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New probable members of a galactic cluster in the direction of the Large Magellanic Cloud

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Abstract. A *BV* photographic photometric analysis has established magnitudes and colours for an additional 20 stars in the vicinity of Anon. Bok group. Of these, five are new probable members of the group. An age of 500 Myr is derived for this group through the theoretical evolutionary isochrone comparison.

Key words : *BV* photometry—galactic cluster

1. Introduction

The loose stellar grouping Anon. Bok ($\alpha_{1950} = 5^h18^m.0$, $\delta = -68°.5$) seen projected on the Large Magellanic Cloud was first investigated by Bok & Bok (1960) and later by Sanduleak & Philip (1968). An analysis by Murray *et al.* (1969) showed that 19 out of 23 stars studied by Sanduleak & Philip shared a common proper motion. Jones (1969) obtained a mean radial velocity of $+3 \pm 2$ km s^{-1} for six of the stars. Philip (1973) derived the effective temperatures and gravities for all the members through intermediate-band photometry and concluded that this loose stellar grouping resembled the Hyades. The true distance-modulus obtained in these investigations ranged from $8^m.0$ to $8^m.4$. The mean colour excess for this group is stated to be $E(B - V) = +0.06$ and $+0.07$.

The main objectives of the present investigation are to identify more cluster members using the photoelectric sequence given by Sanduleak & Philip, to re-estimate the distance modulus by using all cluster members and the age of this group through photographic photometry.

2. Observations and reduction

The photographic observations were obtained with the 60 cm reflector of the University of Toronto at Las Campanas, Chile, during 1977 October. The plate-filter combinations were selected to match the standard *UBV* system:

$$\text{IIa D} + \text{RG495} = V \qquad \text{IIa O} + \text{GG385} = B$$

Exposure times range from 30 to 45 min depending upon the plate-filter combination. Chemical processing of each plate followed standard procedure. All plates were measured with the Astro-Mechanics iris-astrophotometer at Saint Mary's University. Altogether 3V and 4B plates were measured and magnitudes were established for approximately 50 stars in the region of the cluster using as standards 12 stars observed photoelectrically by Sanduleak & Philip. In order to check the transformations, the magnitude residuals (in the sense of Sanduleak & Philip *minus* Kilambi) for V and B bandpasses were plotted against standard photoelectric V magnitude and $(B-V)$ index for all stars for which accurate photometry is available. No significant magnitude or colour dependences were found and from internal scatter the standard deviation for each measurement was $\pm 0^{m}.03$ for all nonvariable stars. The quoted standard deviation is also applicable for all other nonvariable program stars derived from the internal scatter from plate to plate. There are at least 6 stars whose magnitude and colour indices derived in this analysis differ from previously published photometry beyond the above quoted standard deviation value. These stars are considered as suspected variables and are pointed out in the reference column of table 1. Table 1 gives the V, $B-V$ values for all stars and the first

Table 1. BV observations of Anon. Bok group

Star No.	V	$B-V$	Sp. Type	$E(B-V)$	M_v	Remarks
1	+8.86	+0.26	A3	0.18	+0.32	1
2	11.48	0.40	F2	0.05	+3.33	1
3	10.00	0.38	A5	0.23	+1.31	1,3,4
4	9.15	0.20	A3	0.12	+0.79	1
5	10.55	0.55	F2	0.20	+1.95	1
6	9.68	0.27	A3	0.19	+1.11	1,3
7	9.13	0.13	A3	0.05	+0.98	1
8	12.59	0.56				2
9	10.90	0.35	F0	0.03	+2.81	1
10	10.50	0.21	A7	0.01	+2.47	1
11	9.25	0.21	A0	0.22	+0.59	1,4
12	10.42	0.15	A5	0.00	+2.42	1,3
13	11.38	0.43	F8	−0.10	+3.31	1
14	10.28	0.13	A3	0.05	+2.13	1,3,4
15	11.60	0.50	F5:	0.05	+3.45	1,4
16	11.62	0.38	F2	0.03	+3.53	1
17	10.38	0.24	A5	0.09	+2.11	1,3
18	12.55	0.67				2
19	12.27	0.53	F8:	0.00	+4.27	1,3,4
20	9.78	0.36	A2	0.31	+0.85	1,3
21	12.75	0.53	F7	0.03	+4.66	1
22	11.20	0.50		0.07	+2.99	1,3
23	11.80	0.59		0.07		2,3
*25	11.85	1.30				2
*28	12.60	0.53		0.07	+4.39	1
29	12.23	0.83				2
30	10.44	0.88				2
31	12.11	0.41				2
*33	10.80	1.47				2,3
*37	12.47	0.80				2
*44	12.50	0.82				2
45	12.66	0.09				2
46	11.86	1.44				2
*48	12.03	0.63		0.07	+3.82	1
49	12.61	0.66		0.07	+4.40	1
*51	12.19	0.88				2,3
*56	12.64	+0.51		0.07	+4.43	1
*59	12.48	−0.18				2
*62	12.69	+0.41				2
*67	+11.45	+1.38				2

