STUDY OF THE GALACTIC CLUSTER NGC 6823

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Abstract. Photoelectric *UBV* magnitudes have been determined for 41 stars in NGC 6823. The reddening across the cluster field is determined and found that it varies from $E(B-V)=0.60$ to 1.16 mag. The true distance modulus to the cluster is estimated at 12.7 ± 0.3 mag. It is found that cluster stars are not co-equal in age.

1. Introduction

The young open cluster NGC 6823 ($\alpha_{1950} = 19^h41^m.0$, $\delta_{1950} = +23°1'$; $l^{II} = 59°.41$, $b^{II} = -0°.15$) is part of the OB association I Vulpecula (Morgan *et al.*, 1953). Erickson (1971) has determined the relative proper motions in the cluster field with a mean error of ± 0.0008 seconds of arc per year and has computed the probabilities of cluster membership, p, for 92 stars brighter than $V = 13^m.0$. The distribution of these stars according to p is shown in Table I, which indicates that most of the stars have either a high or a near zero probability of cluster membership (e.g., of the 92 stars, 37 have $p > 70\%$ and 47 have $p = 0\%$). Following the discussion by Sanders (1976) on the cluster membership, we have included all the 41 stars, having $p \geqslant 48\%$ in our observing program in which the possibility of finding cluster members is more.

Barkhatova (1957) had determined the photographic and photovisual magnitudes for the cluster stars. *UBV* photometry of the cluster has been attempted earlier by Hoag *et al.* (1961), Bigay and Lunel (1966), and Moffat (1972). According to Moffat (1972) the photoelectric values determined by Bigay and Lunel (1966) for this cluster, show a systematic magnitude dependent deviation from those of Hoag *et al.* (1961). *UBV* photoelectric magnitudes are available for only eight program stars (Hoag *et al.*, 1961; Bigay and Lunel, 1966), *UBV* photographic magnitudes are available for another 21 program stars (Hoag *et al.*, 1961; Moffat, 1972), photographic and photovisual magnitudes are available for another seven program stars (Barkhatova, 1957) and for the remaining five program stars approximate *UBV* magnitudes, based on image diameter measurements, are available within a mean error of ± 0.20, ± 0.23 and ± 0.39 mag. for V, $(B-V)$ and $(U-B)$ respectively (Erickson, 1971). Recently, spectroscopic observations have been obtained for the cluster covering 17 of our program stars by Turner (1979).

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TABLE I

Distribution of stars in NGC 6823 according to membership probability, p, determined by Erickson (1971) on the basis of relative proper motions

Serial number	p (%)	Number of stars present in the interval
1	0	47
2	1–10	3
3	11–20	1
4	21–30	0
5	31–40	0
6	41–50	1
7	51–60	2
8	61–70	1
9	71–80	4
10	81–90	4
11	91–99	29
Total number of stars		92

Due to the lack of photoelectric photometry of the cluster members, the present *UBV* photometry is aimed at determining the same for the program stars and investigating the cluster parameters on the basis of these observations.

2. Observations and Reductions

The observations were carried out between September–November 1978 on the 104-cm Sampurnanand reflector of the Uttar Pradesh State Observatory. The instrumentation and the method of observations are the same as described earlier by us (Sagar and Joshi, 1979). For standardising the instrumental magnitudes and colours, we have used the photoelectric sequences given by Hoag *et al.* (1961). The stars used for this purpose are marked in Table II. Star numbers 8 and 64, the variations whereof are within the errors of the observations ($\pm 0^m_.019$ for V; $\pm 0^m_.023$ for $(B-V)$ and $\pm 0^m_.026$ for $(U-B)$), were used for the determination of atmospheric coefficients on various nights of observing and the necessary corrections for nightly extinction were applied. A minimum of two sets of observations, on different nights, were taken for each star and the average *UBV* values are listed in Table II.

