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Study of Faint Young Open Clusters as Tracers of Spiral Features in our Galaxy

Paper 5: NGC 2236 (OCl 501)

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Abstract. Continuing the study of faint young open clusters as tracers of spiral features in our Galaxy, photoelectric and photographic photometry of 39 stars was done in the field of the faint open cluster NGC 2236 ≡ OCl 501 in the direction of Monoceros constellation. Out of these stars, a total of 22 down to $m_v \simeq 15.4$ mag have been found to be probable members. There is apparently a variable extinction across the field of the cluster with $E(B-V)$ ranging between 0.84 mag and 0.68 mag. The median age of this cluster is estimated to be 7.6×10^7 years and the cluster is thereby considered as belonging to the marginally old category. Thus, it cannot be specifically used as a spiral arm tracer in the study of our Galaxy. This cluster is located at a distance of 3.72 ± 0.13 kpc, which places it at the inner edge of the outer Perseus spiral feature of the Milky Way.

Key Words: star clusters, open—spiral feature tracers—stars, photometry.

1. Introduction

In 1899, Roberts (*cf.* Alter, Balazs & Ruprecht 1970) identified the cluster NGC 2236 (≡ OCl 501 ≡ C 0627 + 068; $l = 204^\circ\!.37$; $b = -1^\circ\!.69$) on a photographic plate and gave a count of 171 stars in the region. Then, almost three decades later, Shapley (1930) determined its distance to be 8320 parsecs and pointed out that it was one of the most remote open clusters. He mentioned that it has an angular diameter of 5 arcmin and that it contained 50 stars. Trumpler (1930), on the other hand, estimated a distance of 2290 parsecs, while Collinder (1931) and Barkhatova (1950) respectively gave the figures of 4750 parsecs and 1600 parsecs. Bok, Olmsted & Boutelle (1949) discussed the relationship of this cluster with the Milky Way and stated that no known clusters in this region are found at distances greater than 3000 parsecs. More recently, Rahim (1970) obtained a distance of 3430 parsecs through RGU photographic photometry, while Barkhatova, Orekhova & Shashkina (1988, hereafter BOS) determined it as 2800 parsecs on the basis of photographic photometry in the *UBV* system.

The classification of this cluster, given by Ruprecht (1966) is III 2 p in the Trumpler system, while Trumpler (1930) himself had classified it as I 2 m. The finding chart is displayed in Fig. 1, the identification numbers having been introduced in this paper. This paper is a continuation of the study of faint young open clusters, which was

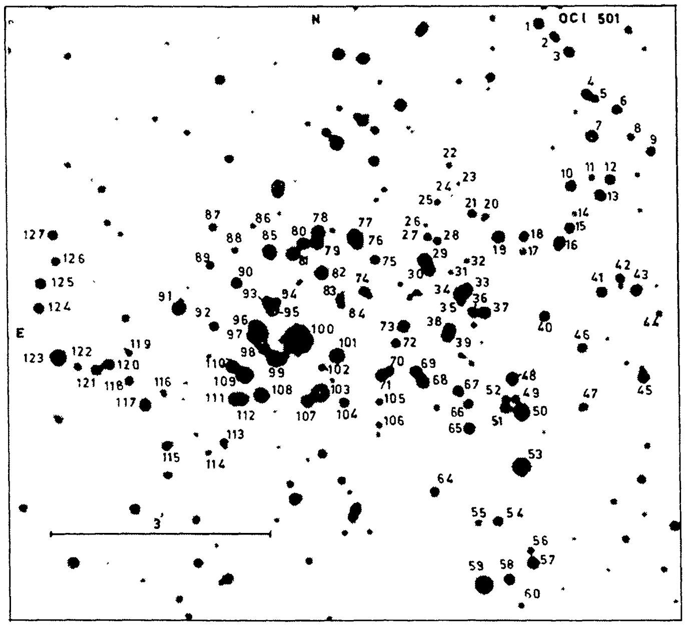

Figure 1. Finding chart for the field of NGC 2236 (OCl 501), reproduced from the Palomar Observatory Sky Survey (POSS) Charts. The identification numbers are introduced in the present paper.

initiated by the late Professor M. K. V. Bappu with the main aim of utilizing them as tracers of spiral features in our Galaxy (Babu 1983, Paper 1; 1985, Paper 2; 1987, Paper 3; 1989, Paper 4).