Remarks: 1. Member. 2. Non-member.
3. Suspected variable. 4. Porbable Am Star from 4-colour photometry.

*The star nos. which do not appear in the series are too faint for the photoelectric calibration.

column gives an identifying number, starting at 24 in the present investigation. The identification chart for all program stars is shown in figure 1.

3. Interstellar reddening and membership

The interstellar reddening for cluster members has been derived from the spectral types given by Sanduleak & Philip. The spectral type and intrinsic colour relation given by Fitzgerald (1970) was used. The derived reddening values given in column 5 of table 1 indicate that the reddening is not uniform over the cluster area. Preliminary proper motion analysis by Murray *et al.* (1969) showed that at least 19 out of 23 stars studied by Sanduleak & Philip share a common proper motion of ± 0.002 yr^{-1} to within a standard error. The computed mean reddening for these 19 members from the present analysis is $E(B-V) = 0.10 \pm 0.09$. But, Philip's intermediate band photometric analysis showed that 5 of these stars have a larger m_1-index compared to the other cluster members and probably belong to an A metallic-line subgroup. Elimination of these objects yielded a mean reddening value of $0^m.07 \pm 0^m.07$. The mean reddening thus computed agrees with that derived by Sanduleak & Philip and also by Jones (1969). All cluster members for which spectral types are available were corrected for reddening *individually* and a mean value of $E(B-V) = 0^m.07$ was used for the *new cluster members* selected on the basis of a V_0, M_v diagram described in the next section. All V magnitudes were corrected for absorption using a value of $R = 3.0$.

The proper motion analysis by Murray *et al.* (1969) showed that 19 stars share common proper motion. The question of additional membership was investigated using the V_0, M_v (ZAMS) technique given by Walker (1965). Absolute visual magnitudes were determined from the ZAMS calibration given by Schmidt-Kaler (1965) using the values of $(B-V)_0$. The V_0, M_v (ZAMS) diagram for all program stars is shown in figure 2. The solid line corresponds to $V_0 - M_v = 8^m.00$ and the dashed lines to $V_0 - M_v = +8^m.5$ and $+7^m.25$. The lower line has been drawn assuming that duplicity might brighten stars up to $0^m.75$. All stars which lie within these boundaries were considered as probable members and the stars which lie on and very close to these boundaries were treated cautiously for inclusion as members after judging their position on the $C-M$ diagram. In this way an additional 5 stars were found to be probable members even though magnitudes and colours were established for additional 20 stars. However, the technique is good only for the stars which are on the main sequence and the earlier evolved members lie outside of these boundaries on this diagram, the membership of the early evolved stars were judged on the basis of proper motion analysis only.

Distance modulus, $C-M$ diagram and age

The distance modulus for each cluster member was computed using V_0 and M_v (ZAMS) derived from the relation between $(B-V)_0$ and M_v (ZAMS) given by Schmidt-Kaler (1965). The mean true distance modulus for all 24 probable members is $7^m.57 \pm 0.61$. However, seven of these stars deviate from the mean zero-age main sequence, possibly due to their evolutionary status, variability, or binary nature. Elimination of these stars has yielded a mean distance modulus of $+7^m.85 \pm 0^m.49$. In addition, the superposition of the ZAMS on the unreddened

