to obtain new distance moduli based on four-color and Hβ photometry. Using this system it is possible to discriminate against nonmembers and since B stars are used we need not be concerned about metal abundance. Evolutionary effects are small on the luminosity index, β, and calibrations exist which can account for it. This paper presents data for the cluster NGC 6087 which contains the Cepheid S Nor (period = $9^d.75$).

II. THE OBSERVATIONS

Table I lists the stars we have observed in NGC 6087. The star numbers are from Fernie (1961) and the spectral types were taken from Feast (1957). The V magnitudes are the means of values given by Fernie and by Breger (1966). The four-color and Hβ indices were obtained at Cerro-Tololo Inter-American Observatory during July 1978 and April 1979. The seventh and ninth columns give the number of nights on which the four-color indices and Hβ were measured, respectively. It can be seen that the β index was measured at least three times for each star. From the scatter in the individual measurements the following standard deviations for a single observation were obtained: $0^m.007$ for $(b-y)$; $0^m.009$ for m_1; $0^m.013$ for c_1; $0^m.011$ for β.

It has been pointed out by Muzzio (1978) and Schmidt and Taylor (1979) that a color term should be included in the reduction of Hβ photometry of reddened stars. In the present case, the reddening is relatively small; we have, nevertheless, included the color terms which were determined from the filter response curves as discussed by Schmidt and Taylor. Since the filters used in 1978 were different from those used in 1979, a

TABLE I. Photometric data for NGC 6087.

Star	Spectral type	V	$b-y$	m_1	c_1	n	β	n	$E(b-y)$	$V_0 - M_v$
1	B6V	8.33	0.068	0.066	0.503	6	2.666	8	0.130	9.97
7	B9III	8.28	0.096	0.049	0.828	3	2.671	4	0.135	10.59
8		8.99	0.068	0.066	0.535	3	2.696	4	0.127	9.64
9	B9V	9.43	0.068	0.088	0.668	3	2.732	3	0.113	9.45
10	A0V	7.93	0.100	0.043	0.581	3	2.606	4	0.153	12.54
11	B5V	9.40	0.077	0.072	0.551	3	2.706	4	0.134	9.75
13	B5V	9.30	0.067	0.071	0.513	3	2.713	4	0.128	9.38
14	B8Ve	9.67	0.088	0.084	0.666	3	2.733	4	0.133	9.56
15	B8III-V	10.16	0.065	0.084	0.524	2	2.728	3	0.125	9.87
17	B8V	8.78	0.074	0.073	0.807	2	2.751	3	0.113	8.77
18		9.90	0.076	0.091	0.668	2	2.761	3	0.121	9.21
19	B8V	9.88	0.053	0.096	0.621	2	2.755	3	0.100	9.30
20		8.46	0.059	0.071	0.604	2	2.684	3	0.108	9.77
22		9.69	0.063	0.079	0.380	2	2.612	3	0.139	13.55
23		9.82	0.064	0.074	0.601	2	2.714	3	0.114	10.15
25		9.87[a]	0.082	0.102	0.649	2	2.751	3	0.128	9.31

[a] Breger gives $V = 10.05$ while Fernie gives 9.69.

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comparison of the observations for the two years provides an indication of the reliability of this procedure. For stars measured during both years, the mean difference in β is $0^m.004 \pm 0^m.004$ in the sense that the 1978 values are smaller. The smallness of the difference gives us confidence that our handling of the color terms has been adequate. The values in the table are simple averages of all the measurements.

From their locations in the $[m_1] - [c_1]$ diagram it was determined that all the stars in Table I are B stars and therefore early enough in spectral type for the application of the B star calibration derived by Crawford (1978). The color excesses and distance moduli obtained from this calibration are listed in the last two columns of the table.

Since no comprehensive membership studies have been done for this cluster, it is necessary to examine the present photometry to remove nonmembers. We can reject stars 10 and 22 on the basis of their large distance moduli; they are obviously background stars. In Figure 1 we have plotted diagrams of V_0 vs c_1 and β vs c_1. In these diagrams we can see that stars 7 and 17 fall above and to the right of the distribution of most of the rest of the stars. This suggests that they are more evolved than would be consistent with the other cluster stars and we conclude they are not members. Star 20 also deviates significantly from the rest of the distribution and may also be a nonmember. Omitting these stars we obtain a mean true distance modulus of $9^m.60 \pm 0^m.30$ (standard deviation for one star) and a color excess of $E(b-y) = 0^m.123 \pm 0^m.010$ for the remaining eleven stars. It should be noted that only the rejection of stars 10 and 22 has affected the mean distance modulus. If we included all the stars except these two, the mean modulus would be $9^m.62 \pm 0^m.45$ and the color excess would be $E(b-y) = 0^m.122 \pm 0^m.011$.

