J. Astrophys. Astr. (1983) **4**, 235–252

Membership of Stars in Faint Galactic Open Clusters

G. S. D. Babu *Indian Institute of Astrophysics, Bangalore 560034*

Received 1983 July 1; accepted 1983 October 7

Abstract. Low-dispersion spectra of the order of 1000 Å mm^{-1} have been obtained for stars in several faint galactic clusters with a transmission grating placed in front of the photographic plate at the Cassegrain focus of the Kavalur 102-cm telescope. The intensity distribution in the shorter wavelengths has been taken as the principal criterion for the spectral classification of the individual stars in the area covered by the photographic plate. The uncertainty in this procedure has been found to be about two spectral subclasses. A combination of these spectral classes with the visual magnitudes derived from the image diameters on the POSS charts provide the HR diagrams for each cluster area. These diagrams are adequate to establish the cluster membership of any star to a first approximation. This technique has been tested on six galactic open clusters, four of which are well-studied. We find good agreement both in terms of the ages of the clusters and individual stellar membership.

Key words: open clusters—HR diagram—objective-grating technique

1. Introduction

While summarising the latest picture of our Galaxy, Bok & Bok (1981) pointed out that, on the basis of optical observations, the principal spiral features can be traced reasonably well out to distances of about 5000 pc from the Sun—possibly even to 8000 pc in a few dust-free directions (Muzzio & McCarthy 1973; McCarthy & Miller 1973, 1974; FitzGerald & Moffat 1976). Furthermore, an inspection of various external spiral galaxies shows that the spiral arms are by no means smooth and continuous structures. There are often holes and bifurcations in them; loops, spurs and fringes are quite common; and our Galaxy may not be an exception in this respect. Therefore, to gain a better understanding of the spiral structure of our Galaxy, one is obliged to take up a study of the most luminous spiral tracers such as hot O and B stars, long-period Cepheids, hot emission-line Wolf-Rayet stars and H II regions, in order to reach the greatest distances from the Sun. Especially valuable are the clusters containing hot luminous stars, for which the distances can be more accurately derived.

Observations of some such objects have been carried out by many earlier workers (*e.g.* Moffat & Vogt 1975; FitzGerald & Moffat 1976; Humphreys 1979; Bok & Bok

1981), from which the Sagittarius-Carina arm, the Orion-Cygnus arm, the Perseus arm and the possible outer Perseus arm have been quite clearly outlined. In the nearby regions of the Sun, a few extra features like bifurcations or spurs do reveal themselves.

In an attempt to push this type of observation to larger distances, the late Professor M. K. V. Bappu initiated a study of faint, young galactic open clusters with stars of spectral type B3 or earlier as their members. The choice of clusters has generally been restricted to those with their brightest stars being of apparent magnitude 12.0 or fainter. Since such relatively faint stars are not easily amenable to slit spectroscopy techniques of spectral classification by moderate telescopes, a programme of objective-grating spectroscopy was suggested. This employs the technique of placing a transmission grating directly in front of the photographic plate.

Some of the results and the feasibility of the technique are presented here. When these results are combined with the magnitudes obtained from the Palomar Observatory Sky Survey (POSS) charts, the HR-diagrams of the clusters can be constructed, from which the membership of individual stars may be determined to first approximation. Only then is it possible to estimate the earliest spectral type ($\sim$ age) in the cluster, with a minimum confusion from the field stars.

2. Instrumentation and spectral types

Hoag & Schroeder (1970) had first introduced an instrument which contained a transmission grating in the converging beam of the telescope, thus modifying the technique of objective-grating spectroscopy. Later, Miller & Graham (1974) employed this in their search for faint blue stars. A similar arrangement is used in the present work with a transmission grating of 300 lines mm^{-1} (blazed at 6200 Å in the first order) placed at a distance of 25 mm in front of the photographic plate (generally Kodak 103a-O) at the Cassegrain focus of the Kavalur 102-cm telescope. This gives a dispersion of 970 Å mm^{-1} in the first order. Since the exposed area is only 16 arcmin × 16 arcmin and is centrally situated in the available 40 arcmin diameter field, the image distortions are negligible even in the absence of the field corrector. Therefore, no extra optical elements

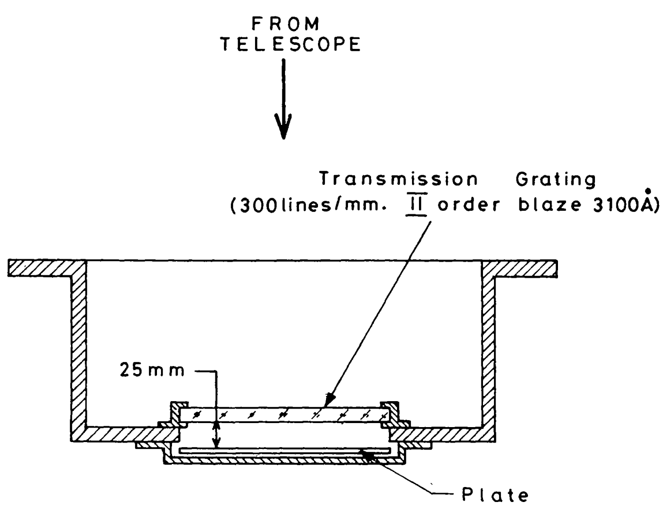

Figure 1. Schematic diagram of the instrument used for obtaining the objective grating spectra with a dispersion of 970 Å mm^{-1} in the first order.

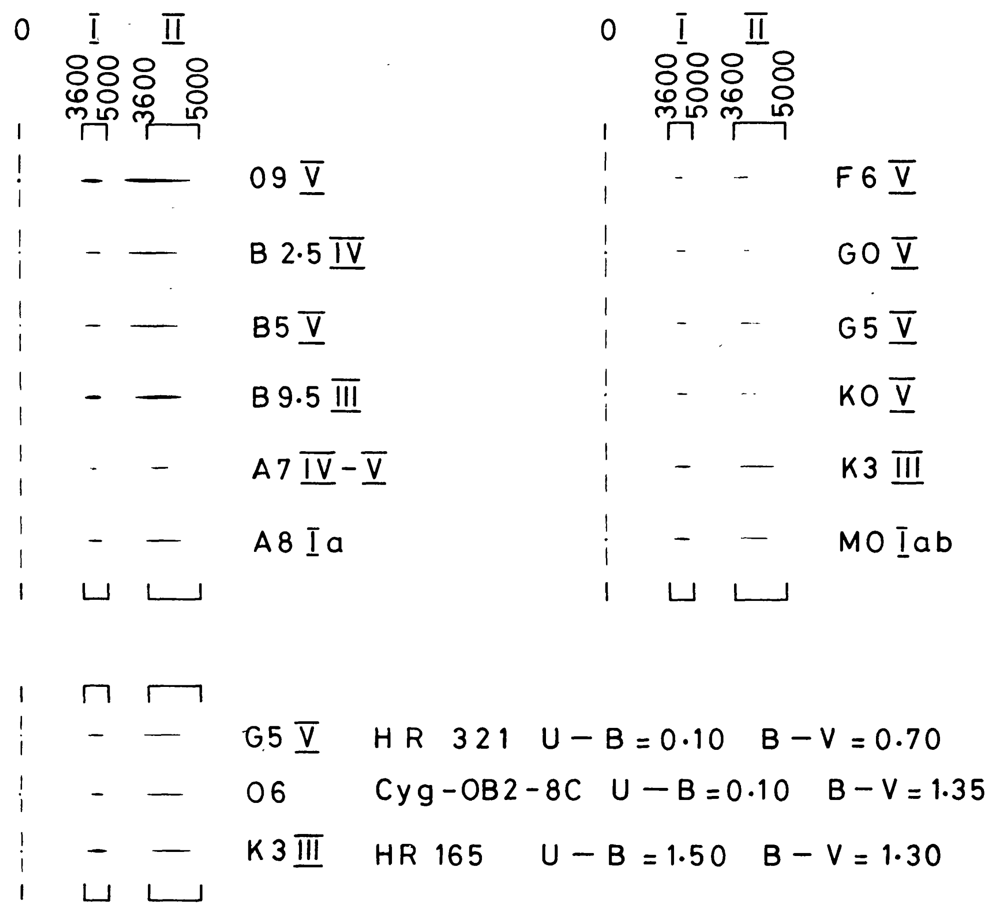

Figure 2. A sample of MK standards used for calibrating the objective-grating spectra based mainly on the shape of the energy distribution in the first and second orders. The three spectra at the bottom are shown as an example of the effects of interstellar extinction on an early-type star compared with the unreddened late-type star.

need to be introduced in the path of the light, thus saving the already faint starlight from unwanted absorption. The details of the instrument are shown in Fig. 1.