3. Reddening

The $(U-B)$, $(B-V)$ diagram of NGC 6823 is plotted in Figure 1, in which we have fitted the intrinsic zero-age Main Sequence (ZAMS), after adopting the slope of reddening line to be 0.72, by Schmidt–Kaler (1965) to the MS stars of the cluster. We find that the colour excess $E(B-V)$ for MS stars varies from

$0^m.60$ to $1^m.16$ (i.e. $\Delta E(B-V) = 0^m.56$). According to Burki (1975), if the Main Sequence cluster stars have $\Delta E(B-V)$ greater than $0^m.11$, the same is indicative of the presence of non-uniform extinction across the cluster. Therefore, we infer that reddening is extremely variable across the cluster. Presence of differential reddening has also been noticed by earlier investigators (cf. Alter *et al.*, 1970; Erickson, 1971; Moffat, 1972; Turner, 1979). In order to ascertain the behaviour of the variation of the reddening, we have divided the cluster field into areas of 2×2 square minutes of arc as indicated in Table III and have determined the reddening across each box as was done by us previously for other clusters (cf. Sagar and Joshi, 1978, 1979). The reddening has been determined using the

TABLE II

Photoelectric *UBV* values of stars in NGC 6823. Stars with asterisked number belong to the photoelectric sequence by Hoag *et al.* (1961). The adopted value of reddening, $E(B-V)$, is also given. Star number and the corresponding membership probability, p, are taken from Erickson (1971).

Star number	V	$(B-V)$	$(U-B)$	$E(B-V)$	p (%)	Remarks
1	$13^m.13$	$0^m.46$	$0^m.07$	$0^m.54$	73	
4	10.28	0.82	−0.27	1.12	91	
5	12.67	0.72	−0.25	0.98	97	
8	9.48	0.78	−0.45	1.13	98	
9	12.48	0.50	0.08	0.59	95	
13	12.27	0.65	0.03	0.79	67	
18	11.99	0.75	−0.20	1.00	98	
24	11.85	0.70	−0.42	1.02	94	
30	12.61	0.70	−0.19	0.93	85	
32	12.25	0.61	0.24	0.67	97	
36	12.50	1.70	1.38	0.93	97	1, 3
46	8.90	0.86	−0.18	1.14	88	1
50	12.94	0.59	−0.27	0.82	96	
54*	11.63	0.55	−0.47	0.84	97	
57	12.10	0.53	−0.44	0.81	97	
59	12.14	0.54	−0.36	0.79	93	
63*	13.35	1.46	1.26			
68*	9.79	0.44	−0.60	0.75	95	
69	12.04	0.51	−0.16	0.68	97	
72 + 73	10.33	0.53	−0.52	0.84	97, 77	2
74	11.31	0.58	−0.46	0.88	95	
77	10.53	0.81	−0.17	1.07	97	1
78	10.45	1.97	1.98	1.07	93	3
80	12.38	0.66	−0.30	0.92	96	
81	11.07	0.57	−0.59	0.91	98	
83*	9.39	0.56	−0.59	0.90	97	
84*	11.60	0.76	−0.32	1.06	97	
86*	11.89	0.74	−0.39	1.06	96	
88	11.83	0.73	−0.33	1.02	97	
89	12.61	0.65	−0.03	0.81	82	

Table II (continued)

Star number	V	$(B-V)$	$(U-B)$	$E(B-V)$	p (%)	Remarks
92	12.65	0.75	0.05	0.91	51	
93	12.72	0.80	−0.26	1.09	93	
96	11.98	0.48	−0.04	0.60	55	
101	12.99	0.58	0.18	0.65	48	
103	12.95	1.38	0.83	1.06	95	3
104	11.74	0.87	−0.22	1.16	98	
110	9.25	1.19	0.65	1.16	79	3
113	12.92	0.68	0.34	0.72	75	
115	10.79	0.39	−0.56	0.67	97	
119	10.99	0.46	−0.50	0.74	95	
143	12.67	0.54	0.15	0.61	82	

Explanation for numbers under 'Remarks' column:

1. Magnitudes determined on different nights show a large difference, as compared to the photometric errors, which suggest that these stars may be variables.
2. Combined magnitudes of star number 72, 73 and another star (having brightness approximately equal to star number 73) are reported here, as they could not be separated by the smallest diaphragm used by us during the observations.
3. For these stars, we have adopted the $E(B-V)$ value of the nearest star (vide: Section 3).

