ASTRONOMY & ASTROPHYSICS
SUPPLEMENT SERIES

MAY II 1995, PAGE 75

Astron. Astrophys. Suppl. Ser. **111**, 75-84 (1995)

A deep $UBVRI$ CCD photometric study of the moderately young southern open star cluster NGC 4755 = κ Crucis*

R. Sagar[1,2] and R.D. Cannon[2]

[1] Indian Institute of Astrophysics, Bangalore 560034, India
e-mail address: sagar@iiap.ernet.in
[2] Anglo-Australian Observatory,P.O. Box 296, Epping NSW 2121, Australia
e-mail address: rdc@aaoepp2.aao.gov.au

Received August 19; accepted November 28, 1994

Abstract. — CCD observations in U, B, V, R and I passbands have been used to generate $(U-B)$, $(B-V)$ colour-colour and deep V, $(B-V)$; V, $(U-B)$ and V, $(V-I)$ colour-magnitude diagrams for the young open cluster NGC 4755. The sample consists of 813 stars reaching down to $V \sim 20$ mag. There appears to be non-uniform extinction over the face of the cluster with a mean value of $E(B-V) = 0.41$ mag and a range of about 0.05 mag. The true distance modulus to the cluster has been estimated as 11.6±0.2 mag. An age of ~ 10 Myr has been assigned to the post-main sequence (MS) cluster members. Ages of the post-MS and pre-MS stars indicate that massive ($M > 10\ M_\odot$) and low mass ($M < 2\ M_\odot$) stars in the cluster are formed nearly at the same time from a molecular cloud which might have existed for a minimum period of about 6 − 7 Myr.

Key words: stars: formation — HR diagram — open clusters and associations: individual: NGC 4755

1. Introduction

It was believed for quite some time that all stars in a cluster have the same age. Contrary to that it is now clear that in young (age < 10^8 yr) open clusters they do not have the same age (cf. Adams et al. 1983; Sagar 1985a and references therein). Therefore, it is useful to determine the length of time over which star formation was active in a particular region. This comes from the spread in ages of stars in a moderately young (~ 20−50 Myr) open cluster because only in these objects we can hope to identify by photometric and other types of studies, all the stars formed in a particular event. The spread in ages of cluster members may also place a lower limit on the time during which the parent molecular cloud must have existed. It may also answer the related question of, which stars form first – high mass or low mass ones or they formed together. One may also be able to investigate the so-called *Pleiades problem*, whereby the age calculated from the main sequence (MS) turn-off is not consistent with that from low-mass stars contracting onto the main sequence, using conventional models in each case. However, according to Mazzei & Pigatto (1989), such problem does not exist if the Pleiades turn -off age is based on the isochrones derived from the convective core overshooting stellar evolutionary models.

In order to address the questions raised above, there is a considerable advantage in focussing attention on the faint ($V \sim 16-18$ mag) multicolour stellar photometry of moderately young open clusters. The advantage for age spread determination is that both their nuclear age (τ_n) and contracting age (τ_c) may be estimated. τ_n comes from fitting theoretical isochrones to the most luminous stars in the cluster. They must show significant effects of evolution for a reliable estimate of τ_n (Sagar 1985b), and hence clusters should be a few tens of million years old. τ_c is the pre−main sequence contraction time for low mass stars which have just arrived on the zero−age main−sequence (ZAMS). For its reliable estimation, one should identify the low−luminosity turn−on point for the cluster, which can be done confidently only if one can observe some pre−MS stars. The colour magnitude diagrams (CMDs) of moderately young open clusters show the effect of evolution at the brighter end and contain pre−MS stars at the fainter end and hence are useful for the present purpose. Consequently, we have selected five such objects namely NGC 3228, 4103, 4755, 5662 and 6087 to address the ques-

Send offprint requests to: R. Sagar: Indian Institute of Astrophysics, Bangalore 560034, India
*Table 4 is available in electronic form via an anonymous ftp 130.79.128.5 copy at the CDS

Table 1. Published photometric observations for NGC 4755. N is the number of stars observed and V_l is the limiting V magnitude of the photometric observations

Source	N	V_l (mag)	Observations	Photometric System
Arp & van Sant (1958)	17	13.4	photoelectric	Cape UBV
Arp & van Sant (1958)	202	13.9	photographic	Cape UBV
Graham (1967)	5	8.0	photoelectric	H_β
Schild (1970)	17	10.2	photoelectric	UBV
Perry *et. al.* (1976)	60	13.5	photoelectric	UBV
Perry *et. al.* (1976)	37	11.5	photoelectric	uvbyH_β
Shobbrook (1984)	46	13.5	photoelectric	uvby
Dachs & Kaiser (1984)	86	15	photoelectric	UBV
Dachs & Kaiser (1984)	553	16	photographic	UBV
Kjeldsen & Frandsen (1991)	~ 140	18	CCD	UBV and Gun r
Balona & Koen (1994)	142	15	CCD	uvbyH_β

tions raised above. *UBVRI* photometry and other results for NGC 4755 are presented here.

The southern galactic cluster NGC 4755 (C1250−600; l =303°.2, b=2°.5) is also known as Herschel's Jewel Box or κ Crucis. It is very rich and has been classified as Trumpler class I3r (cf. Lyngå 1987). Several photometric (Arp & van Sant 1958; Graham 1967; Schild 1970; Perry et al. 1976; Shobbrook 1984; de Waard et al. 1984; Dachs & Kaiser 1984; Kjeldsen & Frandsen 1991; Balona & Koen 1994) as well as spectroscopic (Feast 1963; Schild 1970) studies have been carried out for this cluster. The number of stars observed by various investigators in different photometric systems are given in Table 1 along with the limiting magnitude of the photometry. Most of the photometric studies are limited to $V \sim 14$ mag. Therefore it is impossible to study the pre-MS stellar evolutionary phase of the cluster members. Stellar photometric stability within the cluster members has been studied by Frandsen et al. (1989) using CCD observations taken in Johnson V and Gunn r filters. The chemical compositions of some bright stars have been estimated by Brown et al. (1986). They find that the abundances of cluster stars, deduced from comparison with LTE and non-LTE model atmosphere calculations, are generally consistent with a normal (or approximately solar) stellar composition. In order to separate bright ($V \leq 12.5$ mag) cluster members from field stars, King (1980) has estimated relative proper motion in the cluster region for 164 stars with an accuracy of ±0.06 arcsec per century and found that 89 of them are likely to be cluster members. Using those proper motion members which have *UBV* photoelectric photometric and/or spectroscopic measurements, Sagar (1987) has studied the variable interstellar extinction in the cluster and found that the values of colour excess, $E(B-V)$ (which is an indicator of interstellar extinction) range from 0.30 to 0.55 mag with a mean value of 0.41 mag. They show random spatial variation but have no correlation with either spectral type or luminosity of the star.