2. Selection of the cluster and observations

This cluster also, like those in Papers 2, 3 and 4, was subjected to the rapid selection techniques described in Paper 1. In that procedure, low-dispersion spectra of the order of 970 Å mm^{-1} are obtained for the stars in the cluster region with a transmission grating placed in front of the photographic plate at the Cassegrain focus of the 102-cm telescope at the Vainu Bappu Observatory, Kavalur. The exposure time for this modified objective grating spectroscopy was 120 minutes on a Kodak 103 a-O emulsion. Then using the intensity distribution in the shorter wavelength region as the principal criterion, approximate spectral types could be assigned to a total of 24 stars, which are listed in Table 1, the uncertainty being about two spectral subclasses in each case. Along with these, the respective visual magnitudes, V(POSS), estimated from the image diameters on the Palomar Observatory Sky Survey Charts (*cf.* Babu 1983) are also given in Table 1. A plot between these two parameters of the above mentioned 24 stars is shown in Fig. 2. In this diagram, in spite of some scatter, a total of 11 stars seem to be forming a probable main sequence. Six other stars (19, 37, 58, 65, 81 and 99) are at a completely separated location on the right hand side of the diagram. The remaining stars are too bright to be considered as part of the main sequence. Thus, since the star 101 is showing a nearness to the spectral type of B3, this cluster is taken up for further detailed study to confirm its distance, age category, etc. with the intention of using it as

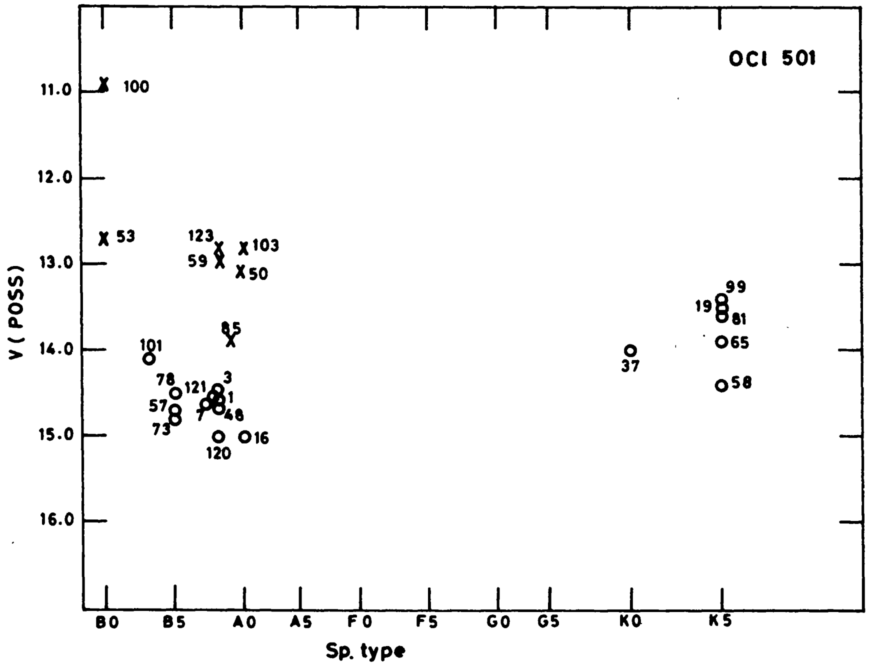

Figure 2. The approximate spectral types obtained from the modified objective grating spectra are plotted against the V magnitudes estimated from the POSS charts, for the stars in the field of OCl 501. The unfilled circles and the crosses respectively denote the probable members and the non-members.

a possible spiral arm tracer. It may be noted here that Rahim (1970) had estimated the earliest spectral type to be A0 and mentioned that this cluster is too old to be used as a spiral arm tracer.

The photoelectric photometry of thirteen stars in the region of this cluster was done using a standard UBV photometer mounted at the Cassegrain focus of the 61-cm telescope at the Siding Spring Observatory of the Australian National University. A dry-ice-cooled photomultiplier was used along with an on-line computer to collect the data. The instrumental magnitudes, corrected for the atmospheric extinction, were standardized with the help of the photometric sequences taken from the work of Landolt (1973). These values are given in Table 1 as V, $(B-V)$ and $(U-B)$, the uncertainties being respectively in the range of 0.02 to 0.03, 0.02 to 0.04 and 0.05 to 0.08 mag. The larger errors were mainly applicable to the fainter ($m_v > 15$) stars.