Q-method of Johnson and Morgan with the help of O, B stars. The average value of $E(B-V)$ found in an area is indicated in the appropriate box in Table III, along with the number of stars used for this purpose.

From Table III, it is clear that reddening is variable across the cluster field. The variation of the reddening is not systematic but, in general, a relatively large value of $E(B-V)$ is found at the centre and along the diagonal, joining the north-west corner to the south-east corner of the cluster. For the remaining cluster region it is relatively small.

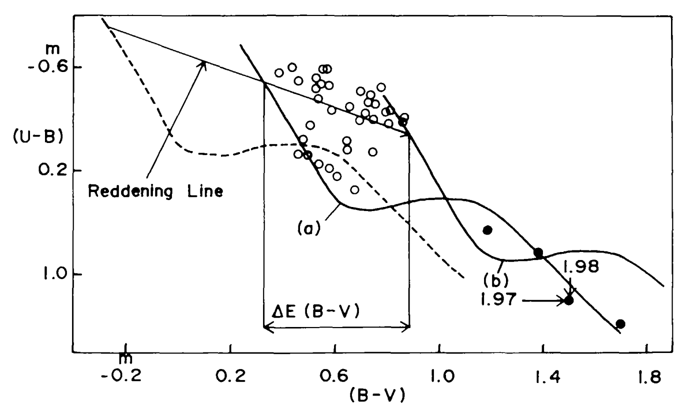

Fig. 1. The $(U-B)$, $(B-V)$ diagram of NGC 6823. The dotted curve is the intrinsic ZAMS taken from Schmidt-Kaler (1965) while the continuous curves correspond to fitted ZAMS for (a) the minimum and (b) the maximum values of the reddening, in MS cluster stars. Open circles denote MS stars while filled ones are non MS stars.

TABLE III

Variation of reddening across the cluster NGC 6823. The average value of $E(B-V)$ in mag, in areas 2×2 sq. arc. min is indicated in the appropriate boxes, with the number of stars used for this purpose given in brackets. Coordinates are relative to star number 86 in arc min.

$\Delta\alpha$ \ $\Delta\delta$	−14.0 to −12.0	−12.0 to −10.0	−10.0 to −8.0	−8.0 to −6.0	−6.0 to −4.0	−4.0 to −2.0	−2.0 to 0.0	0.0 to 2.0	2.0 to 4.0	4.0 to 6.0	6.0 to 8.0	8.0 to 10.0	10.0 to 12.0	12.0 to 14.0
−18.0 to −16.0				0.54 (1)										
−16.0 to −14.0						0.59 (1)		1.12 (1)			1.13 (1)		0.98 (1)	
−14.0 to −12.0									0.79 (1)					
−12.0 to −10.0								1.02 (1)		1.00 (1)				
−10.0 to −8.0		0.67 (1)					0.93 (1)							
−8.0 to −6.0	0.79 (1)													
−6.0 to −4.0							0.82 (1)					1.14 (1)		
−4.0 to −2.0							0.80 (2)	0.84 (1)						
−2.0 to 0.0						0.83 (3)	0.89 (5)				1.07 (1)			
0.0 to 2.0					0.81 (1)	1.02 (1)		1.08 (2)	0.76 (2)					
2.0 to 4.0				1.16 (1)					0.71 (1)					
4.0 to 6.0								0.74 (1)	0.67 (1)	0.72 (1)				
6.0 to 8.0				0.57 (1)										
8.0 to 10.0														
10.0 to 12.0		0.61 (1)												

In view of the above discussions, individual stars have been suitably dereddened in the discussion to follow, by applying corrections based on Table III. Only for four stars (vide: Table II) for which the $E(B-V)$ value is not available from Table III, we have adopted the $E(B-V)$ value of the nearest star. The $E(B-V)$ value thus obtained for individual stars is listed in Table II.