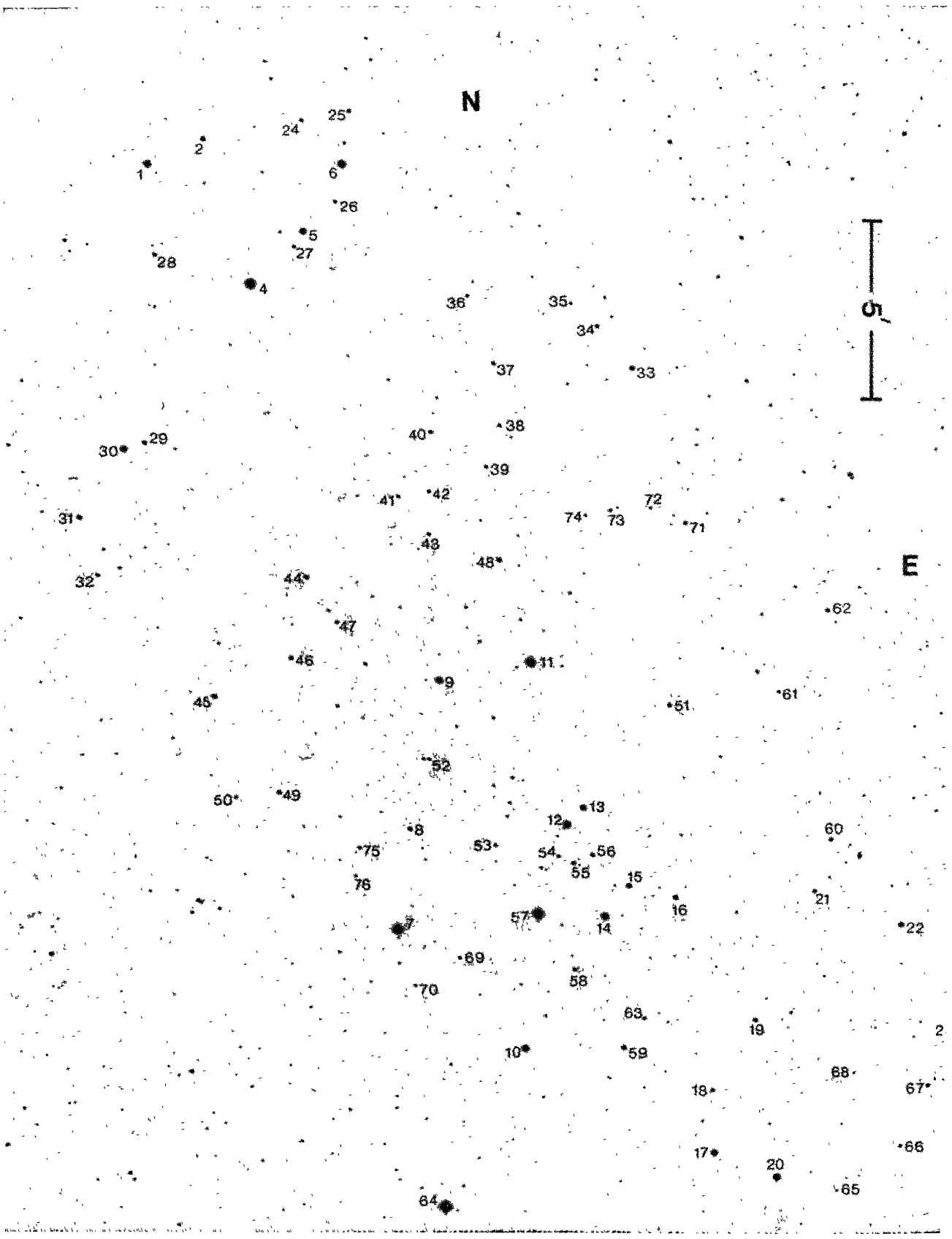

Figure 1. Identification chart for Anon. Bok group in blue light.