In order to extend the measurements to some more members of this cluster, the direct photography of the region was carried out using both the 102-cm telescope of Vainu Bappu Observatory (VBO) and the 1-m telescope of Siding Spring Observatory (SSO). The combinations of the photographic emulsions on Kodak plates and the filters along with the exposure times are given in Table 2.

From these plates, the photographic magnitudes on an arbitrary scale, were obtained for a total of thirty nine stars, including all the thirteen photoelectrically observed ones, by using the PDS microdensitometer in conjunction with the computational facilities available at the Mount Stromlo Observatory in Australia. These magnitudes were then standardized using the photoelectric observations mentioned earlier, the uncertainties being about ± 0.12 mag in U and ± 0.08 mag in B and V with

Table 1. The observational data for individual stars in the open cluster OCl 501.

Star No Present	Star No Rahim (1970)	Spectral type (approx.)	V (POSS)	V	$(B-V)$	$(U-B)$	V_0	$(B-V)_0$	$(U-B)_0$	$E(B-V)$	Membership
1	2	3	4	5	6	7	8	9	10	11	12
Photoelectric Photometry											
1	164	B8	14.6	14.59	0.53	−0.05	12.35	−0.16	−0.55	0.69	m
3	165	B8	14.5	14.59	0.67	0.68	—	—	—	—	—
6	167	—	—	14.28	1.38	1.39	—	—	—	—	—
7	168	B5	14.6	14.49	0.58	0.01	12.12	−0.15	−0.52	0.73	m
13	172	—	—	15.34	0.61	0.14	13.00	−0.11	−0.38	0.72	m
40	178	—	—	15.07	0.55	0.05	12.83	−0.14	−0.45	0.69	m
48	183	B8	14.6	14.53	0.71	0.40	12.03	−0.06	−0.15	0.77	m
53	203	B0	12.7	12.55	0.31	−0.42	—	—	—	—	—
59	245	B8	12.9	12.61	0.64	−0.56	—	—	—	—	—
73	80	B5	14.8	14.73	0.65	0.06	12.13	−0.15	−0.52	0.80	m
100	1	B0	10.9	10.72	0.32	−0.06	—	—	—	—	—
101	2	B3	14.1	14.02	0.32	−0.25	—	—	—	—	—
123	18	B8	12.8	12.76	0.66	−0.58	—	—	—	—	—

Photographic photometry											
4	166	—	—	15.37	0.59	0.16	13.13	−0.10	−0.34	0.69	m
10	173	—	—	15.27	0.53	0.07	13.19	−0.11	−0.39	0.64	m
16	177	A0	15.0	14.96	0.54	−0.01	12.72	−0.15	−0.51	0.69	m
19	174	K5	13.5	13.28	1.53	0.94	10.94	0.81	0.42	0.72	m
29	74	—	—	14.25	0.42	0.17	—	—	—	—	—
30	75	—	—	14.46	0.63	0.57	—	—	—	—	—
37	184	K0	14.0	13.93	1.37	1.13	—	—	—	—	—
38	—	—	—	14.45	0.56	0.60	—	—	—	—	—
50	195	A0	13.1	12.92	0.71	−0.47	—	—	—	—	—
57	247	B5	14.7	14.55	0.75	0.30	11.79	−0.10	−0.31	0.85	m
58	246	K5	14.4	14.26	1.66	1.33	12.18	1.02	0.87	0.64	m
65	191	K5	13.9	13.70	1.68	1.38	11.65	1.05	0.93	0.63	m
67	189	—	—	15.26	0.73	0.63	—	—	—	—	—
68	187	—	—	14.01	0.87	0.56	11.93	0.23	0.10	0.64	m?
69	186	—	—	14.72	0.61	0.41	12.64	−0.03	−0.05	0.64	m?
70	82	—	—	14.64	0.65	0.62	—	—	—	—	—
78	39	B5	14.5	14.28	0.74	0.24	11.52	−0.11	−0.37	0.85	m
81	42	K5	13.6	13.54	1.56	1.09	11.39	0.90	0.61	0.66	m
85	43	B8	13.9	13.78	0.74	0.40	11.15	−0.07	−0.18	0.81	m
99	6	K5	13.4	13.23	1.58	1.12	11.05	0.91	0.64	0.67	m
103	3	A0	12.8	12.65	0.79	−0.57	—	—	—	—	—
108	5	—	—	13.05	1.50	0.96	10.90	0.84	0.48	0.66	m
109	8	—	—	13.30	1.20	0.64	—	—	—	—	—
110	9	—	—	14.38	0.95	0.41	—	—	—	—	—
120	15	B8	15.0	14.79	0.73	0.30	12.12	−0.09	−0.29	0.82	m
121	16	B8	14.6	14.53	0.85	0.61	11.86	0.03	0.02	0.82	m

Table 2. Journal of photographic observations.