4. Distance

In order to construct the V_0, $(U-B)_0$ colour-magnitude-diagram (CMD) for NGC 6823 (Figure 2), we have determined the intrinsic $(U-B)$ colours and V magnitudes of the stars, using their individual values of $E(B-V)$, listed in Table II, in the same way as described elsewhere (Sagar and Joshi, 1979). For young clusters $(U-B)_0$ CMD is more reliable than $(B-V)_0$ CMD for the determination of the distance modulus (cf. Sagar and Joshi, 1979). We have, therefore, determined the distance modulus by fitting the standard ZAMS given by Schmidt-Kaler (1965) to the cluster Main Sequence present in the $(U-B)_0$ CMD (Figure 2). The value of the distance modulus, thus obtained, is $12^{m}.7 \pm 0.3$ implying that the distance to the cluster is 3.5 ± 0.5 kpc. For the same cluster, the estimate of distance modulus comes out to be $12^{m}.9 \pm 0.6$ by Walker and Hodge (1968); $10^{m}.2$ to $12^{m}.0$ by Erickson (1971) and $12^{m}.3$ by Moffat (1972).

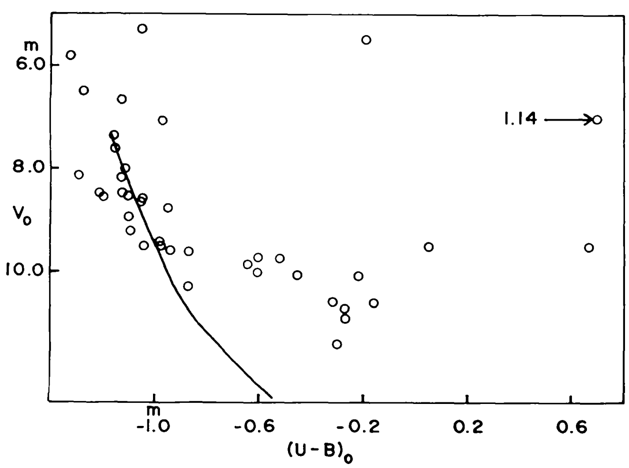

Fig. 2. The V_0, $(U-B)_0$ diagram of NGC 6823. The solid curve represents the ZAMS fitted to the cluster MS stars.

5. H-R Diagram

After correction for variable reddening across the cluster, as described in Section 3 has been applied the H-R diagram of NGC 6823 is plotted in Figure 3 for a true distance modulus of $12^{m}.7$. From the H-R diagram the following inferences can be drawn:

(1) Stars having $(B-V)_0$ colour redder than $-0^{m}.2$ and fainter than $M_v = -3^{m}.1$,

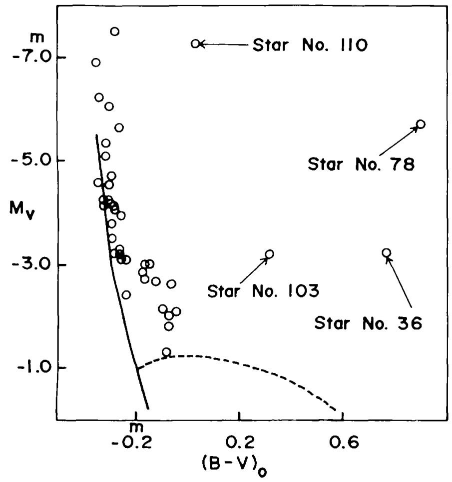

Fig. 3. H-R diagram of NGC 6823. The solid curve is the ZAMS. Peculiar stars from the standpoint of stellar evolution are marked. Dotted curve represents the theoretical gravitational isochrones for 0.3 million years.

have perhaps not yet reached the ZAMS and are still under gravitational contraction. Eleven program stars belong to this category.

(2) A well-defined Main-Sequence cluster, extending from $M_v = -7\overset{m}{.}5$ to $-2\overset{m}{.}4$, is clearly visible and no giant branch appears. Twenty-five program stars belong to this category.

(3) Star number 46, the brightest member of the cluster, with $M_v = -7\overset{m}{.}5$, $(B-V)_0 = -0\overset{m}{.}28$ and $(U-B)_0 = -1\overset{m}{.}05$, is a Main Sequence star of spectral type B2 (Walker and Hodge, 1968).