The observations and reductions have been described in the next two sections. The variable extinction, other photometric results and the question of star formation processes have been described in the other sections of the paper.

2. Observations

The observations for the cluster regions and standard stars were carried out between 27 March - 2 April 1989 and 22 - 28 June 1989 in the *UBVR* and I bands using a blue coated GEC P8603 CCD Astromed Comp detector at the $f/8$ Cassegrain focus of the ANU 1.0 metre telescope located at Siding Spring Observatory. At the Cassegrain focus a pixel (which is 22 microns square) of the 385 × 578 size CCD corresponds to 0.56 arcsec on the sky. The read out noise for the system was about 8 electrons per pixel and the number of electrons per ADU is equal to 1. Flat-field exposures ranging from 1 to 5 s in each filter were made of twilight sky. Thirteen E-region standards namely E4-7-K, E4-37-S, E5-c, E5-k, E5-m, E5-o, E5-59-Y, E6-98, E6-8-M, E6-40-X, E7-m, E7-s and E7-u (cf. Graham 1982) were observed for calibration purposes. The two regions marked on plate 1 (Fig. 1) were observed for the construction of the CMD of the cluster. The centre of Region 1 is located ~ 3.2 arcmin south-west while that of Region 2 ~ 3.5 arcmin north-east to the cluster centre marked by Dachs & Kaiser (1984). The regions were chosen in a way to exclude the very bright cluster members, but include some previously photoelectrically observed stars and also to assure that they are not far from the cluster nucleus, thus maximising the number of measurable cluster members and minimising the proportion of field stars included in the CMD. For this purpose 2−3 graded exposures of both regions in each pass bands were taken (see Table 2). They range from 200 to 600 s in U, from 20 to 600 s in B and from 1 to 300 s in V, R and I.

Table 2. Log of CCD observations in NGC 4755

Region	Filter	Exposure time (Seconds)	Date
1	U	100, 600	27/28 March 1989
	B	20, 200, 600	"
	V	1, 10x2, 100x2, 300	"
	I	1, 10, 300	"
2	U	100, 600	25/26 June 1989
	B	60, 500	"
	V	20, 100, 300	"
	R	10, 100	"
	I	10, 100	"

3. Reductions

The data were reduced on the Anglo-Australian Observatory, Epping VAX 11/780 and micro VAX 3500 computers. The flat-field and data CCD frames were bias subtracted and trimmed using the FIGARO software. The flat-field frames were summed for each colour band. This reduces the addition of extra noise in the data frames when they are flat-fielded, which will ultimately improve the accuracy of the magnitude estimation of faint stars. The evenness of flat fields are better than a few percent in all the filters.

The magnitude estimate of a star on the data frames has been done using DAOPHOT software (Stetson 1987, 1992). Further processing and conversion of these raw instrumental magnitudes into standard photometric system have been done using the procedure outlined by Stetson (1992). The image parameters and errors provided by DAOPHOT were used to reject poor measurements. About 10% stars were rejected in this process. DAOMASTER programme was used for cross identifying the stars measured on different frames of a cluster region. In those cases where brighter stars are saturated on deep exposure frames, their magnitudes have been taken only from the short exposure frames. Most of the stars brighter than $V \sim 10.5$ mag could not be measured because they are saturated even on the shortest exposure frames.

In deriving the colour equations for the CCD system and evaluating the zero-points for the data frames, we have used the mean values of atmospheric extinction for the site. The colour equations for the CCD system were determined by performing aperture photometry on the photoelectric E-region standards which cover a range in brightness (8.8 mag $\leq V \leq$ 16.5 mag) as well as in colour (0.03 mag $\leq (V-I) \leq$ 1.73 mag). By fitting least square linear regressions in the observed aperture magnitudes as a function of the standard photometric indices, following colour equations are derived for the system:

$$\Delta u_{\rm ccd} = \Delta U + 0.07(\pm 0.03)(U-B)$$

$$\Delta b_{\rm ccd} = \Delta B - 0.15(\pm 0.01)(B-V)$$

$$\Delta v_{\rm ccd} = \Delta V + 0.001(\pm 0.002)(V-I)$$

$$\Delta r_{\rm ccd} = \Delta R + 0.05(\pm 0.01)(V-R)$$

$$\Delta i_{\rm ccd} = \Delta I - 0.01(\pm 0.01)(V-I)$$

where $UBVR$ and I are the standard magnitudes taken from Graham (1982) and $u_{\rm ccd}$, $b_{\rm ccd}$, $v_{\rm ccd}$, $r_{\rm ccd}$ and $i_{\rm ccd}$ are CCD aperture magnitudes. For establishing the local standards, we selected about 30 isolated stars in both the cluster regions and used DAOGROW programme for the construction of aperture growth curve required for determining the difference between aperture and profile-fitting magnitudes. These differences and difference in exposure times and atmospheric extinctions are used in evaluating zero-points for the reference cluster frames. In both the imaged regions, there is a good agreement (within ±0.02 mag) between the zero-points estimated from E- region standards and from stars observed photoelectrically by Dachs & Kaiser (1984). This indicates that calibration procedure has not introduced any systematic error in the magnitudes of the stars of the two regions. The zero-points are uncertain by $\sim$ 0.02 mag in U and B and by $\sim$ 0.01 mag in V, R and I. The internal errors estimated from the scatter in the individual measures of different exposures are listed in Table 3 as a function of magnitude for all filters. The errors are large (more than 0.10 mag) for stars fainter than V = 17 mag.

Table 3. Internal photometric errors as a function of brightness. σ is the standard deviation per observation in magnitude

Magnitude range	σ_U	σ_B	σ_V	σ_R	σ_I
≤ 11.0	0.002	0.004	0.008	0.012	0.012
11.0 – 12.0	0.005	0.006	0.009	0.016	0.014
12.0 – 13.0	0.011	0.007	0.012	0.023	0.024
13.0 – 14.0	0.017	0.013	0.015	0.027	0.037
14.0 – 15.0	0.048	0.025	0.021	0.050	0.043
15.0 – 16.0	0.080	0.040	0.027	0.072	0.068
16.0 – 17.0	0.094	0.050	0.046	0.085	0.078
17.0 – 18.0	-	0.065	0.072	-	0.127

The X and Y pixel coordinates as well as V, $(U-B)$, $(B-V)$, $(V-R)$ and $(V-I)$ magnitudes of the stars observed in both regions of NGC 4755 are listed in Table 4 along with the number of observations in each filter. A few bright stars are identified in Fig. 1. Stars observed by Arp & van Sant (1958) and Dachs & Kaiser (1984) have also been identified in Table 4 (available electronically).