Band	Emulsion	Filter	Exposure time
U	II a–O	UG 2	45 min (SSO)
B	103 a–O	GG 13	30 min (SSO)
V	II a–D	GG 11	90 min (VBO)

the larger errors applicable to the stars fainter than 15 mag. The V, $(B-V)$ and $(U-B)$ values of those twenty-six non-photoelectrically observed stars also are included in Table 1 under the section of photographic photometry.

3. Reddening

Fig. 3 shows the colour-colour diagrams of this cluster, where mean $(B-V)$ and mean $(U-B)$ values are used for the individual stars. In this diagram, in spite of a considerable amount of scatter, some stars appear to be following a sequence which is generally shifted from the unreddened main sequence given by Schmidt-Kaler (1982). The overall shift is attributed to the gross reddening effect due to the interstellar medium in the line of sight, while the spread, beyond a certain amount termed as natural dispersion, would indicate a differential extinction across the field of the cluster (Burki 1975). Further, though it is well known that the slope of the reddening line changes with colour, Crawford & Mandwewala (1976) showed that the effect is only moderate for spectral types earlier than A0. And for the late type stars, especially of Ia and Ib luminosity classes, the effect is a little larger, which however, has been considered as a non-critical factor, being beyond the scope of this work. Thus, in order to find out the presence and the amount, if any, of the differential nature in the gross reddening effect, the un-reddened colour-colour curve is shifted (following Burki 1975) onto the reddened sequence, in such a way that the shift is parallel to the reddening line (adopted from the work of Hiltner & Johnson 1956), as shown in Fig. 3. The maximum and minimum colour excesses are then found from the boundaries of the observed sequence in the portion of the early type stars. These boundaries show a difference Δ between $E(B-V)_{max}$ and $E(B-V)_{min}$ as

$$\Delta E(B-V) = E(B-V)_{max} - E(B-V)_{min}$$
$$= 0.84 - 0.68 = 0.16 \text{ mag.}$$

Similarly,

$$\Delta E(U-B) = E(U-B)_{max} - E(U-B)_{min}$$
$$= 0.60 - 0.49 = 0.11 \text{ mag.}$$

These values of Δ, being slightly larger than the values due to the natural dispersion (see Burki 1975 for a complete description), indicate some amount of variable extinction across the field of the cluster. Therefore, the individual corrections for interstellar reddening were applied to the stars which are determined to be cluster members (*cf.* next section). The individual $E(B-V)$ values have also been included in