The advantage of using a grating with smaller number of grooves is that the zero order images can be used for the identification of stars in a crowded field. We have used the first- and the second-order spectra for the determination of individual spectral types, the shape of the intensity distribution being the criterion. Several MK standard stars have been used for calibrating these spectra, a sample of which is given in Fig. 2. The effects of interstellar extinction on the spectra has not proved a limitation of this technique, since a reddened early-type star can still be differentiated from an unreddened star of a later spectral type (Hoag & Schroeder 1970; Miller & Graham 1974). This is illustrated in Fig. 2, where a heavily obscured early type star of the Cyg-OB2 association is included.

This technique was tried on ten well-studied open clusters and our estimates of spectral type have been plotted against known *V* magnitudes in Fig. 3, which agree well with the available colour-magnitude diagrams. Some basic data on these clusters are included in Table 1.

Table 1. Some basic data on ten well-established clusters (*cf.* Fig. 3) and of two less-known ones, which are included in the present work.

Cluster								Earliest spectral type		
OCl	Name	IAU number	l deg	b deg	Trumpler type	No. of members	Distance kpc	Litt. (ref.)	Present study	Magnitude range
148	NGC 6871	C2004+356	72.6	+2.1	IV 3 p	22	1.6	O9 (1)	B0	6.8–11.9
411	NGC 1664	C0447+436	161.7	−0.4	III 1 p	8	1.3	A0 (1)	B8	7.5–12.5
506	Collinder 97	C0628+059	205.4	−1.8	IV 3 p	9			B5	7.6–13.3
537	Dolidze 25	C0642+003	211.9	−1.3	IV 2 p	10	5.3	O (2)	B2	8.9–13.6
556	Haffner 3	C0701−060	219.8	+0.0	IV 1 p	{9, 7}			{A0, B0}	10.1–14.3
598	NGC 2414	C0731−153	231.4	+2.0	I 3 m	7	4.2	B1 (3)	B2	8.2–13.4
618	NGC 2384	C0722−209	235.4	−2.4	IV 3 p	9	3.3	B0 (3)	B3	9.1–13.3
621	NGC 2367	C0718−218	235.6	−3.9	IV 3 p	9	2.9	B1 (3)	B3	9.4–13.3
626	NGC 2421	C0734−205	236.2	+0.1	I 2 m	18	1.9	B0.5 (2)	B2	10.5–13.8
635	Trumpler 7	C0725−239	238.3	−3.4	II 3 p	12	1.6	B1 (3)	B2	9.1–13.0
713	Ruprecht 55	C0810−324	250.7	+0.8	IV 2 p	8	4.4	B2 (2)	B2	8.5–12.7
754	Pismis 6	C0837−460	264.8	−2.9	II 2 p	8	1.7	B2 (4)	B1	8.9–13.2

References:
1. Becker (1963)
2. Moffat & Vogt (1975)
3. Vogt & Moffat (1972)
4. Vogt & Moffat (1973)

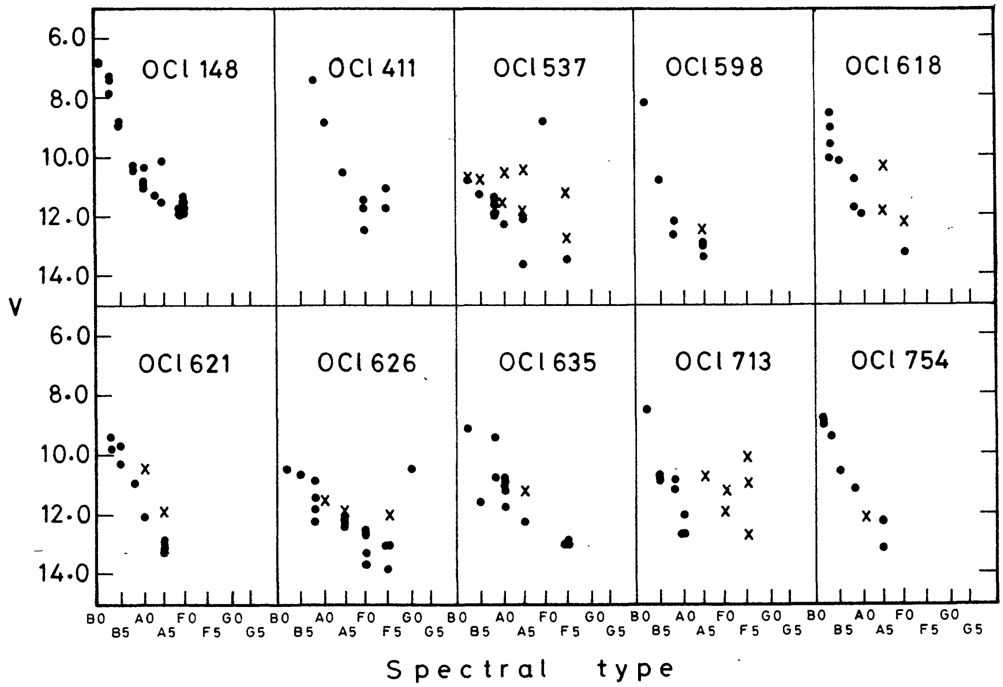

Figure 3. Spectral types estimated on the basis of the objective-grating spectra for the individual stars of a few known clusters are plotted against their known *V* magnitudes. Crosses denote probable non-members based on previous work.