We compare the present CCD photometry with the available photoelectric and photographic observations. The differences (Δ) between the present data and data obtained by others are plotted in Fig. 2 and the statistical

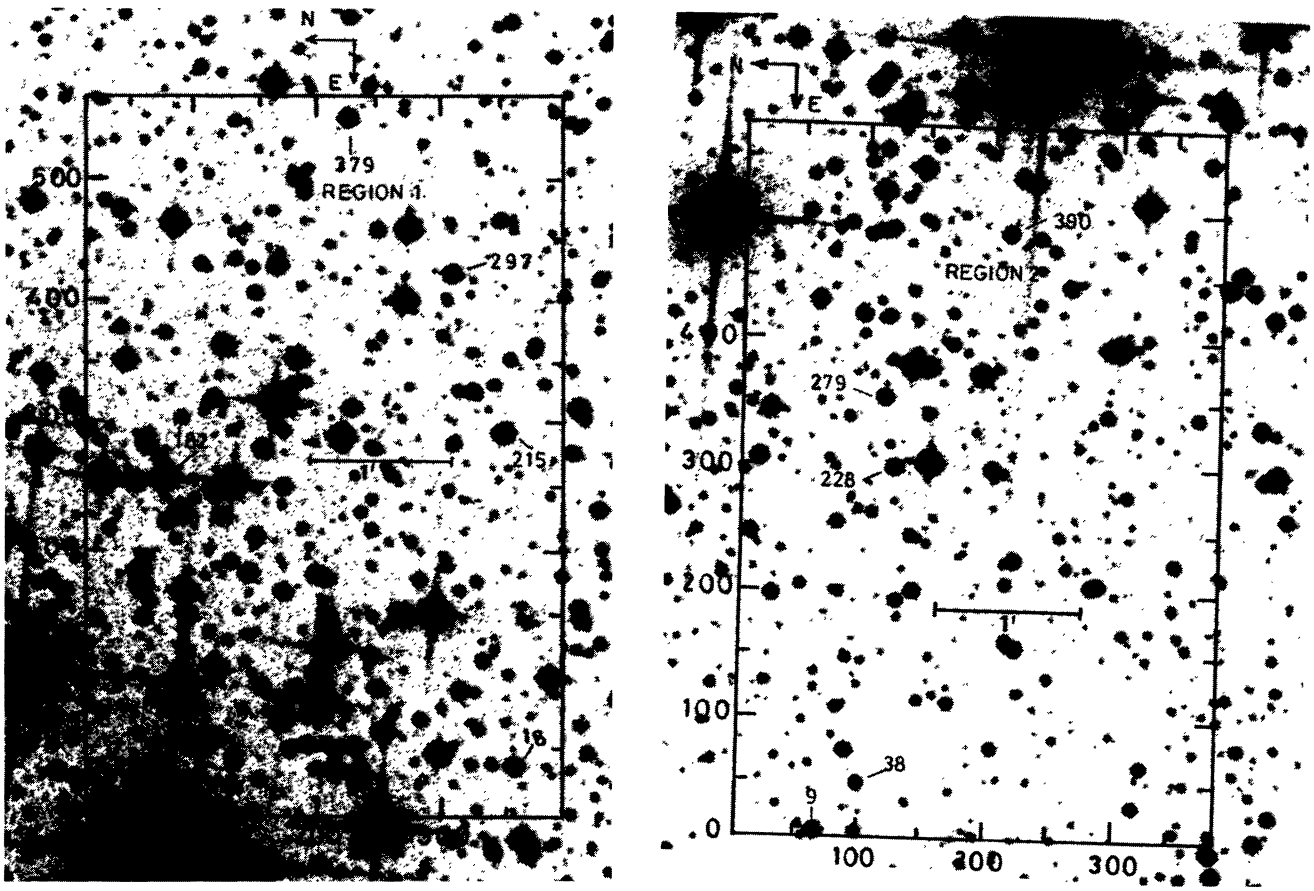

Fig. 1. Identification map for the imaged regions. Region 1 and 2 correspond to quadrants IV and II in Fig. 1a of Dachs & Kaiser (1984). They are located at ~ 3.2 and 3.5 arcmin away from the cluster centre in the south-west and north-east parts of the cluster respectively. The map is reproduced from the B glass plate of the ESO sky survey. The size of a CCD frame is 3.5 × 5.4 arcmin and the coordinates are in pixel units

Table 5. Statistical results of the photometric comparison. The difference (Δ) is always in the sense present minus comparison data. The mean and standard deviation (σ) are based on N stars. A few points discrepant by more than 3.5 σ have been excluded from the analysis

Comparison data	ΔV		Δ(B-V)		Δ(U-B)	
	Mean ±σ	N	Mean ±σ	N	Mean ±σ	N
Dachs & Kaiser (1984) photoelectric data	-0.045±0.060	14	0.006±0.029	15	-0.017±0.070	15
Dachs & Kaiser (1984) photographic data	-0.136±0.124	59	-0.007±0.147	59	-0.018±0.189	59
Arp & van Sant (1958) photoelectric	0.047±0.074	3	-0.018±0.040	4		
Arp & van Sant (1958) photographic	0.083±0.111	13	-0.218±0.180	13		
Perry et al. (1976) photoelectric	-0.055±0.053	6	0.027±0.044	7	-0.002±0.038	7

results are listed in Table 5. These show that:

i) in general the *UBV* photoelectric photometric data are in fair agreement with the present CCD data. The largest discrepancy in ΔV is ~ 0.45 mag for the star H observed by Dachs & Kaiser (1984). Inspection of CCD images indicates that photoelectric measurements of this star have been affected by the presence of a nearby star (Star 104 in Region 1) of similar $(B-V)$ colour which is ~ 1 mag fainter in V. The agreement between the photoelectric and present CCD data becomes excellent if the total light of the star and its companion in the CCD measurement is calculated, mimicking aperture photometry.

ii) the *UBV* photographic data of Dachs & Kaiser (1984) show no systematic difference with the CCD data in $(U-B)$ and $(B-V)$ colours. However, in comparison to CCD data, photographic V magnitudes are system-