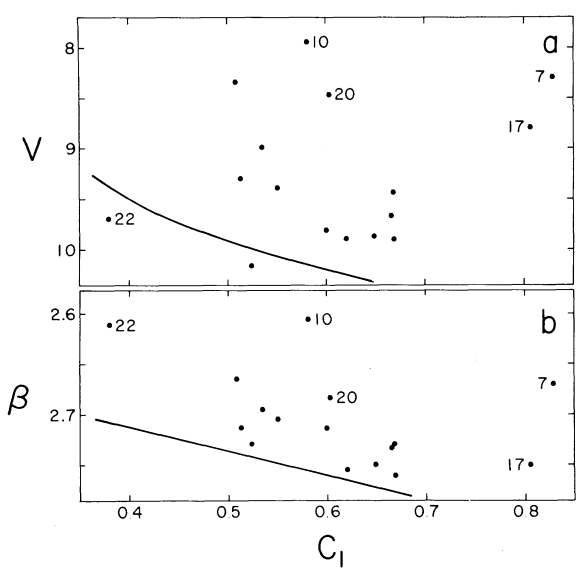

FIG. 1. a) Visual magnitudes plotted against the c_1 index. Deviant stars discussed in the text are identified by number. The solid curve is the zero age main sequence for a true distance modulus of $9^m.60$. b) The diagram of the β index against the c_1 index. For B stars this diagram is similar to the HR diagram. The zero age main sequence is also shown.

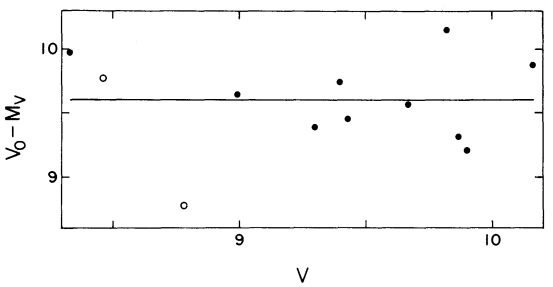

FIG. 2. The true distance moduli of individual stars plotted against the apparent magnitudes. The solid line indicates the adopted mean distance modulus for NGC 6087. Open circles indicate stars which are considered nonmembers, while the filled circles are members.

In Figure 2 the true distance moduli are plotted against the apparent magnitudes. It can be seen that there is no significant dependence. This indicates that the effects of evolution on the Hβ index have been properly allowed for in the absolute magnitude calibration.

If we carry the errors given above for the photometry through the calibrations we find a standard deviation for a single star (observed an average of 3.6 times) of $0^m.15$. Combining this with an assumed intrinsic scatter of $0^m.20$ (Crawford 1978) we obtain a total error of $0^m.30$. This agrees with the internal errors found above when five stars were rejected. Therefore, we adopt as our true distance modulus a value of 9.60 ± 0.09 (standard error of the mean).

III. DISCUSSION

Previous determinations of the reddening of NGC 6087 have ranged from $E(B-V) = 0^m.18$ to 0.23 (Breger 1970; Sandage and Tammann 1969). This corresponds to $E(b-y)$ from $0^m.13$ to 0.17 which is only slightly higher than our value of 0.123.

Sandage and Tammann (1969) obtained a distance modulus for NGC 6087 of $(V_0 - M_V) = 9^m.76$ from previous UBV photometry. This should be increased to account for revisions in the Hyades distance since the main sequence fitting was based on a Hyades distance modulus of $3^m.03$. Recent convergent point studies (Hansen 1975; McAlister 1977) give values ranging from $3^m.18$ to $3^m.42$, trigonometric parallaxes (Klemola *et al.* 1976) give $3^m.33$ and interior theory (Anthony-Twarog and Demarque 1977) yields $3^m.34$. Thus a correction of about $0^m.26$ seems reasonable and raises the modulus of NGC 6087 to 10.02.

The present value for the distance modulus, $9^m.60$, is $0^m.4$ less than the earlier value (which has been used widely in discussions of pulsation masses, e.g., Cox 1979). We note that this discrepancy is similar to that

found for M 25 which also contains a Cepheid (Schmidt 1977). In both cases this will give rise to a discrepancy between the pulsational mass and the evolutionary mass. On the other hand, the implied decrease in the luminosities of the Cepheids will bring the zero point of the period-luminosity relation obtained from the cluster Cepheids into better agreement with those obtained by other means (de Vaucouleurs 1978). We will discuss these questions in detail in a later paper after the cluster photometry is complete.

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