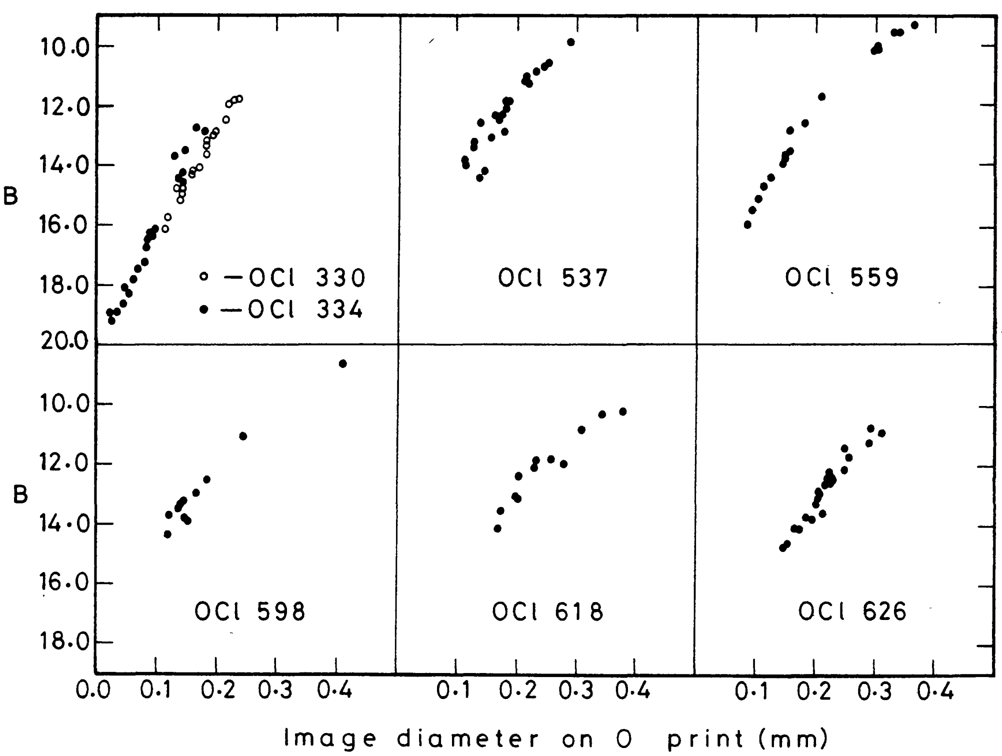

Figure 4. Relationship between the POSS chart O-print image diameters of the individual stars belonging to various clusters and their corresponding *B* magnitudes.

3. Palomar charts and magnitudes

One way of separating cluster members from field stars is to construct an HR-diagram using the $(B-V)$ colours and V magnitudes of the individual stars. However, when telescope time is at a premium for obtaining these two parameters, one has to resort to other means of constructing the HR-diagrams. This is where the already available POSS charts become useful.

Following the procedure given by Bappu (1978), I have sabattiered the contact copies of both O (blue) and E (red) POSS charts containing the field of the cluster. The image diameters of the individual stars in the field are measured on these copies. The calibration curves relating image diameter to stellar magnitude were constructed by measuring the image diameters of several stars of known B and V magnitudes on the same copies. According to van den Bergh (1957), the O-print image diameters are directly related to the B magnitudes, while the E-print image diameters are related to a quantity r defined as $r = V - \frac{2}{3}(B-V)$. Figs 4 and 5 show some examples of the respective relationships for some of the known clusters representing different POSS charts.

It is interesting to note that in both these diagrams, the relationship for the stars fainter than $m(B)$ or $m(r) = 11.0$ (wherever available) are nearly linear. The average slope is $-30.5 \pm 3\,\mathrm{mag\,mm^{-1}}$ for the O prints and $-33.5 \pm 2\,\mathrm{mag\,mm^{-1}}$ for the E prints. The average extrapolated intercepts are 19 ± 2 mag and 20 ± 1 mag respectively.

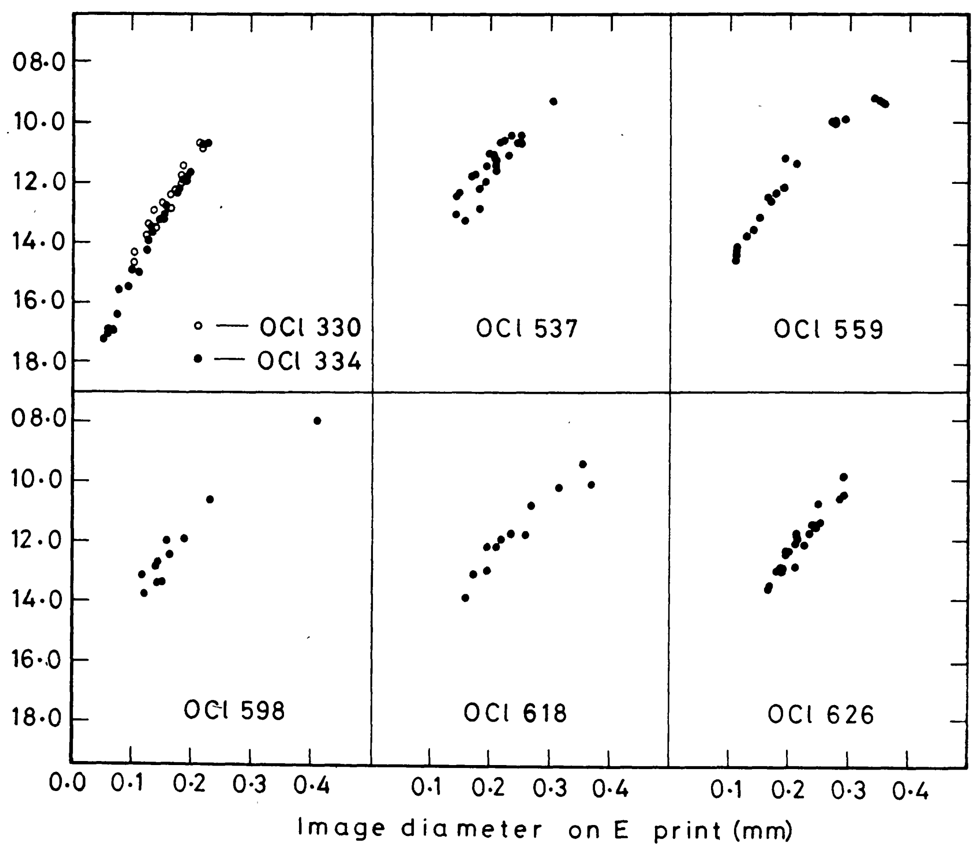

Figure 5. Relationship between the POSS chart E-print image diameters of the individual stars belonging to various clusters and their corresponding red magnitudes expressed as $r = V - \frac{2}{3}(B-V)$.

4. HR-diagrams of open clusters

Since the average $(O - C)$ uncertainties involved in the above technique of obtaining the magnitudes are of the order of 0.3 to 0.4 mag, it is not advisable to consider the $(B - V)$ colours from these measurements. However, this accuracy is sufficient for the construction of the respective spectral type versus magnitude (HR) diagrams where the objective-grating results obtained in Section 2 may be used in place of $(B - V)$.

Two conditions may now be laid down in attributing the membership to the individual stars in the field:

1. The star should be reasonably near to the obvious core of the physical group as seen on the POSS photograph.
2. The star should fall into the evolutionary main sequence of the spectral type–magnitude diagram.

We have neglected the effects of differential reddening in this work. The members of the individual clusters are thus determined and whichever cluster is found to consist of stars of B 3 or of earlier spectral type is considered a young cluster.

The above technique has been tested out on a few well-established clusters, four of which are presented here as a sample. While observing these clusters, the numbering of the stars as given by the earlier authors has been retained; these are called 'known' stars in this paper. I have continued the numbering for a few 'additional' stars in the respective cluster fields. Two less-known clusters are also included as a part of the programme, and the numbering of the stars in these clusters is original to this paper. The accompanying star charts are taken from the corresponding POSS maps.

In each HR-diagram shown in this paper, part (a) of the figure includes all the stars for which the spectral types as well as the V magnitudes are obtained from this work. Part (b) shows the diagram after removing all the possible non-members of the given cluster. Part (c) reproduces the colour-magnitude diagram given by earlier authors, when available. The following is a brief explanation for each of the six clusters. OCl is the running number in the catalogue of open clusters compiled by Alter, Balazs & Ruprecht (1970).

4.1 *OCl 537* (*Dolidze 25*)

This cluster has been observed earlier by Moffat & Vogt (1975). The field is shown in Fig. 6 where eleven 'additional' stars (24 to 34) have been introduced. The spectral types and V magnitudes have been determined for a total of twenty-nine stars, twenty of them being the 'known' stars. Table 2 compiles the results.