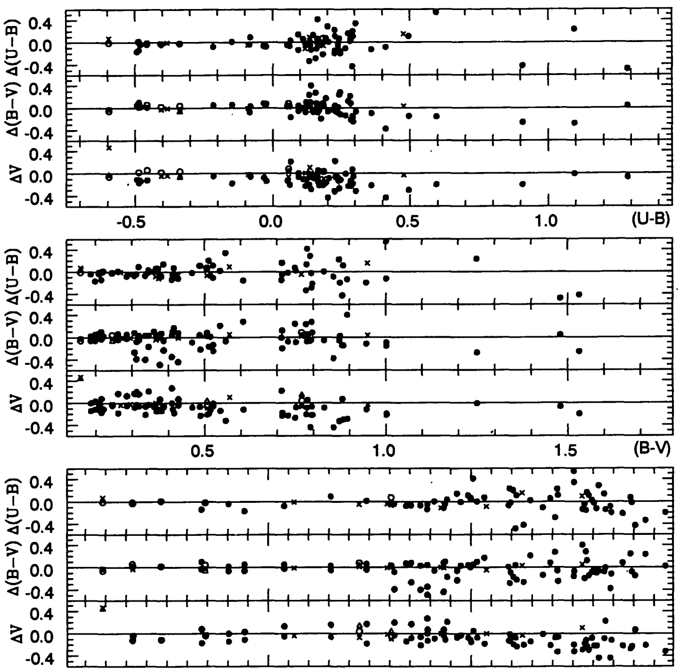

Fig. 2. A comparison of present photometry with data given by Arp & van Sant (1958), Perry et al. (1976) and Dachs & Kaiser (1984). The differences (Δ) are in the sense present minus others' data, plotted against the CCD photometry. Photoelectric data by Dachs & Kaiser (1984); Perry et al. (1976) and Arp & van Sant (1958) are denoted by crosses, open circles and triangles respectively, while photographic data by Dachs & Kaiser (1984) and Arp & van Sant (1958) are denoted by filled circles and asterisks respectively

atically fainter by $\sim$ 0.15 mag. In the case of Arp & van Sant's (1958) photographic data, $(B-V)$ colours are systematically redder by $\sim$ 0.25 mag. Scatter in data points is relatively more for stars fainter than V = 14 mag.

4. Interstellar extinction

Based on $uvby\mathrm{H}_\beta$ photometric observations, Shobbrook (1984) and Balona & Koen (1994) conclude that extinction is uniform over the cluster face. But their data show a variation of $\sim$0.12 mag in the value of colour excess $E(b-y)$ over the cluster region (cf. Alfaro & Delgado 1991; Balona & Koen 1994). An analysis based on UBV photometric and MKK spectral type by Dachs & Kaiser (1984) and Sagar (1987) also indicate a small variation in interstellar extinction across the cluster face. The value of $E(B-V)$ varies from 0.32 mag to 0.54 mag with a mean value of 0.41 mag. The spatial variation of $E(B-V)$ is random (cf. Table 5 by Sagar 1987), although relatively larger values of $E(B-V)$ are found in the north-east area (Region 2 in Fig. 1) of the cluster. In order to see whether the regions under study have the same value of $E(B-V)$ or not, we plotted $(U-B)$, $(B-V)$ diagram (Fig. 3) and V, $(U-B)$; V, $(B-V)$ and V, $(V-I)$ diagrams (Fig. 4) for stars of both regions and notice that:

i) in Fig. 3, $(B-V)$ colour of Region 1 stars are systematically bluer than Region 2 stars for a given value of $(U-B)$ amongst stars with $(B-V) < 0.45$ mag.

ii) in stars brighter than $V \sim 16$ mag (see Fig. 4), all photometric colours of Region 2 stars are systematically redder than those of stars in Region 1 at a given V magnitude.

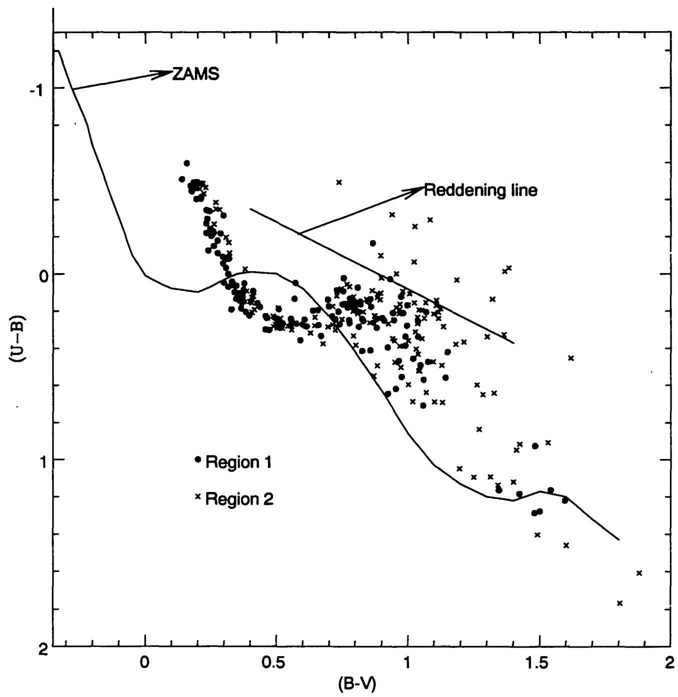

Fig. 3. The $(U-B)$ versus $(B-V)$ diagram for the stars observed by us. The slope of the reddening line is 0.72. The continuous curve represents the locus of unreddened zero−age main-sequence (ZAMS) taken from Schmidt−Kaler (1982)

These points indicate that stars of Region 2 suffer more extinction compared to stars in Region 1 which is in agreement with the results of Sagar (1987). To quantify the value of $E(B-V)$, we applied the Q method (cf. Johnson & Morgan 1953; Sagar & Joshi 1979) on early type stars with $(B-V) < 0.5$ mag. There are 64 such stars in the Region 1 and 26 in the Region 2. Figure 5 shows the frequency distribution of $E(B-V)$ as well as plot of $E(B-V)$ versus intrinsic V magnitude and $(B-V)$ colour for the early type stars of both regions. This indicates that the mean value of $E(B-V)$ for a region is independent of luminosity and temperature of the stars. The median value of $E(B-V)$ is 0.39 mag for stars of Region 1 and 0.44 mag for stars of Region 2. Stars with $12 < V_0 < 13$ and $-0.08 < (B-V)_0 < 0.0$ show large scatter in their $E(B-V)$ values (Fig. 5). This may be due to the presence of either circumstellar material around stars or