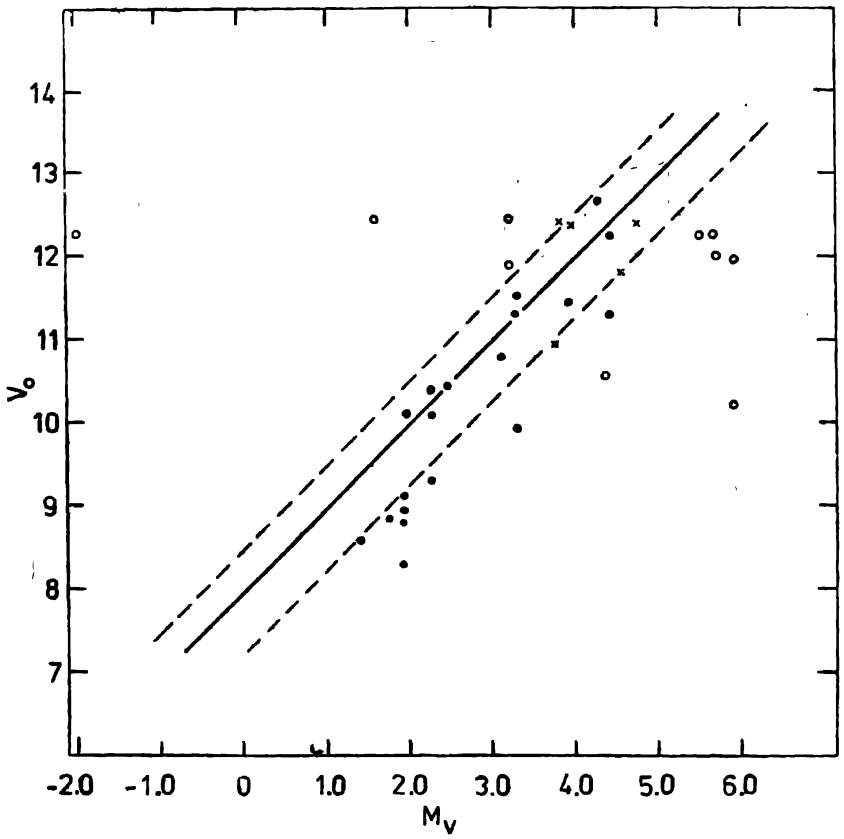

Figure 2. The V_0, M_v diagram for the stars in the region of Anon. Bok group. The solid line refers to $V_0 - M_v = 8^m.0$ and the dashed lines to $V_0 - M_v = 8^m.5$ and $7^m.25$. Cluster members (●) from proper-motion study; non-members (○) and new probable members (×) from this analysis are shown.

$C - M$ diagram has also yielded a distance modulus of $8^m.15 \pm 0^m.2$. A mean distance modulus of $8^m.0 \pm 0^m.2$ was adopted and corresponds to 400 ± 40 pc. This is almost equal to the value of $8^m.09 \pm 0.015^m$ derived by Philip (1973) from observations of only 7 stars, a value of $8^m.4$ derived by Murray *et al.* (1969) and $8^m.1$ obtained by Jones (1969).

The unreddened $C - M$ diagram for all members is given in figure 3. The cluster has a well-developed main-sequence with a turning point at $(B - V)_0 \leqslant +0.2$. Figure 3 also shows the theoretical evolutionary isochrones for an assumed composition of $Y = 0.30$ and $Z = 0.02$ as given by Demarque & McCluare (1978, personal communication). The observed main-sequence fits rather well with an evolutionary isochrone of 500 Myr except a few stars which lie above the theoretical ZAMS and could belong to a binary population. Further, extensive spectroscopic and photometric studies are essential in order to resolve the exact nature of these objects.

An interesting point to be noted at the present time is the observed distribution of cluster members along the main-sequence. Owing to the abrupt onset of convection, a gap ($\Delta(B - V) \approx 0^m.07$) near $(B - V)_0 \approx 0^m.20$ was predicted by Bohm-Vitense (1958) and shown to exist in several nearby clusters (Bohm-Vitense & Canterna 1974). This gap is also clearly visible in Anon. Bok cluster with a gap width of