In Fig. 7(a), we have considered seven 'known' stars (2, 5, 6, 7, 8, 20 and 21) as non-members, in agreement with the earlier work. However, Moffat & Vogt consider three more stars (3, 4 and 14) as non-members. Out of the 'additional' stars, 25 and 26 could well be non-members. An inspection of the star field along with the HR diagram shows that the bulk of the cluster is concentrated in the lower half of the photograph, which makes the membership of 1 and 24 doubtful. Thus, in Fig. 7(b), we find a sequence of seventeen stars—seven of them being 'additional' which, in all likelihood, are representative of the cluster. Fig. 7(c) is plotted using $(B - V)$ and V values of Moffat & Vogt, which have not been corrected for interstellar extinction. A comparison of this

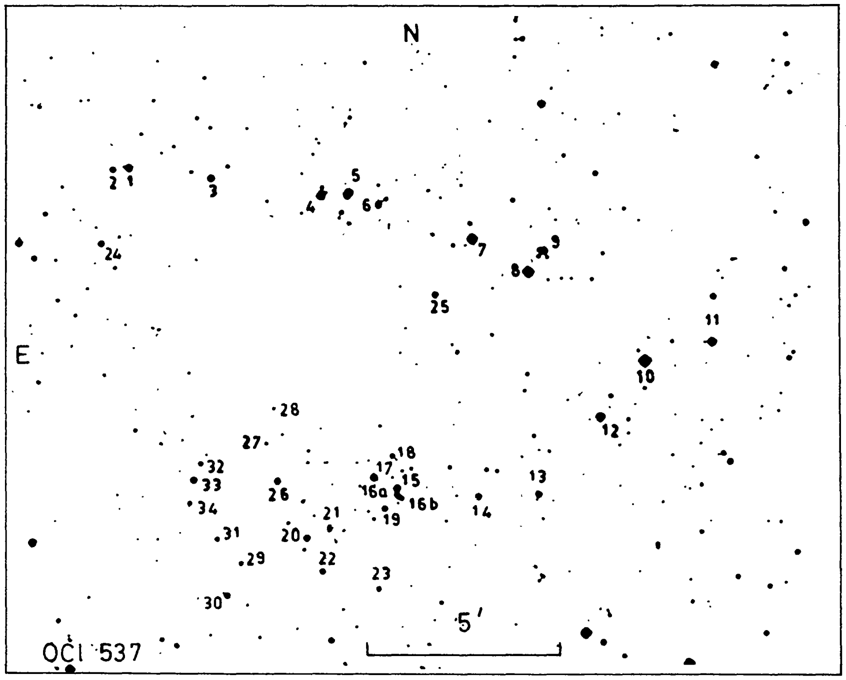

Figure 6. Field of OCl 537 (Dolidze 25).

Table 2. OCl 537 (Dolidze 25).

Star no.	Spectral type	V	Membership	Star no.	Spectral type	V	Membership
1	B5	11.1	m?	18	F5	13.5	m
2	A5	11.8	...	19	A5	12.8	m
3	A0	11.5	...	20	F5	11.5	...
4	B2	10.6	...	21	F5	13.2	...
5	B5	10.4	...	22	A5	12.7	m
6	A5	11.7	...	24	B8	11.7	m?
7	A0	10.6	...	25	K0	11.7	...
8	A5	10.3	...	26	G5	11.4	...
9	A0	11.9	m	27	F5	14.4	m
10	F0	8.9	m	28	F5	14.5	m
12	B2	11.0	m	31	F0	13.5	m
13	B8	12.3	m	32	F0	13.4	m
14	B8	11.9	...	33	B8	11.6	m
15	B8	11.5	m	34	F5	14.0	m
17	B8	11.7	m				

with the clear sequence in Fig. 7(b) indicates that our method is quite effective in differentiating a reddened early-type member star from an unreddened late-type field star. However, it is not possible to estimate or avoid the amount of absorption in V magnitudes from this technique.

4.2 *OCl 598* (*NGC 2414*)

Vogt & Moffat (1972) have observed eleven stars of this cluster and considered ten of these eleven as members. The field is shown in Fig. 8, where four 'additional' stars

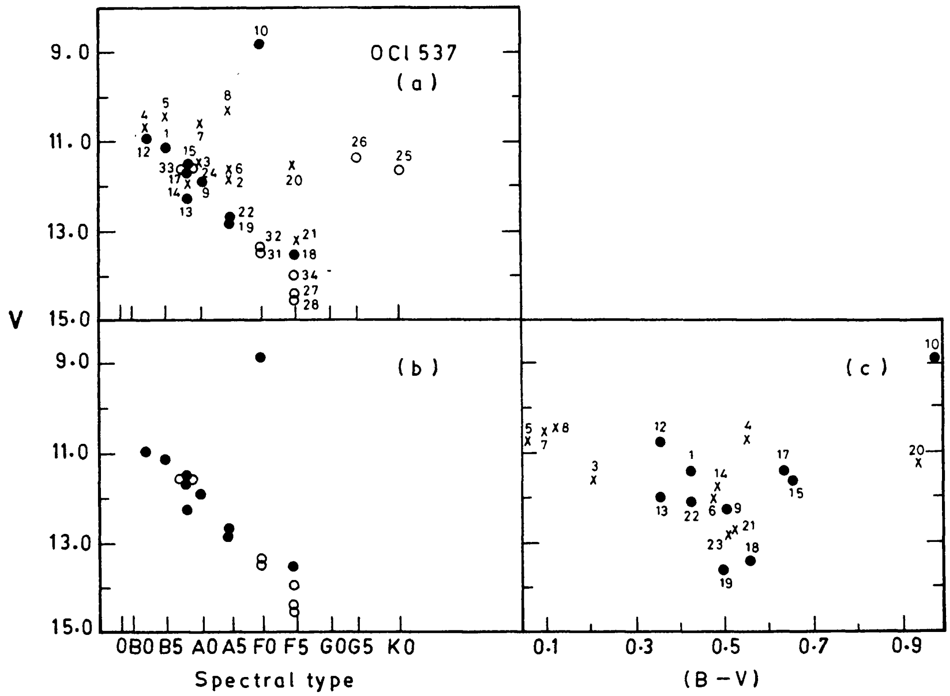

Figure 7. (a) Spectral types of all the individual stars of OCl 537 which could be estimated on the basis of the objective-grating spectra, plotted against the corresponding V magnitudes from POSS charts. The filled circles and the crosses denote the members and the non-members of the cluster, respectively (Moffat & Vogt 1975). The open circles represent the stars added in the present work. (b) Spectral type versus magnitude (HR) diagram of OCl 537 after removing all the possible non-members of the cluster. (c) The colour-magnitude diagram of OCl 537 as given by Moffat & Vogt (1975).

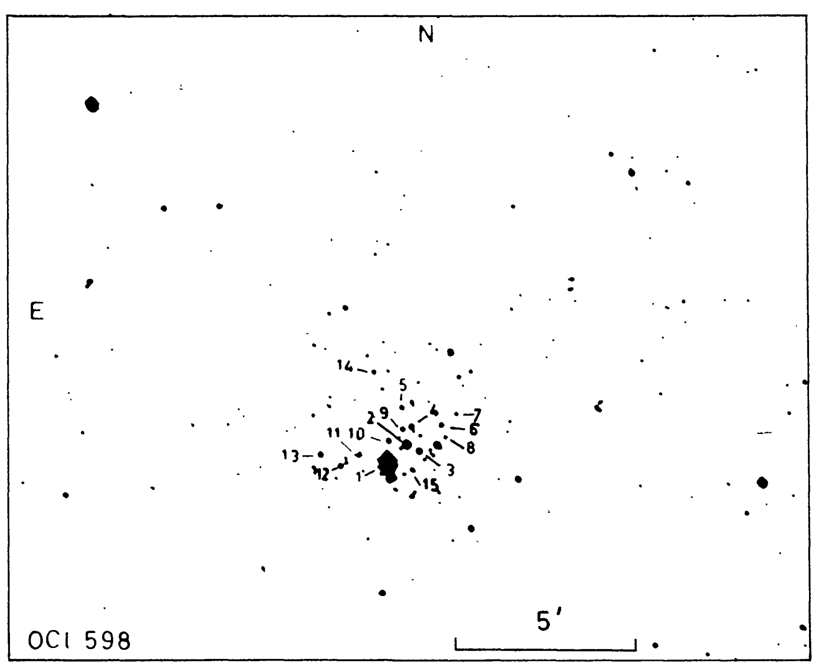

Figure 8. Field of OCl 598 (NGC 2414).