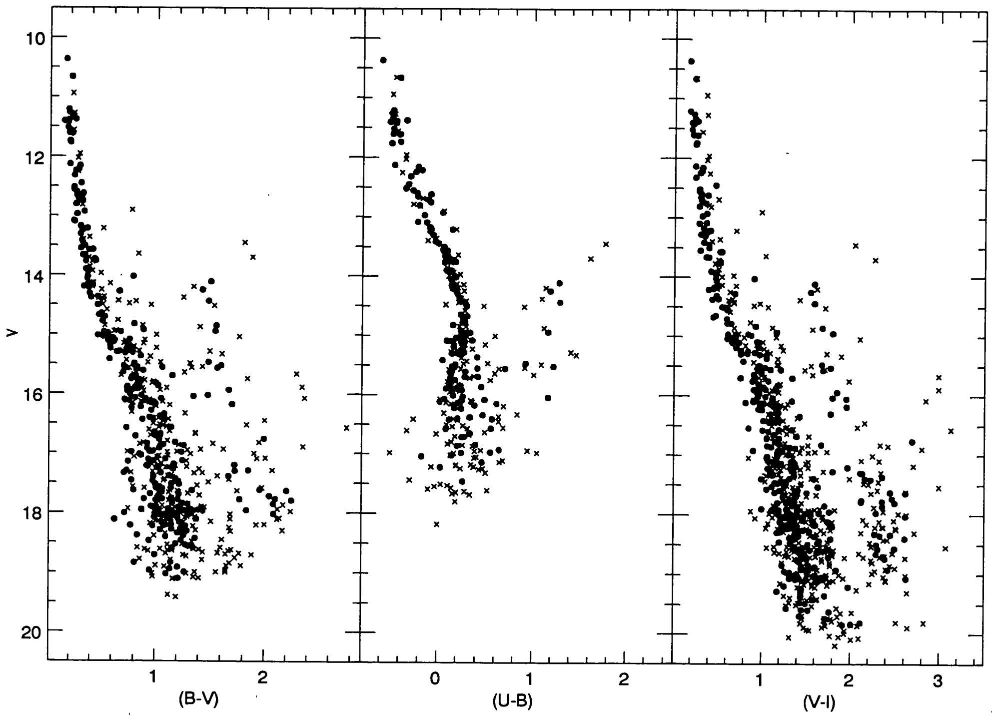

Fig. 4. The V, $(B-V)$; V, $(U-B)$ and V, $(V-I)$ diagrams for the stars observed by us. Symbols mean the same as in Fig. 3

patchy distribution of interstellar matter in the cluster region. Further infrared and spectroscopic observations are needed to understand the cause of scatter in Fig. 5. To see whether the law of interstellar extinction in the direction of the cluster is normal or not, we used the present data in combination with UBV photoelectric data of Dachs & Kaiser (1984) and analysed in the following way :

i) The $E(U-B)$ and $E(B-V)$ values have been calculated for the King's (1980) proper motion cluster members having MKK spectral classification (available for 28 stars from Mermilliod 1992) and photoelectric UBV values using the calibration given by Schmidt-Kaler (1982). The mean value of $E(U-B)/E(B-V)$ ratio is 0.74±0.10.

ii) For stars with $(B-V) < 0.5$ mag, $(B-V)_0$ values are determined using UBV photometric Q method mentioned above. The $E(B-V)$ and $E(V-I)$ values are calculated using Walker's (1985) calibration between $(B-V)_0$ and $(V-I)_0$ and the present $(B-V)$ and $(V-I)$ measurements. The mean value of the ratio $E(V-I)/E(B-V)$ is 1.23 ± 0.11 .

iii) For a normal interstellar extinction law, the ratio $E(U-B)/E(B-V) = 0.72$ (Schmidt-Kaler 1982) and $E(V-I)/E(B-V) = 1.24$ (Dean et al. 1978). The mean values of these ratios obtained above are in good agreement with the normal values indicating that the law of interstellar extinction in the direction of the cluster is normal.

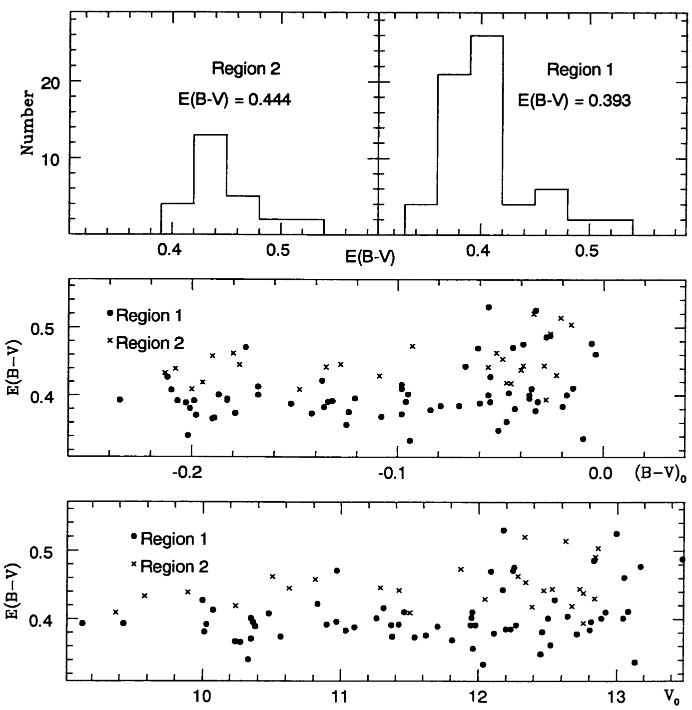

Fig. 5. The frequency distribution of $E(B-V)$ as well as the dependence of $E(B-V)$ on V_0 and $(B-V)_0$ are shown here for the stars of both regions. Median values of $E(B-V)$ for both regions are also indicated

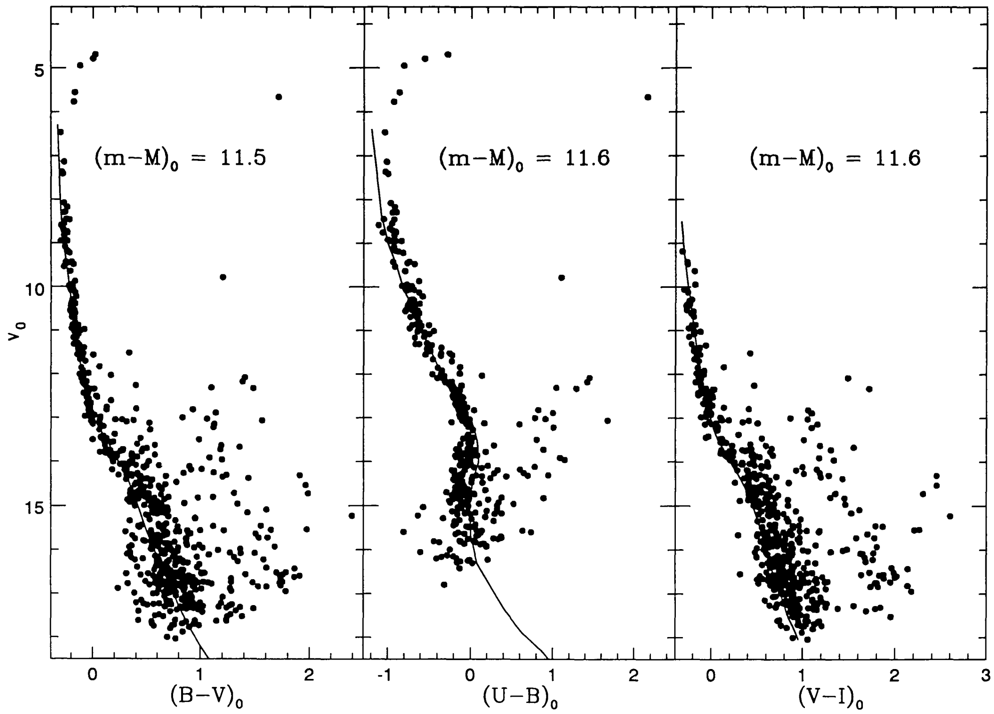

Fig. 6. The V_0, $(B-V)_0$; V_0, $(U-B)_0$ and V_0, $(V-I)_0$ diagrams for stars observed by us as well as for stars observed photoelectrically in *UBV* passbands by Dachs & Kaiser (1984). Continuous curves are the ZAMS fitted to the unevolved part of the cluster MS for the values indicated in the diagram. The mean value of distance modulus $(m-M)_0$ to the cluster is 11.6 mag

