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A photometric study of the open cluster M39

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Summary. Photoelectric *UBV* magnitudes of 50 stars in the field of M39 have been obtained for most of which previous photoelectric data were not available. These include 36 new members given by Platais (1984). The reddening for the cluster has been found to be 0.03 mag. A distance of 300 pc has been estimated for the cluster. The age of the cluster lies between 2.0×10^8 and 4.0×10^8 yr.

1 Introduction

The sparse Galactic star cluster M39 (l=92°.5, b=−2°.3, NGC 7092, C2130+482) provides an ideal opportunity for the investigation of various modern astrophysical problems specially related to star formation and stellar evolution due to its nearby location. On the basis of reliable proper motion study Platais (1984) found 81 stars as probable cluster members. The cluster M39 has been observed photometrically as well as spectroscopically by several authors [see references in Alter, Ruprecht & Vanysek 1970; Lynga 1981; Mermilliod (*Catalogue of* UBV *photometry and MK spectral types in open clusters,* private communication); Platais 1984], however, the photoelectric *UBV* magnitudes have been obtained only for 38 stars (Johnson 1953; McNamara & Sanders 1977; Platais 1984). For another 20 stars only photoelectric *BV* magnitudes are available while for the remaining stars only approximate photographic *UBV* magnitudes have been obtained by Platais (1984). The lack of photoelectric *UBV* magnitudes for a good number of probable cluster members made this study desirable.

In this work we have carried out photoelectric *UBV* photometry of 50 stars for most of which photoelectric *UBV* magnitudes were not known earlier. On the basis of available photometric observations we have estimated the reddening and distance to the cluster. The colour–magnitude diagram and evolutionary aspects of the cluster have also been discussed.

2 Membership

Cluster membership can be accomplished on one or more criteria namely photometric, kinematic, statistical and spectroscopic. Amongst these the method based on the proper motion study provides relatively more reliable segregation of cluster members from field stars if the

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Table 1. List of existing proper motion studies in the region of M39.

Investigated Area	No. of stars	B limit (mag)	Epoch Difference in years	Pair of plates used	$\sigma\mu$ (arcsec/100 yr)	Reference
$35' \times 35'$	50	~13.0	23	2	0.13	Ebbighausen (1940)
$40' \times 40'$	151	~13.2	36 to 40	5	0.27	Van Schewick (1957)
$80' \times 80'$	1079	~15.2	36 to 53	4	0.19	Lavdovskij (1961, 1965)
Circular $d \sim 300'$	2964	~13.6	64 to 74	13	0.65	Artiukhina & Kalinina (1970)
$70' \times 65'$	1710	~16.0	31 to 66	9	0.18	McNamara & Sanders (1977)
Circular $d \sim 110'$	7931	~16.7	70	9	0.15	Platais (1984)

probable error of an individual proper motion is of the order of ± 0.0001 arcsec (Vasilevskis 1962). The existing proper motion studies in the cluster region of M39 are listed in Table 1. The studies carried out by McNamara & Sanders (1977) and Platais (1984) include the stars up to $B \approx 16.0$ mag, but the latter study is more extensive and complete. McNamara & Sanders carried out separation of members only up to $B \approx 11.0$ mag while Platais (1984) obtained it for stars up to $B \approx 16.5$ mag. The list of probable members given by Platais (1984) includes all the members assigned by Ebbighausen (1940) and McNamara & Sanders (1977), except stars numbered 272 and 1527 (numbers are according to McNamara & Sanders). Due to the reasons mentioned above, cluster members were selected for the present observations only on the basis of the proper motion study of Platais.

3 Observations and reductions

The observations reported herein were made during 1983 October and November, using the 104-cm reflector of the Uttar Pradesh State Observatory, Naini Tal, using a thermoelectrically cooled EMI 6094S photomultiplier and standard *UBV* filters. Nightly atmospheric extinction coefficients were used in order to determine the instrumental magnitudes. For standardizing the instrumental magnitudes, stars were chosen from the photoelectric observations given by Johnson (1953) and these are marked in Table 2. *UBV* magnitudes for the program stars were determined differentially, taking standard stars 2451 and 4294 as a comparison, which were observed on each observing night. A minimum of two sets of observations, on different observing nights, was taken for each star. The average V, $(B-V)$ and $(U-B)$ magnitudes are listed in Table 2. The probable error in the reported *UBV* values is ± 0.02 mag in V and $(B-V)$ and ± 0.03 mag in $(U-B)$ for stars of $V \approx 13$ mag. We have compared the present *UBV* photometry with the *BV* photometry of Platais (1984). In this comparison probable variable stars have not been considered. This leaves 25 stars common to the present work and that of Platais. The difference between the magnitudes and colours of these stars obtained in the present study and Platais is

$$\Delta V = -0.01 \pm 0.004 \text{ mag}; \qquad \Delta(B-V) = -0.01 \pm 0.005 \text{ mag}.$$

The comparison between the photometry of McNamara & Sanders (1977) and Platais (1984) which is based on the 7 common non-variable stars, is $\Delta V = \Delta(B-V) = -0.01 \pm 0.005$ mag.