Table 3. OCl 598 (NGC 2414).

Star no.	Spectral type	V	Membership	Star no.	Spectral type	V	Membership
1	B2	8.2	m	8	...	14.0	...
2	B5	10.7	m	9	...	13.3	...
3	B8	11.9	m	10	...	13.0	...
4	B8	12.6	m	11	A5	13.3	m
5	F0	13.0	...	12	K0	12.4	...
6	A5	13.3	m	13	B5	12.2	m
7	F0	14.2	m	14	B8	13.5	...

(12 to 15) are also numbered. The spectral types and V magnitudes were obtained for all the numbered stars excepting star 15. Table 3 lists the results.

Though star 12 appears to be within the physical group of the cluster as seen in the photograph, it could well be a foreground, late-type star (Fig. 9a). Star 5 has already been termed a non-member by Vogt & Moffat. We show in Fig. 9(b) a sequence with the most likely members, the earliest spectral type being B2. This sequence matches closely with the one given by Vogt & Moffat (Fig. 9c).

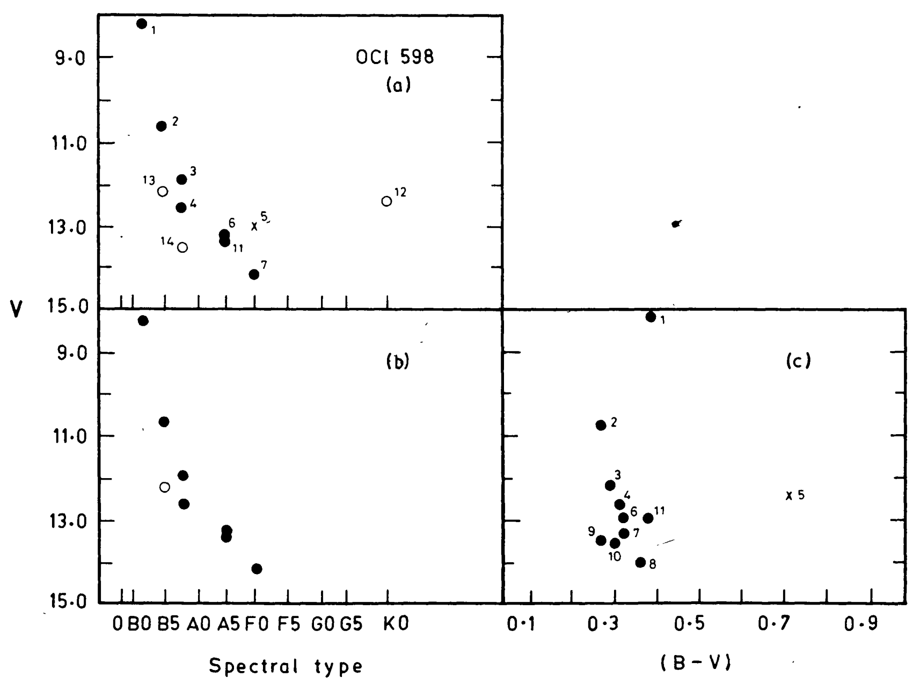

Figure 9. (a) Spectral type plotted against V magnitude for stars of OCl 598. The filled circles and the cross denote the members and the non-member respectively. The open circles represent the stars added in the present work. (b) Spectral type versus magnitude diagram after deleting all the possible non-members. (c) Colour-magnitude diagram as given by Vogt & Moffat (1972).

4.3 *OCl 618 (NGC 2384)*

Fifteen stars of this cluster have been observed by Vogt & Moffat (1972), four of which turned out to be non-members. Five 'additional' stars have been numbered (16 to 20) as shown in Fig. 10. For stars 6 and 7 the spectral type could not be estimated while for stars 1, 2 and 10 the *V* magnitudes were not obtained due to over-exposure of the images on the corresponding POSS photographs. The results are compiled in Table 4.

Among the remaining fifteen stars, 3, 14 and 15 are 'known' non-members and star 17 appears to lie away from the general sequence. This last one could be a background A-type star (Fig. 11a). Fig. 11(b) shows a sequence of seven 'known' and four 'additional' members. The earliest spectral type appears to be B3. There is good agreement between this and the colour-magnitude diagram given by Vogt & Moffat (Fig. 11c).

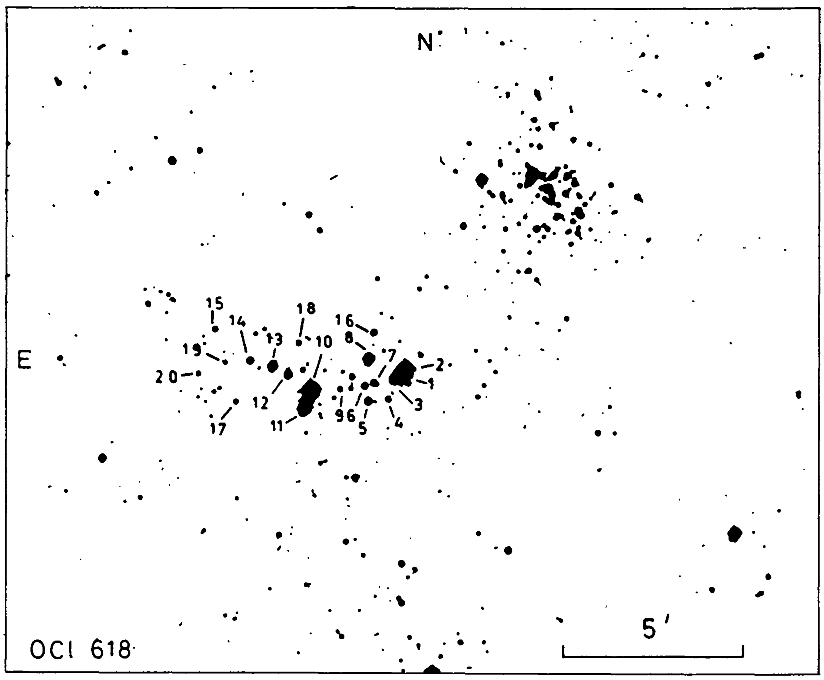

Figure 10. Field of OCl 618 (NGC 2384).

Table 4. OCl 618 (NGC 2384).