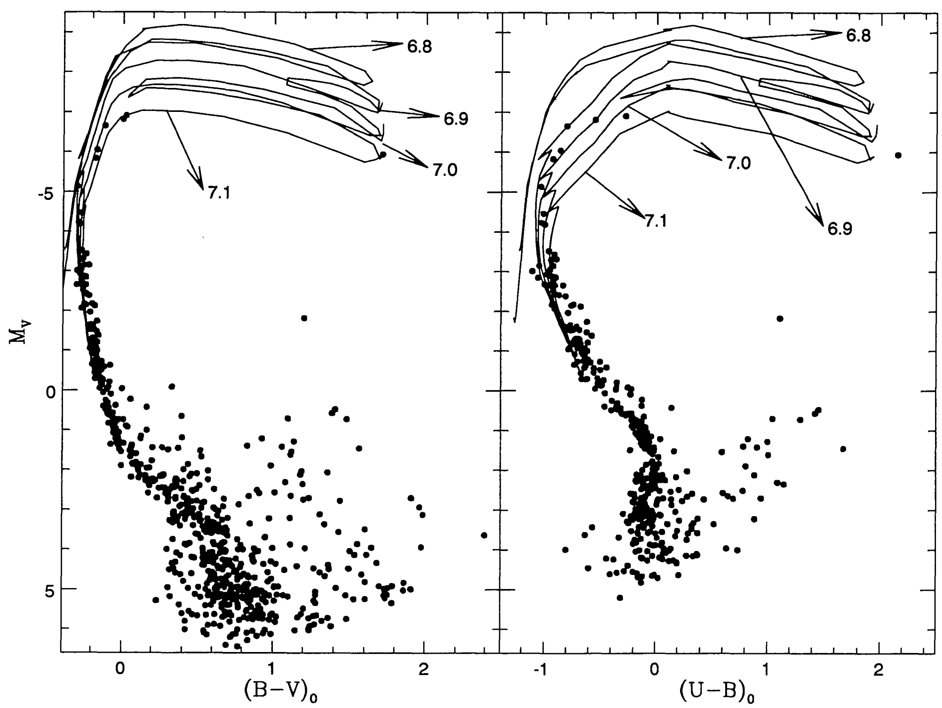

Fig. 7. The M_v, $(B-V)_0$ and M_v, $(U-B)_0$ diagrams. Isochrones fitted to the cluster sequence are taken from Maeder & Meynet (1991). They have been derived from the convective core overshooting stellar evolutionary models of Pop I stars. They indicate that the age of the cluster is ~ 10 Myr

5. Distance to the cluster

In order to determine the distance modulus of NGC 4755, we have plotted V_0, $(B-V)_0$; V_0, $(U-B)_0$ and V_0, $(V-I)_0$ diagrams for all the stars measured by us in Fig. 6. King's (1980) proper motion cluster members observed photoelectrically in *UBV* system by Dachs & Kaiser (1984) but not present in our sample have also been plotted in the figure. For plotting this figure, we have converted apparent V magnitude and $(B-V)$, $(U-B)$ and $(V-I)$ colours into intrinsic ones using the values of $E(B-V)$ and following relations for $E(U-B)$ (cf. Kamp 1974; Sagar & Joshi 1979), A_v and $E(V-I)$ (Walker 1987)

$$E(U-B) = [X + 0.05\ E(B-V)]E(B-V)$$

where $X = 0.62 - 0.3(B-V)_0$ for $(B-V)_0 < -0.09$ and $X = 0.66 + 0.08(B-V)_0$ for $(B-V)_0 > -0.09$;

$$A_v = [3.06 + 0.25(B-V)_0 + 0.05\ E(B-V)]E(B-V)$$

and

$$E(V-I) = 1.25 \times E(B-V)[1 + 0.06(B-V)_0 + 0.014\ E(B-V)$$

The individual values of $E(B-V)$ have been used for stars with spectral type earlier than A0 (generally $V <$ 13 mag) as they are known (see Sect. 4). For fainter stars, the median $E(B-V)$ value of the region (i.e. $E(B-V)$ = 0.39 for Region 1 stars and 0.44 for Region 2 stars) has been used since individual values are not known.

In the V_0, $(U-B)_0$ and V_0, $(B-V)_0$ diagrams, we fitted the ZAMS given by Schmidt-Kaler (1982) while the ZAMS given by Walker (1985) was fitted in the V_0, $(V-I)_0$ diagram. After accounting for the colour dispersion expected from the error in observations, the visual fit of the ZAMS to the bluest envelope of the CMDs give $(m-M)_0 = 11.6$ mag from V_0, $(U-B)_0$ and V_0, $(V-I)_0$ and 11.5 mag from V_0, $(B-V)_0$. The mean value of $(m-M)_0$ is 11.6±0.2 mag where the error is estimated from the errors in R, $E(B-V)$ and the errors in fitting the ZAMS. This yields a distance of 2.1±0.2 kpc to the cluster. The present value of distance modulus is in good agreement with the values of 11.86, 11.6, 11.8, 11.4, 11.82, 11.85 and 11.55 mag estimated by Feast (1963), Schild (1970), Perry et al. (1976), Shobbrook (1984), Dachs & Kaiser (1984), Kjeldsen & Frandsen (1991) and Balona & Koen (1994) respectively. The present value can be considered reliable as it has been derived by fitting the ZAMS over a wide range of V ($\sim$ 7 mag) of the cluster MS.