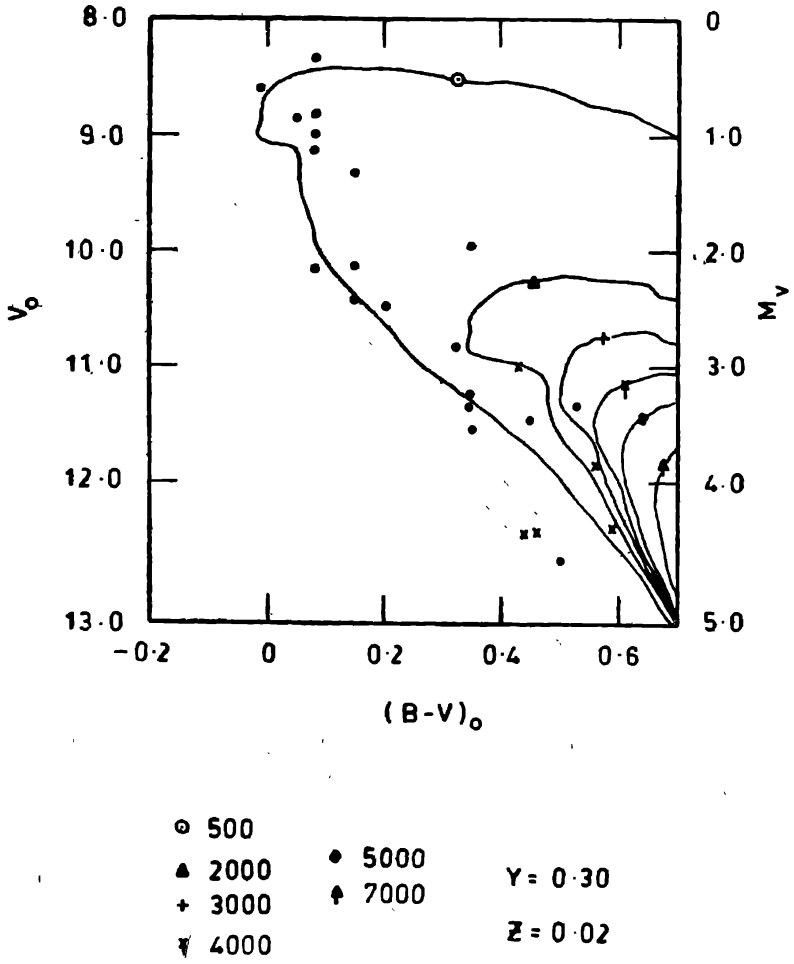

Figure 3. The V_0, $(B - V)_0$ relation for Anon. Bok group. The solid lines represent theoretical evolutionary isochrones (in millions of years) for an assumed chemical composition (Preliminary) given by Demarque *et al.* The symbols are the same as in figure 2.

almost $0^m.10$. An additional gap around $(B - V)_0 \approx 0^m.05$ is also visible. Mermilliod (1976) found a similar gap of $0^m.07$ width in the main-sequence between spectral types B7 and B8 that have ages less than the Pleiades. The gap is caused most likely by the effects of helium and hydrogen ionization zones in the stellar atmosphere and results in a weakening of Balmer jump and the equivalent width of the Balmer lines. However, the gap in the main-sequence of Anon. Bok cluster occurs at a later spectral type than that found by Mermilliod. Therefore, this gap may not be related to the same atmospheric processes unless the gap is also a function of the age of the cluster, which was also suggested by Mermilliod's study. Similar situation also exists in the case of NGC 1039 studied by Canterna *et al.* (1979). Philip's suggestion that Anon. Bok cluster resembles Hyades cluster is somewhat confusing as there are no yellow giants observed in this cluster at all.

A method of age determination has been given by Schlesinger (1969, 1972), who has derived relationships involving mass, luminosity and stellar age from the theoretical evolutionary tracks of Iben (1965). The resulting mean nuclear age (the timescale for core hydrogen burning) computed from the seven earlier type members

has yielded a value of 640 ± 40 Myr for Anon. Bok cluster. This derived age is somewhat higher than that of the one obtained earlier from the isochrone comparison and could have been caused partly by the initial chemical composition differences involved in model construction or in the nature of the treatment of the problem itself.

4. Conclusions

A *BV* photographic photometric analysis has established magnitudes and colours for an additional 20 stars in the vicinity of Anon. Bok group. Of these, 5 are considered to be new probable members of the group. An age of 500 Myr is derived for this group from the theoretical isochrone comparison. The values obtained in the present analysis for the distance modulus, $(m - M)$ and the mean colour excess, $E(B - V)$ agrees with the earlier estimates given by other investigators.

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