Star no.	Spectral type	*V*	Membership	Star no.	Spectral type	*V*	Membership
1	B3	...	...	11	B3	9.6?	m
2	B3	...	...	12	B8	11.4	m
3	A5	11.0?	...	13	B8	10.7	m
4	F0	13.5	m	14	A5	10.5	...
5	A0	12.0	m	15	F0	12.7	...
6	...	12.7	...	16	A5	12.4	m
7	...	12.4	...	17	A0	13.2	...
8	B5	10.1	m	18	F0	13.4	m
9	F5	13.9	m	19	F5	13.9	m
10	B0	...	...	20	F5	13.3	m

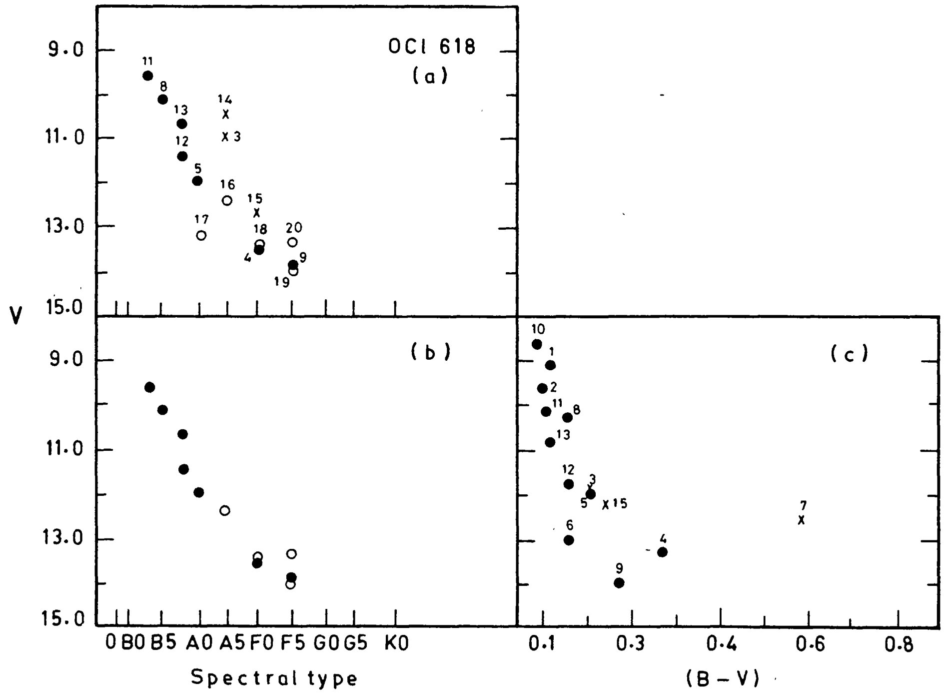

Figure 11. (a) Spectral type plotted against V magnitude for stars of OCl 618. The filled circles, crosses and open circles denote the members, non-members and 'additional' stars respectively. (b) Spectral type versus magnitude diagram after deleting all the possible non-members. (c) Colour-magnitude diagram as given by Vogt & Moffat (1972).

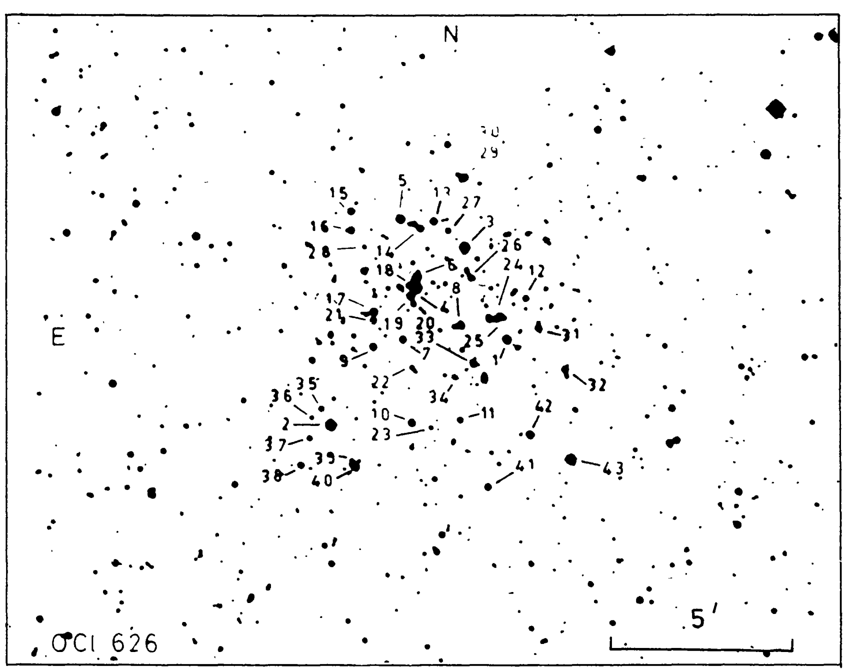

Figure 12. Field of OCl 626 (NGC 2421).

Table 5. OCl 626 (NGC 2421).

Star no.	Spectral type	V	Membership	Star no.	Spectral type	V	Membership
1	B8	11.2	m	22	F5	13.9	m
2	B2	10.5	m	23	...	13.1	...
3	B5	10.4	m	24	F0	...	...
4	B8	11.0	m	25	F5	...	...
5	G0	10.8	gm	26	...	12.8	...
6	A0	11.2	...	27	F0	13.3	m
7	A5	12.1	...	28	...	13.9	...
8	B8	11.5	m	29	F0	12.3	...
9	A5	12.1	m	30	A5	12.5	m
10	A5	12.0	m	31	A5	12.4	m
11	F0	12.7	m	32	...	12.9	...
12	F5	11.9	...	33	A5	12.2?	m
13	A5	12.2	m	34	A5	13.3	m
14	F0	12.7	m	35	G5	12.7	...
15	A5	11.7	...	36	K0	13.8	...
16	A5	12.5	m	37	B8	13.1	...
17	B8	11.8	m	38	G0	11.2	gm
18	...	12.9	...	41	G5	11.5	gm
19	...	12.2	...	42	G5	10.7	gm
20	F0	13.6	m	43	B5	10.6	m
21	...	12.8	...				

4.4 *OCl 626 (NGC 2421)*

Moffat & Vogt (1975) have observed twenty-eight stars in this cluster, out of which six have been termed as non-members. Fifteen 'additional' stars have been numbered here as shown in Fig. 12. The spectral types could not be estimated for stars 18, 19, 21, 23, 26, 28, 32, 39 and 40 whereas the V magnitudes are lacking for only four stars (24, 25, 39 and 40), mainly due to crowding effects. Table 5 shows the results.

Thus, out of the forty-three stars, only thirty-three could be included in Fig. 13(a) where stars 6, 7, 12 and 15 are 'known' non-members and stars 29, 35, 36 and 37 are 'additional' non-members. Stars 38, 41 and 42 are very close to the known red giant star 5 and therefore are adopted as members of the giant branch. Thus Fig. 13(b) shows sixteen 'known' members and eight 'additional' members of this cluster, with the earliest spectral type as B2. The colour-magnitude diagram as given by Moffat & Vogt is shown in Fig. 13(c).

4.5 *OCl 506 (Cr 97)*

This cluster of Trumpler class IV 3p is not a well-studied one. A total of thirteen stars are numbered as shown in Fig. 14. The spectral class versus V magnitude diagram with these stars is given in Fig. 15(a) and the values are compiled in Table 6. The image diameter to V magnitude calibration was established from the nearby known cluster OCl 527 (Arp 1960).