6. HR diagram of the cluster

The M_v, $(B-V)_0$ and M_v, $(U-B)_0$ diagrams for the stars observed by us as well as for the King's (1980) proper motion members observed photoelectrically by Dachs & Kaiser (1984) but not present in our sample have been plotted in Fig. 7 for a non-uniform extinction as described in Sect. 4 and for a true distance modulus of 11.6 mag. From the diagrams, the following inferences can be drawn:

1) An evolutionary effect is clearly visible in the upper part of the cluster MS. One proper motion cluster member has reached the giant phase of the evolution.
2) A well defined cluster MS which extends from $M_v =$ -5 to 2 mag is clearly seen.
3) On the cluster MS, in the magnitude range $M_v =$ -1.75 to -2.1 mag (i.e., $\Delta M_v = 0.35$ mag), there is only one star, while on the both fainter and brighter side of this region stellar density is large. We have therefore called it as a gap on the cluster MS. The reality of the observed gap is tested by the chi-square criterion (Hawarden 1971). The probability that the gap is an accidental result is about 0.8 percent. The $(B-V)_0$ and $(U-B)_0$ colours at the location of the gap are -0.22 and -1.0 mag respectively. From its position in the HR diagram, it appears that this gap is different from the gaps found in many other open clusters (cf. Sagar & Joshi 1978a, b), where they are due to hydrogen exhaustion phase in the evolution of the MS stars having convective cores. Presently it is not clear whether this gap is caused by some stellar atmospheric effects e.g. those invoked by Böhm-Vitense & Canterna (1974) for understanding the gaps found between spectral types A7 - F0V; or by some peculiarities mentioned by Mermilliod (1976) for explaining the gaps located between the spectral types B7 and B8V; or by initial star formation conditions in the cluster or by some unknown physical processes.
4) Stars below $M_v = 0.0$ mag show a large spread (compared to the spread expected from observational errors) in colour at a given brightness level. The main reasons for such spread could be the presence of field stars and pre-MS stars. It is difficult to separate field stars from the cluster members only on the basis of their closeness to the main populated area of the diagrams because field stars at the distance of the cluster and with same reddening will also occupy this area. To know the actual number of cluster members in the sample, their precise proper motion and/or radial velocity measurements are required. However, analyses carried out in the next section indicate that some of them are indeed pre-MS stars.

7. Ages of the cluster members

The stars brighter than $M_v = -5$ mag show evolutionary effects. Most of them have proper motion membership probability $p \geq 50\%$ (cf. King 1980). The ages of these stars have been determined by fitting the stellar evolutionary isochrones from Maeder & Meynet (1991). This indicates that the stars have ages in the range of 8 − 12 Myr with a mean value of 10 Myr. This is in good agreement with the range of 8 − 11.5 Myr determined by Dachs & Kaiser (1984) but is slightly higher than the range 5 − 8 Myr estimated by Kjeldsen & Frandsen (1991).

In order to see whether some of the stars fainter than $M_v = 0$ mag are cluster members or not, we divided the stars observed by us into two groups namely 1 and 2 based on their distance from the cluster centre. Stars (located at relatively larger distances from the cluster centre) with y co-ordinates larger than 420 in Region 1 and less than 140 in Region 2 (cf. Fig. 1) are put in Group 2 and the remaining stars in Group 1. The area of Group 1 stars is $\sim$ 3 times as large as that of Group 2 stars. The frequency of the stars of the both groups in different parts of the M_v, $(B-V)_0$ diagrams is listed in Table 6. This indicates that in a particular region of the HR diagram, number of stars in Group 1 is generally more than three times the number of stars in Group 2 up to $M_v \sim 3.5$ mag and the differences are statistically significant (see last column in Table 6). The mean distance of Group 2 stars from the cluster centre is larger than that of Group 1 stars by a factor of ~ 2.5. We therefore consider Group 2 stars as a representative of field star population and subtract them statistically using zapping technique from stars of Group 1. The difference between the area of Group 1 and 2 stars is taken into account in the subtraction procedure by increasing the number of Group 2 stars by a factor of 3. The subtraction procedure works as follows. The star located nearest to the V, $(B-V)$ position of each Group 2 star within a box of size ± 0.5 mag in V and ± 0.25 mag in $(B-V)$ in the CMD of Group 1 stars is deleted. Figure 8 shows the M_v, $(B-V)_0$ diagram of those Group 1 stars which survived the above subtraction process. In this process, some of the cluster members might also have been deleted since the regions containing field star (Group 2) sample are located only $\sim$ 4 arcmin away from the cluster centre while the gravitational radius of the cluster is 5.1 arcmin (Dachs & Kaiser 1984). Consequently, cluster members have been oversubtracted and the probability that a good fraction of the stars in Fig. 8 are cluster members is very high. Inspection of this figure indicates that:

1) most of the stars fainter than $M_v = 1.5$ mag and redder than ZAMS by 0.2 mag are probably in the process of gravitational contraction. This statement is further strengthened by the fact that a large number of them are lying between the theoretical birthline taken from Palla & Stahler (1992) and the ZAMS. The candidates for pre-MS stars are identified in Table 4. In order to make sure, one should look for signatures of pre-MS stars like H_α emission, irregular variability or ultraviolet excess in them, as Adams et al. (1983) did in NGC 2264. Assuming that some of them are indeed the pre-MS stars, isochrones taken from Iben (1965) for 0.03, 0.3, 1, 3 and 10 Myr have been plotted in Fig. 8 for determining their ages. This indicates that most of the pre-MS stars have age between 3 − 10 Myr. Both the fitting of 6 Myr isochrone to the bulk of the points and the clearly visible kink in Fig. 7 may suggest that most of the pre-MS stars have age around 6 Myr.
2) most of the stars fainter than $V_0 = 15.5$ mag in Fig. 6 are field stars (cf. Table 6). It means that turn-up magnitude for the cluster is at $M_v \sim 4$ mag and fainter cluster members have not yet reached the MS.
3) ages of the post-MS and pre-MS stars are not too different. This may indicate that massive ($M > 10\ M_\odot$) and low mass ($M < 2\ M_\odot$) stars are formed almost at the same time in the cluster.

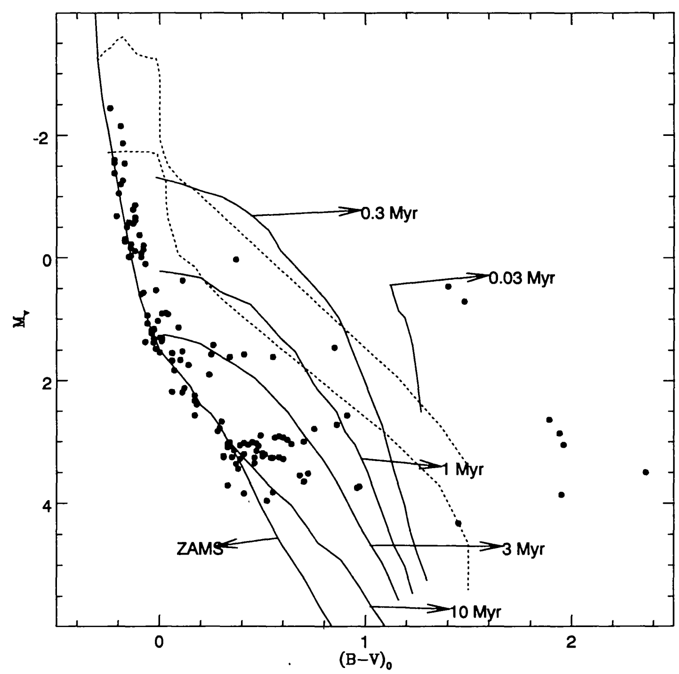

Fig. 8. The M_v, $(B-V)_0$ diagram for the Group 1 stars after field star subtraction (see text). Theoretical stellar evolutionary isochrones taken from Iben (1965) for the pre-MS phase of evolution are plotted. They indicate that the ages of the pre-MS cluster members range from 3 to 10 Myr. The birthline taken from Palla & Stahler (1992) are shown by dotted lines. Upper dotted curve is for a rate of accretion of $10^{-4}\ M_\odot$ per year while the lower one is for that of $10^{-5}\ M_\odot$ per year

It may be noted that in the absence of kinematical data for most of the stars observed by us, it is difficult to separate unambiguously, the cluster members from the field stars only on the basis of present observations.