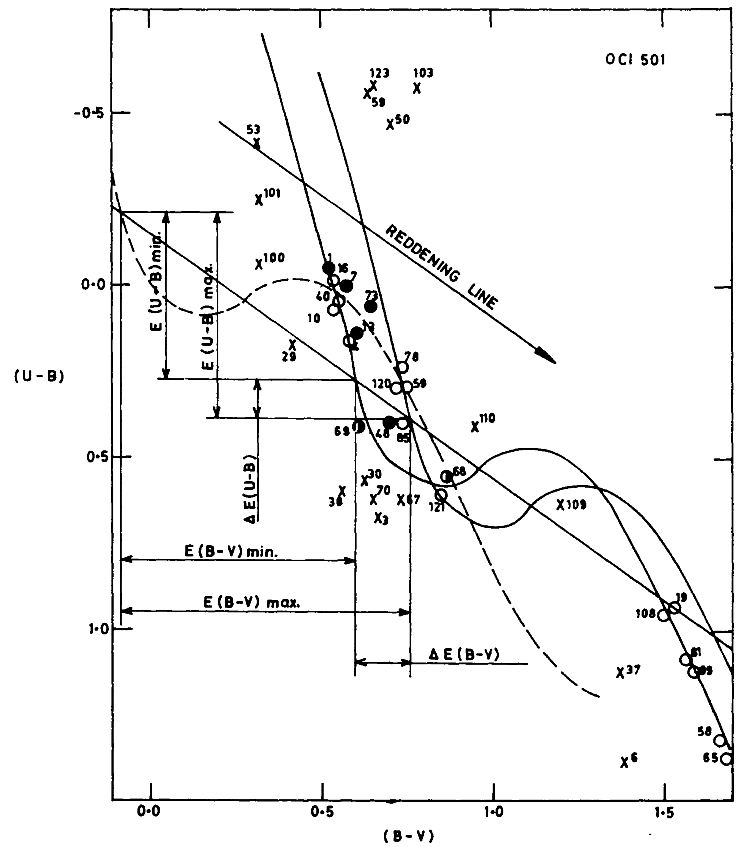

Figure 3. The $(B-V)$ versus $(U-B)$ diagram of the stars in the field of the open cluster OCl 501. The filled circles and the unfilled circles represent respectively the members of the cluster which are observed photoelectrically and photographically. The half-filled circles are the doubtful members and the crosses denote the non-members. The dashed line is the main sequence (MS) for the unreddened stars (Schmidt-Kaler 1982), while the solid lines represent the MS when it is fitted to the observations with the maximum and minimum reddening by shifting it parallel to the reddening line (Hiltner & Johnson 1956).

Table 1. In this context, it may be noted that Rahim (1970) had found a value for $E(G-R)$ as 0.51 mag which is equivalent of $E(B-V)=0.37$ mag (*cf.* Steinlin 1968 for the transformations) and did not mention anything about the variable reddening. On the other hand, BOS determined an average value of $E(B-V)=0.46$ mag and the substantial amount of spread seen in their colour-colour diagram (Fig. 3 of BOS) clearly indicates a variable extinction across the cluster field.

Using the above mentioned individual $E(B-V)$ values, the corresponding values of A_v were obtained from the expression

$$A_v = R \,.\, E(B-V)$$

where R is the ratio of total-to-selective absorption, taken to be 3.25 ± 0.05 as suggested by Moffat & Schmidt-Kaler (1976). These A_v values are found to be between 2.05 mag and 2.76 mag as against the value of $A_v = 1.19$ mag (or $A_G = 1.37$ mag) given by Rahim (1970) and the value of $A_v = 1.38$ mag (using $R = 3.0$) given by BOS. The observed V values were then corrected by using the respective A_v values. All the individually corrected magnitudes and the corrected colours are included in Table 1 as V_0, $(B-V)_0$ and $(U-B)_0$.

4. Membership

For determining the membership of the individual stars in this cluster, only the photometric criteria were used as described by Vogt & Moffat (1972). Further, since this work is mainly aimed at exploring the possibility of utilizing the cluster as a spiral-feature-tracer in our Galaxy, the complete membership assignment is not a necessary requirement. With this in view, the colour-colour diagram (Fig. 3) as well as both the colour-magnitude diagrams (Figs 4 & 5) were examined and out of the observed 39, a total of 22 stars have been found to be fulfilling the required criteria for being adopted as probable members of the cluster. It may also be noticed that six (19, 58, 65, 81, 99 and 108) of the twenty two stars mentioned above are in such a location that they could perhaps be considered as belonging to the red giant sequence of the cluster. In addition, a few others are situated slightly away from the respective main sequences of the colour-magnitude diagrams (Figs 4 & 5) showing an evolved nature.

The brightest star (100), which appears almost at the centre of the cluster in the finding chart, is found to be a non-member on the basis of the photometric criteria and the non-membership of this star is in agreement with that found by Rahim (1970). Two of the stars (68 and 69), being marginally outside the boundaries in the colour-colour diagram (Fig. 3), have been taken as doubtful members and are indicated by "m?", in Table 1. In the same table, the rest of the members are marked with the letter "m". The members based on the photoelectric photometry and the photographic photometry are respectively denoted by filled and unfilled circles in all the diagrams. The two doubtful members are shown by half-filled circles while the non-members are indicated by crosses.