Even though, some of the stars in the field are bright enough to be included in SAO

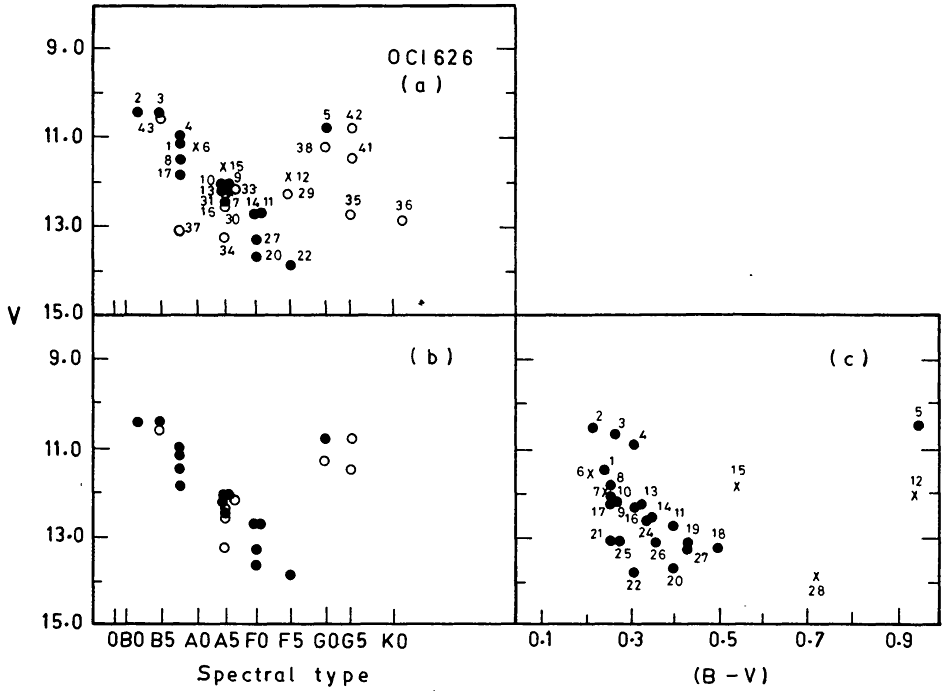

Figure 13. (a) Spectral type plotted against V magnitude for stars of OCl 626. The filled circles, crosses and open circles represent the members, non-members and 'additional' stars respectively. (b) Spectral type versus magnitude diagram after deleting all the possible non-members. (c) Colour-magnitude diagram as given by Moffat & Vogt (1975).

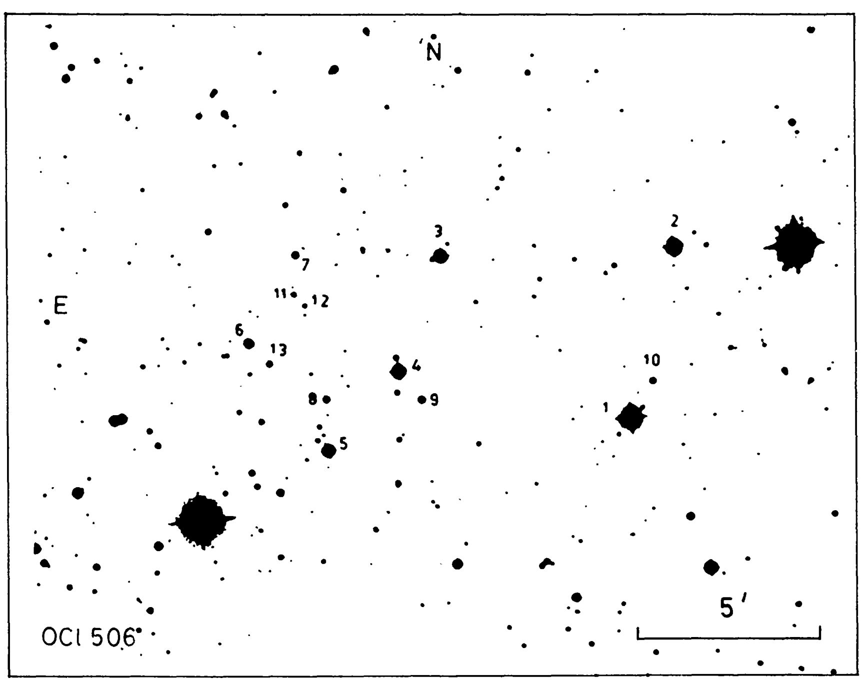

Figure 14. Field of OCl 506 (Cr 97).

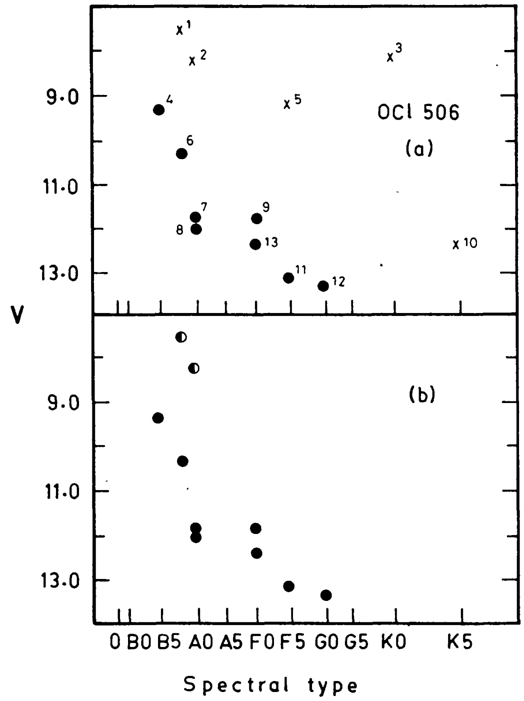

Figure 15. (a) Spectral type plotted against V magnitude for stars of OCl 506. The filled circles represent the members and the crosses denote those stars for which a definite membership could not be ascribed by us. (b) Spectral type versus magnitude diagram after deleting the non-members. The half-filled circles are doubtful members.

and BD charts, surprisingly no work has been done on them as members of a cluster. However, out of the brightest five stars in our list, only star 4 is considered as a member of the cluster. Stars 1 and 2 are doubtful members because of their location at the edge of this sparse cluster, while stars 3 and 5 have a very remote chance of being members of a possible giant sequence. Star 10 is termed a non-member. Finally, Fig. 15(b) shows eight, possibly two more, stars as likely members of the clusters. Since the earliest spectral type is B5, we have categorised this as a young cluster.

Table 6. OCl 506 (Cr 97).

Star no.	Spectral type	V	Membership
1 (SAO 113979)	B8	7.6	m?
2 (SAO 113977)	A0	8.3	m?
3 (SAO 113987)	K0	8.3	...
4 (BD + 5°1274)	B5	9.3	m
5 (BD + 5°1276)	F5	9.3	...
6	B8	10.3	m
7	A0	11.8	m
8	A0	12.0	m
9	F0	11.8	m
10	K5	12.5	...
11	F5	13.2	m
12	G0?	13.3	m
13	F0	12.4	m

4.6 *OCl 556* (*Haffner 3*)

This is the second poorly studied cluster chosen in this programme; it is classified as II 2p in the Trumpler system by Ruprecht (1966), though Haffner (1975) had earlier put it as IV 1p. I have numbered a total of twenty-five stars shown in Fig. 16. The results are presented in Table 7. The nearby cluster OCl 559 (Hoag *et al.* 1961) has been used as the source for image diameter to *V* magnitude calibration. The interesting feature of the field of OCl 556 is that there are two distinct concentrations or physical groups separated by a small region of low star density.