8. Conclusions

The new U, B, V, R and I CCD photometry down to $V \sim 20$ mag is presented for about 800 stars in the region of the young open cluster NGC 4755. The present work in

Table 6. Frequency distribution in the M_v, $(B-V)_0$ diagram of the Group 1 and 2 stars. N_1 and N_2 denote the number of stars in the Group 1 and 2 respectively. N_m denotes the total number of statistically expected cluster members in the magnitude bin

M_v range	Number of stars in the $(B-V)_0$ range										Total stars		
	-0.3 to 0.0		0.0 to 0.4		0.4 to 0.8		0.8 to 1.2		1.2 to 2.4				
	N_1	N_2	N_1	N_2	N_1	N_2	N_1	N_2	N_1	N_2	N_1	N_2	N_m
-2.5 to -1.5	7	1	0	0	0	0	0	0	0	0	7	1	4
-1.5 to -0.5	18	1	0	0	0	0	0	0	0	0	18	1	15
-0.5 to 0.5	19	2	2	0	0	0	0	0	0	0	21	2	15
0.5 to 1.5	21	2	14	2	0	0	2	1	2	0	39	5	24
1.5 to 2.5	1	0	40	8	6	4	7	1	1	0	55	13	16
2.5 to 3.5	0	0	23	2	41	4	6	3	6	1	76	10	46
3.5 to 4.5	0	0	6	2	52	16	11	3	11	3	80	24	8
4.5 to 5.5	0	0	4	2	49	30	38	9	17	7	108	48	-

combination with earlier photoelectric and spectroscopic observations leads to the following conclusions.

i) Visual fittings of the ZAMS to the cluster sequence in the $V_0, (B-V)_0$, $V_0, (U-B)_0$ and $V_0, (V-I)_0$ diagrams over a broad range of V mag (~ 7) gives a distance of 2.1±0.2 kpc to the cluster.

ii) Variable reddening is present across the cluster with a mean value of $E(B-V) = 0.41$ mag and a range of about 0.05 mag. The law of interstellar extinction in the direction of the cluster is normal.

iii) The dispersion in the evolutionary ages of cluster members indicates that star formation processes in the parent molecular cloud of the cluster might have continued for a minimum of about $6-7$ Myr.

iv) Our data suggest that massive stars have formed about 4 Myr before the bulk of the low mass stars.

Acknowledgements. We gratefully acknowledge the Mount Stromlo Observatory for the allotment of observing time for this project. We thank D.C.V. Mallik, H.C. Bhatt and T. Richtler for reading the manuscript critically. Useful comments given by the referee J. Dachs are gratefully acknowledged. We are thankful to Barry F. Croke and A. Subramaniam for providing the help during observations and reductions respectively. Financial supports for RS provided by Department of Industry, Technology and Commerce of Australia and by IAU are gratefully acknowledged.

References

Adams M.T., Strom K.M., Strom S.E. 1983, ApJS 53, 893
Alfaro E.J., Delgado A.J. 1991, A&A 241, 69
Arp H.C., van Sant C.T. 1958, AJ 63, 341
Balona L.A., Koen C. 1994, MNRAS 267, 1071
Böhm-Vitense E., Canterna R. 1974, ApJ 194, 269
Brown P.J.F., Dufton P.L., Lennon D.J., Keenan F.P. 1986, MNRAS 220, 1003
Dachs J., Kaiser D. 1984, A&AS 58, 411
Dean F.J., Warren P.R., Cousins A.W.J. 1978, MNRAS 183, 569
de Waard G.J., van Genderen A.M., Bijleveld W. 1984, A&AS 56, 373
Feast M.W. 1963, MNRAS 126, 11
Frandsen S., Dreyer P., Kjeldsen H. 1989, A&A 215, 287
Johnson H.L., Morgan W.W. 1953, ApJ 117, 313
Graham J.A. 1967, MNRAS 135, 377
Graham J.A. 1982, PASP 94, 244
Hawarden T.G. 1977, Observatory 91, 78
Iben I. Jr. 1965, ApJ 141, 993
Kamp L.W. 1974, A&AS 16, 1
King D.S. 1980, J. Proc. R. Soc. N. S. W. 113, 65
Kjeldsen H., Frandsen S. 1991, A&AS 87, 119
Lyngå G. 1987, Catalogue of Open Cluster Data, 5th edition, 1/1 S7041, Centre de Données Stellaires, Strasbourg
Maeder A., Meynet G. 1991, A&AS 89, 451
Mazzei P., Pigatto L. 1989, A&A 213, L1
Mermilliod J.–C. 1976, A&A 53, 289
Mermilliod J.–C. 1992, Bull. Inf. CDS 40, 115
Palla F., Stahler S.W. 1992, ApJ 392, 667
Perry C.L., Franklin C.B.Jr., Landoldt A.U., Crawford D.L. 1976, AJ 81, 632
Sagar R. 1985a, Abastumani astrophys. Obs. Mt Kanobili Bull. 59, 191
Sagar R. 1985b, Ap&SS 113, 171
Sagar R. 1987, MNRAS 228, 483
Sagar R., Joshi U.C. 1978a, BASI 6, 12
Sagar R., Joshi U.C. 1978b, BASI 6, 37
Sagar R., Joshi U.C. 1979, Ap&SS 66, 3
Schild R.E. 1970, ApJ 161, 855
Schmidt–Kaler, Th., 1982, In: Landolt/Bornstein, Numerical Data and Functional Relationship in Science and Technology, New series, Group VI, Vol. 2b, eds. K. Scaifers & H.H. Voigt (Springer-Verlag, Berlin) 14
Shobbrook R.R. 1984, MNRAS 206, 273
Stetson P.B. 1987, PASP 99, 191
Stetson P.B. 1992, IAU col. 136 on stellar photometry - current techniques and future developments, eds. C.J. Butler & I. Elliott, in press
Walker A.R. 1985, MNRAS 213, 889
Walker A.R. 1987, MNRAS 229, 31