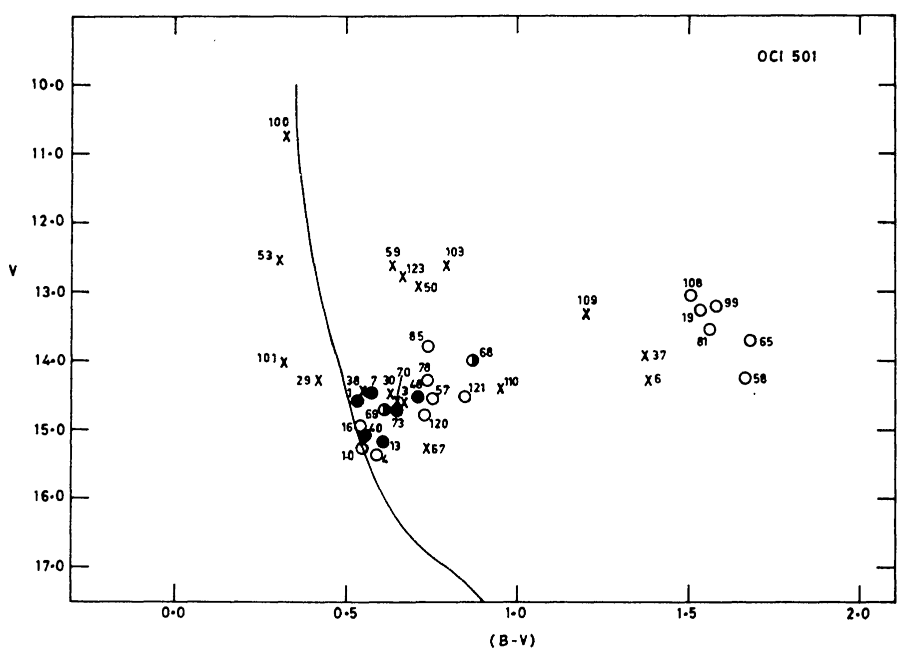

Figure 4. The $(B-V)$ versus V magnitude diagram of the stars in the field of OCl 501. The solid curve represents the zero-age-main-sequence (ZAMS) (*cf.* Schmidt-Kaler 1982), which is shifted to match with the observations. The symbols are same as in Fig. 3.

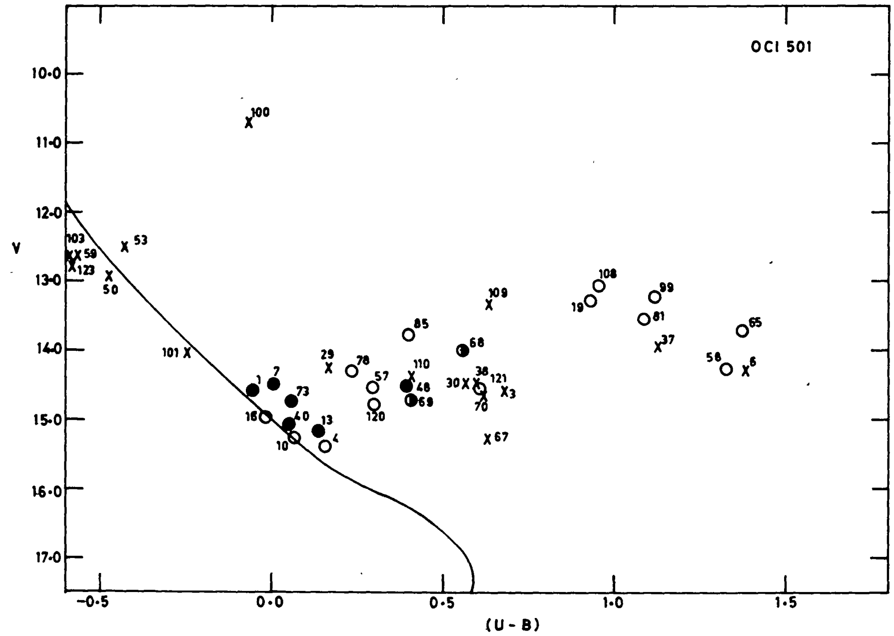

Figure 5. The $(U-B)$ versus V magnitude diagram of the stars in the field of OCl 501. The solid curve represents the ZAMS (*cf.* Schmidt-Kaler 1982), which is shifted to match with the observations. The symbols are same as in Figs 3 and 4.