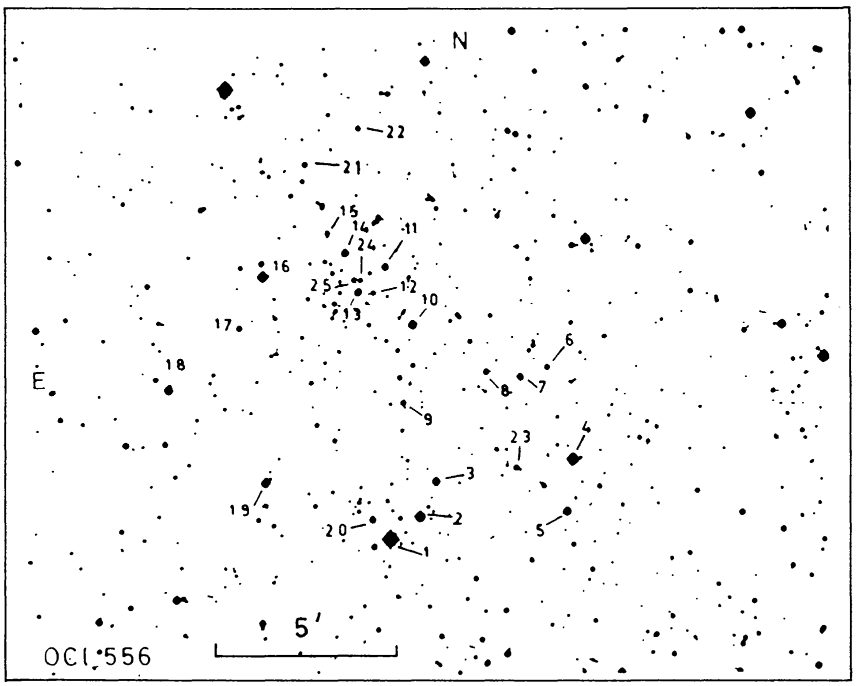

Figure 16. Field of OCl 556 (Haffner 3).

Table 7. OCl 556 (Haffner 3).

Star no.	Spectral type	*V*	Membership*	Star no.	Spectral type	*V*	Membership*
1	B0	10.1	mS	12	G0	14.3	mN
2	A0	11.5	mS	14	F0	12.6	mN
3	A5	12.4	mS	15	F5	14.1	mN
4	B5	11.0	mS	16	A0	11.3	. . .
5	F5	12.2	. . .	17	A0	13.4	. . .
6	G0	14.2	mN	18	A0	12.1	. . .
7	A5	13.8	. . .	19	A0	11.8	mS
8	F5	13.4	mN	20	F5	13.3	mS
9	A5	14.4	. . .	21	F0	13.0	mN
10	A5	12.0	mN	23	F5?	13.2	mS
11	A8	12.6	mN	25	F5?	14.1	mN

* mN and mS indicate the membership in the northern and the southern group, respectively.

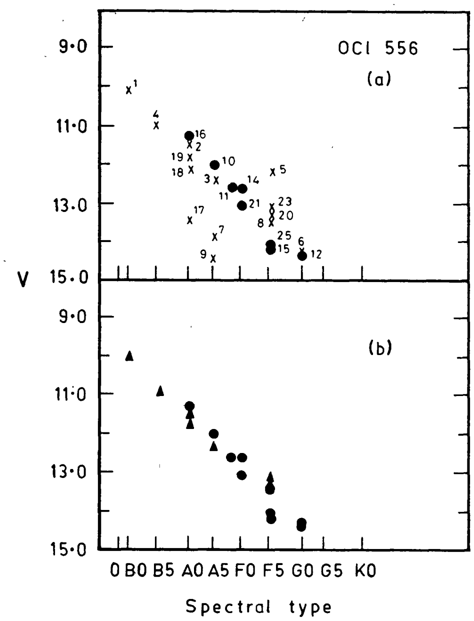

Figure 17. (a) Spectral type plotted against V magnitude for stars of OCl 556. The filled circles and the crosses represent the members and the non-members respectively. (b) Spectral type versus magnitude diagram after deleting the non-members. The filled circles represent the northern group, while the filled triangles denote those of the southern group (see text).

Fig. 17(a) shows the HR diagram for all the numbered stars except star 13, whose spectral type and magnitude could not be obtained. In this figure, stars 5, 7, 9 and 17 are obvious non-members, while star 18 is tentatively discarded because of its location at the edge of the field. Since stars 1, 2, 3, 4, 19, 20 and 23 also are located as farther away as star 18 from the core of the physical group, they are not considered as members of this cluster. However, these stars appear to be members of the southern group and are denoted by filled triangles in Fig. 17(b). On the other hand, stars 10, 11, 12, 14, 15, 16, 21 and 25 are the likely members of the northern group. Stars 6 and 8 have tentatively been included into the northern group, though they are situated at an intermediate position. The earliest spectral type is B0 in the southern cluster and A0 in the northern one.

The field configuration is quite similar to that around BD $-16°$ 1999 = Bo 4 + 5 (Moffat & Vogt 1975). However, while Bo 4 and 5 appear to be at different distances, the main sequences of both the groups comprising OCl 556 are superimposed on each other as seen in Fig. 17(b). Thus, OCl 556 could be either an extended cluster with a foreground strip of interstellar matter cutting across it or two different clusters located almost at the same distance. If the second case turns out to be true, this cluster may provide evidence for sequential star formation (Elmegreen & Lada 1977).

5. Conclusions

We conclude that the spectral type versus V magnitude diagrams work well to establish the cluster reality. Telescope time is needed only for the objective-grating spectroscopy, while the V magnitudes can be obtained from the existing POSS charts. It is possible to observe much fainter stars with this method and thereby pick out the young clusters at greater distances.

Acknowledgements

I solemnly dedicate this paper to the memory of late Professor M. K. V. Bappu, who initiated this programme and gave me the opportunity to collaborate with him. I will remain highly indebted to him for his guidance and encouragement. I am grateful to Professor J. C. Bhattacharyya for a critical reading of the manuscript and for numerous helpful comments. The valuable suggestions of the referees are also gratefully acknowledged.

References

Alter, G., Balazs, B., Ruprecht, J. 1970, *Catalogue of Star Clusters and Associations*, 2 edn, Akademiai Kiado, Budapest.
Arp, H. 1960, *Astrophys. J.*, **131**, 322.
Bappu, M. K. V. 1978, in *Modern Techniques in Astronomical Photography*, Eds R. M. West and J. L. Heudier, ESO, p. 263.
Becker, W. 1963, *Z. Astrophys.*, **57**, 117.
Bok, B. J., Bok, P. F. 1981, *The Milky Way*, 5 edn, Harvard University Press, Cambridge, Chapter 10.
Elmegreen, B. G., Lada, C. J. 1977, *Astrophys. J.*, **214**, 725.
FitzGerald, M. P., Moffat, A. F. J. 1976, *Sky Telesc.*, **52**, 104.
Haffner, H. 1957, *Z. Astrophys.*, **43**, 89.
Hoag, A. A., Johnson, H. L., Iriarte, B., Mitchell, R. I., Hallam, K. L., Sharpless, S. 1961, *Publ. U.S. nav. Obs.*, **17**, 418.
Hoag, A. A., Schroeder, D. J. 1970, *Publ. astr. Soc. Pacific*, **82**, 1141.
Humphreys, R. M. 1979, in *IAU Symp.* 84: *The Large Scale Characteristics of the Galaxy*, Ed. W. B. Burton, D. Reidel, Dordrecht, p. 93.
McCarthy, C. C., Miller, E. W. 1973, *Astr. J.*, **78**, 33.
McCarthy, C. C., Miller, E. W. 1974, *Astr. J.*, **79**, 1396.
Miller, E. W., Graham, J. A. 1974, *Publ. astr. Soc. Pacific*, **86**, 829.
Moffat, A. F. J., Vogt, N. 1975, *Astr. Astrophys. Suppl. Ser.*, **20**, 85.
Muzzio, J. C., McCarthy, C. C. 1973, *Astr. J.*, **78**, 924.
Ruprecht, J. 1966, *Bull. astr. Inst. Csl.*, **17**, 33.
Van den Bergh, S. 1957, *Astr. J.*, **62**, 100.
Vogt, N., Moffat, A. F. J. 1972, *Astr. Astrophys. Suppl. Ser.*, **7**, 133.
Vogt, N., Moffat, A. F. J. 1973, *Astr. Astrophys. Suppl. Ser.*, **9**, 97.