Therefore it is concluded that there is a good agreement between the various existing photoelectric photometric studies. For subsequent studies we have included V, $(B-V)$ and $(U-B)$ magnitudes of 50 stars observed by us, 11 stars observed by Johnson (1953) and 13 stars observed by McNamara & Sanders (1977). Thus we have included all the available photoelectric *UBV*

Table 2. Photoelectric *UBV* magnitudes of probable cluster members in M39 Star number and the corresponding membership probability 'P' are taken from Platais (1984). Star numbers with asterisk belong to the photometric sequence (Johnson 1953).

Star No	Cross identification No	V (mag)	B-V (mag)	(U-B) (mag)	Ref.	P
76	A583	9.74	0.19	0.20		97
194	A631	10.62	0.44	-0.01		49
305		12.34	0.72	0.07		72
390		13.98	0.97	0.35		5
686	M12	13.47	0.86	0.35		74
748	M43	9.36	0.23	0.13	a	33
816	M62	7.54	0.03	0.04	a	97
862	M72	12.63	0.79	0.39		28
1672	M306	12.05	0.75	0.32		39
1746	A935	9.09	0.14	0.13		64
1749	M329	11.26	0.57	0.09		80
2451*	M514,E1	7.34	-0.02	-0.02		97
2666	M560	11.96	0.68	0.22		80
2691	M571,E3	9.07	0.11	0.12	b	69
2880	M635,E4	9.15	0.16	0.11	b	97
3004	M669,E10	10.33	0.40	0.02	b	95
3011	M671	11.96	0.54	0.06		73
3041	M678	13.79	0.90	0.44		52
3061	L379,E6	11.23	0.47	-0.02		70
3122	M697	13.06	0.76	0.26		53
3129		13.07	0.81	0.37		62
3136	A1140	9.77	0.21	0.14		91
3223	M731	12.79	0.73	0.24		64
3288	M748	12.67	0.76	0.25		77
3311	M750	10.13	0.29	0.12	a	98
3359	M765	12.76	0.71	0.27		56
3423	L433,E11	10.90	0.51	0.01		72
3457	M795,E8	9.96	0.27	0.08	b	88
3494	M803,E5	7.85	0.04	-0.01	b	94
3546	M816	13.18	1.01	0.58		77
3592*	M828,E16	10.17	0.28	0.08		96
3598	L464	12.82	0.72	0.28		56
3605	M833,E17	7.97	0.06	0.08	b	96
3655	M852	13.10	0.84	0.52		75
3702	A1225	10.99	0.73	-0.01		69
3781	M892,E26	6.83	-0.04	-0.05	b	97
3798	M897	13.43	0.91	0.47		77
	M848*,E27	9.78	0.31	0.10		-
3814	M899,E23	7.65	0.01	0.03	b	98
3867	M918,E22	8.89	0.13	0.15	a	40
3935*	M935,E20	9.50	0.19	0.11		98
4080	M970,E19	8.92	0.09	0.12	b	98
4130	M986,A1310	10.61	0.37	-0.03		98
4154	M995,E30	8.52	0.01	0.02	b	98
4226	M1009,E34	9.67	0.09	0.09	b	92
4265	M1020,E38	8.23	0.05	0.01	b	97
4294*	M1031,E33	6.55	0.00	0.04		96
4309	M1037,E31	8.67	0.05	0.08	a	97
4322	M1042	12.42	0.66	0.15		75
4325	A1362	11.00	0.61	0.21		41
4438	A1385	11.43	0.50	-0.03		78
4469	A1374	11.78	0.71	0.16		77
4637	M1131	13.62	0.89	0.53		78
	M1165*,E39	8.80	1.17	1.12		-
4673	M1144,E35	9.03	0.08	0.09	b	98
4923	M1216	9.67	0.17	0.13	a	97
5001	M1234	8.81	0.05	0.08	a	97
5045	M1245,E402	6.83	-0.02	0.03	a	98
5100		13.91	0.78	0.31		76
5593	M1394	11.53	0.53	-0.04		79
5604	M1400	12.67	0.62	0.10		46
5609	A1575	10.41	0.35	-0.09		42
5659	A1589	9.04	0.14	0.08		56
5698	M1424,E45	9.07	0.22	0.10	a	89
5729	A1602	9.37	0.11	0.15		70
6362	M1598	9.61	0.19	0.13	a	97
6791	M1724	9.53	0.18	0.14	a	97
6809		11.22	0.45	0.00		81
6991	A1894	10.42	0.27	0.06		87
7082		14.24	1.01	0.84		9
7083		14.05	0.91	0.80		6
7140	L1030	9.39	0.14	0.13		96
7195	A1957	12.54	0.73	0.20		76
7234	A1972	12.38	0.74	0.15		34
7453		13.07	0.75	0.42		71
7718	A2153	9.70	0.23	0.16		97