5. Distance

The distance modulus of this cluster has been determined by fitting the relevant zero-age-main-sequence (ZAMS) given by Schmidt-Kaler (1982) onto the $(B-V)_0$, V_0 and the $(U-B)_0$, V_0 diagrams respectively as shown in Figs 6 and 7. They yielded the values of 12.8 ± 0.02 mag and 12.9 ± 0.03 mag respectively, giving an average distance modulus of 12.85 ± 0.07 mag. Then the distance D to the cluster is obtained as

$$D = 3.72 \pm 0.13 \text{ kpc}$$

from the standard expression $\log D = 0.2\,(V_0 - M) + 1$, where $(V_0 - M)$ is the distance modulus. Incidentally, out of the available earlier determinations of the distance for this cluster, the one given by Rahim (1970) ($D = 3430$ pc) appears to be the closest to the value obtained here.

6. Age of the cluster

The HR diagram of the cluster is shown in Fig. 8, which is plotted for the true distance modulus of 12.85 mag as determined above. On this diagram, the post-main-sequence isochrones given by Barbaro, Dallaporta & Fabris (1969) have been super imposed along with the ZAMS in order to determine the age of the cluster. The main sequence indicates an age of about 3.7×10^7 years, while the post-main-sequence isochrones show a range of 7.1×10^7 to 12.5×10^7 years. Some of the stars seem to have evolved from the main sequence from which the red giant portion is clearly separated by the Hertzsprung gap as was also noticed by Rahim (1970).

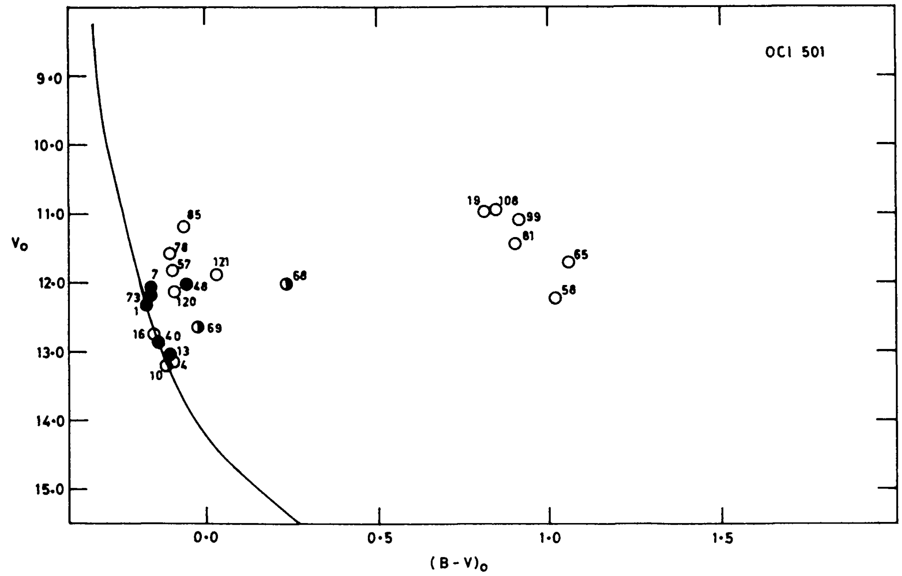

Figure 6. The intrinsic $(B-V)_0$, V_0 diagram of OCl 501. The solid curve represents the ZAMS taken from Schmidt-Kaler (1982). The symbols are same as in Figs 3–5 with all the non-members deleted.

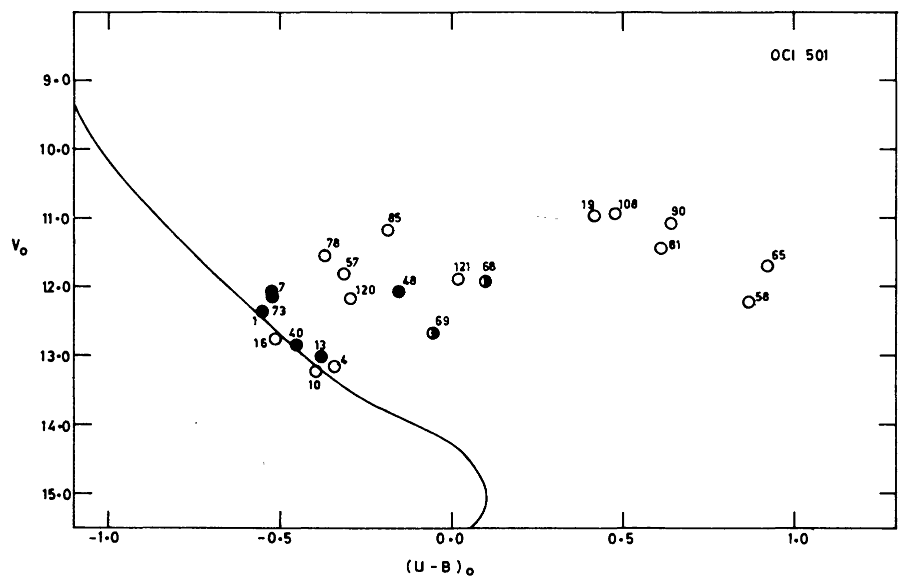

Figure 7. The intrinsic $(U-B)_0$, V_0 diagram of OCl 501. The ZAMS taken from Schmidt-Kaler (1982) is shown by the solid curve. The symbols are same as in Figs 3–6 with all the non-members deleted.