(4) From the standpoint of stellar evolution, star numbers 36, 78, 103 and 110 (vide: Figure 3) occupy anomalous positions in the H-R diagram of NGC 6823. Such peculiar stars have been identified in a few other open clusters (cf. McNamara and Sanders, 1976; Sagar and Joshi, 1978, 1979). The above said stars have their membership probabilities more than 50%. Since our program stars have a median probability of 95%, we can, therefore, statistically expect to find two field stars in our sample. Even then, the anomalous position of the remaining two stars in our sample could not be explained. The peculiar position of star number 110 has also been noted by Turner (1979) in his spectroscopic investigation.

6. Age

The age determined by fitting the sets of isochrones in the cluster H-R diagram is considerably more accurate in comparison with other methods of age determination (cf. Palouš *et al.*, 1977). We have, therefore, determined the cluster age using its H-R diagram and the theoretical evolutionary tracks. We obtain an age estimate of 5×10^6 yr for bright Main Sequence stars, using the isochrones given by Barbaro *et al.* (1969). In this case we have assumed that these stars are evolving off the ZAMS just after the hydrogen burning process in the core and, consequently, the estimated age is an upper limit. From the fit of the theoretical gravitational isochrones (cf. Sagar, 1979) to the H-R diagram of the cluster (Figure 3) it is found that the pre-Main Sequence stars are younger than 3×10^5 yr. Thus, there is a large difference in the age of the bright and faint stars of the cluster. This can not be accounted for either in terms of errors present in their age estimation or in terms of physical processes responsible for producing the scatter in the cluster H-R diagram (cf. Sagar, 1979). On these grounds, we can say that all stars of the cluster do not have the same age.

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References

Alter, G., Ruprecht, T., and Vanýsek, V.: 1970, *Catalogue of Star Clusters and Associations*, 2nd edn, Akademiai, Kiado, Budapest.

Barbaro, G., Dallaporta, N., and Fabris, G.: 1969, *Astrophys. Space Sci.* **3**, 123.

Barkhatova, K. A.: 1957, *Soviet Astron.* **1**, 822, Transl. from the Russian (*Astron. Zh.* **34**, 848).

Bigay, J. H. and Lunel, M.: 1966, *J. Des. Obs.* **49**, 411.

Burki, G.: 1975, *Astron. Astrophys.* **43**, 37.

Erickson, R. R.: 1971, *Astron. Astrophys.* **10**, 270.

Hoag, A. A., Johnson, H. L., Iriarte, B., Mitchell, R. I., Hallam, K. L., and Sharpless, S.: 1961, *Publ. U.S. Naval Obs.* (2nd Series), **17**, part 7.

McNamara, B. J. and Sanders, W. L.: 1976, *Astron. Astrophys.* **52**, 53.

Moffat, A. F. J.: 1972, *Astron. Astrophys. Suppl.* **7**, 355.

Morgan, W. W., Whitford, A. E., and Code, A. D.: 1953, *Astrophys. J.* **118**, 318.

Palouš, J., Ruprecht, J., Dluzhnevskaya, O. B., and Piskunov, J.: 1977, *Astron. Astrophys.* **61**, 27.

Sagar, R.: 1979, 'Studies in Star Clusters', PhD Thesis, University of Gorakhpur, p. 118.

Sagar, R. and Joshi, U. C.: 1978, *Monthly Notices Roy. Astron. Soc.* **184**, 467.

Sagar, R. and Joshi, U. C.: 1979, *Astrophys. Space Sci.* **66**, 3.

Sanders, W. L.: 1976, *Astron. Astrophys.* **46**, 131.

Schmidt-Kaler, Th.: 1965, in H. H. Voigt (ed), *Landolt-Bornstein, Numerical data and Functional Relationship*, Science and Technology, Group VI, Vol. I, p. 284.

Turner, D. G.: 1979, *J. Roy. Astron. Soc. Canada* **73**, 74.

Walker, G. A. H. and Hodge, S. M.: 1968, *Publ. Astron. Soc. Pacific* **80**, 290.