As an additional check, the age of this cluster has also been estimated on the basis of the earliest $(B-V)_0$ on the MS (Allen 1981). This value, being -0.16 mag, yields an age of 2.6×10^7 years. Thus, the age spread in this cluster appears to be between 2.6 $\times 10^7$ years and 12.5×10^7 years, of which about 27 per cent is caused by the observational and related uncertainties. Yet, it could still be considered as one more example to show that the star formation in clusters is not necessarily coeval. However,

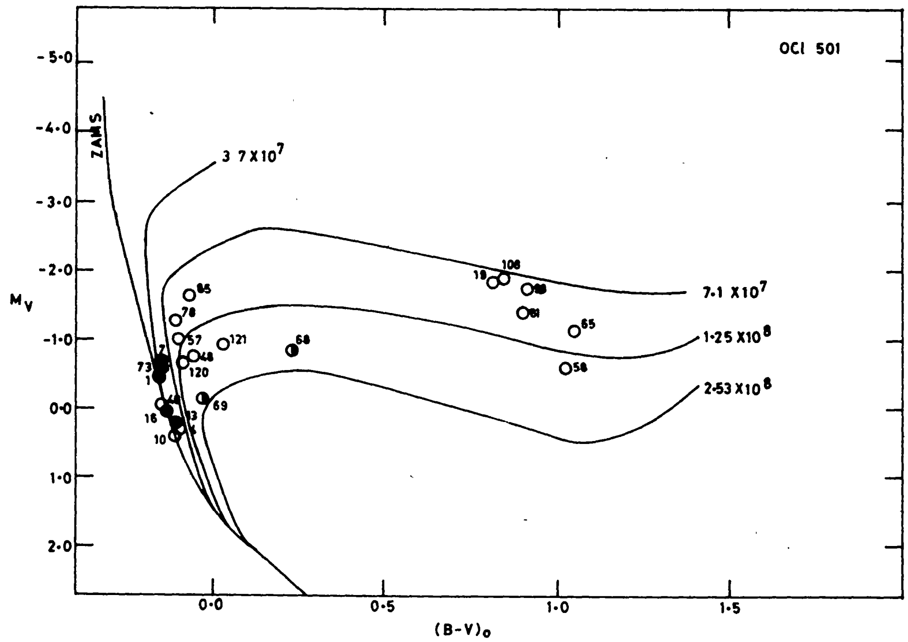

Figure 8. The H-R diagram of the open cluster OCl 501. The ZAMS is same as in Fig. 6, but drawn for the true distance modulus. The post-MS isochrones are taken from the work of Barbaro, Dallaporta & Fabris (1969). The ages are indicated in years alongside the isochrones. The symbols are same as in Figs 3–7.

the median age of 7.6×10^7 years places this cluster in the marginally old category, which agrees with the age category estimated by Rahim (1970) and by BOS.

7. Conclusions

The open cluster NGC 2236 ($\equiv$OCl 501) is found to contain at least 22 stars as probable members down to $m_v \simeq 15.4$ mag, with two of them being doubtful cases. Six of these stars are perhaps members on the red giant branch. The presence of some variable extinction is noticed in front of the cluster region, the variability being between $E(B-V) = 0.84$ and 0.68 mag. The median age of this cluster is found to be 7.6 $\times 10^7$ years and hence this cluster is considered to be belonging to the marginally old category, which is in agreement with Rahim's (1970) finding as well as with BOS. Thus, it cannot be specifically used as a spiral feature tracer in the study of our Galaxy. However, the true distance modulus of 12.85 ± 0.07 mag gives the distance of the cluster as 3.72 ± 0.13 kpc which places it at the inner edge of the outer Perseus spiral feature of our Galaxy in the direction of the Monoceros constellation.

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