Notes: (i) In column 2 the star numbers are given according to other investigators (M-McNamara & Sanders (1977); E-Ebbighausen (1940); L-Lavdovsky (1961); A-Artiukhina & Kalinina (1970)).

(ii) In column 6 the references are given for UBV values taken from other studies (a - McNamara & Sanders (1977), b - Johnson (1953)).

observations of 74 stars of M39. The distribution of these stars according to B magnitude is shown in column 4 of Table 3, which can be compared with the corresponding number of probable cluster members reported by Platais (1984) listed in column 2. This comparison indicates that available photoelectric *UBV* observations may represent a complete sample for the cluster only up to B=14.8 mag.

4 Probable variables

A comparison of the photoelectric *UBV* data of McNamara & Sanders (1977), Platais (1984) and the present observations shows that for stars 1672 and 3004, the *UBV* magnitudes of various authors differ significantly in comparison to their observational errors. Also for stars 3655 and 7082, the *UBV* values obtained by us on different nights, differ by more than the expected error of our observations. Therefore, we believe that these stars may be variables.

5 Reddening

We have fitted the intrinsic zero-age main sequence given by Schmidt-Kaler (1965) to the cluster main sequence stars in the $[(U-B), (B-V)]$ diagram (Fig. 1) and found that main-sequence stars have colour excesses ranging from $E(B-V)$=0.0 to 0.06 mag with a mean value of 0.03 mag. For the same cluster Becker & Fenkart (1971) have found $E(B-V)$=0.06 mag while McNamara & Sanders (1977) have found $E(B-V)$=0.02 mag. The former value is based on the observations of only 14 stars by Johnson (1953). Taking the value of R=3.25 (Moffat & Schmidt-Kaler 1976) we have estimated $A_V=R\cdot E(B-V)$ to be 0.1 mag.

6 Distance

The distance modulus of the cluster, using the zero-age main sequence given by Schmidt-Kaler (1965) and the $[V_0, (B-V)_0]$ and $[V_0, (U-B)_0]$ diagrams shown in Figs 2 and 3 respectively, is

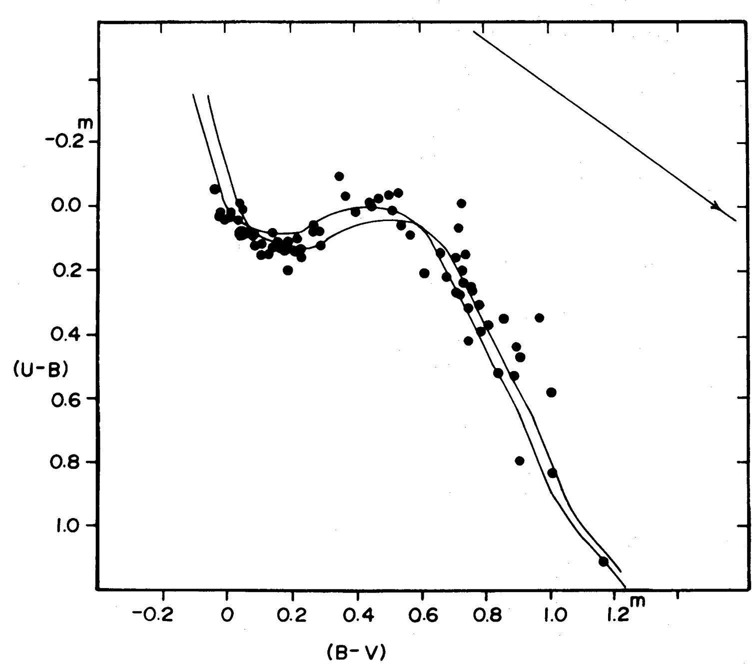

Figure 1. Colour–colour diagram of M39.

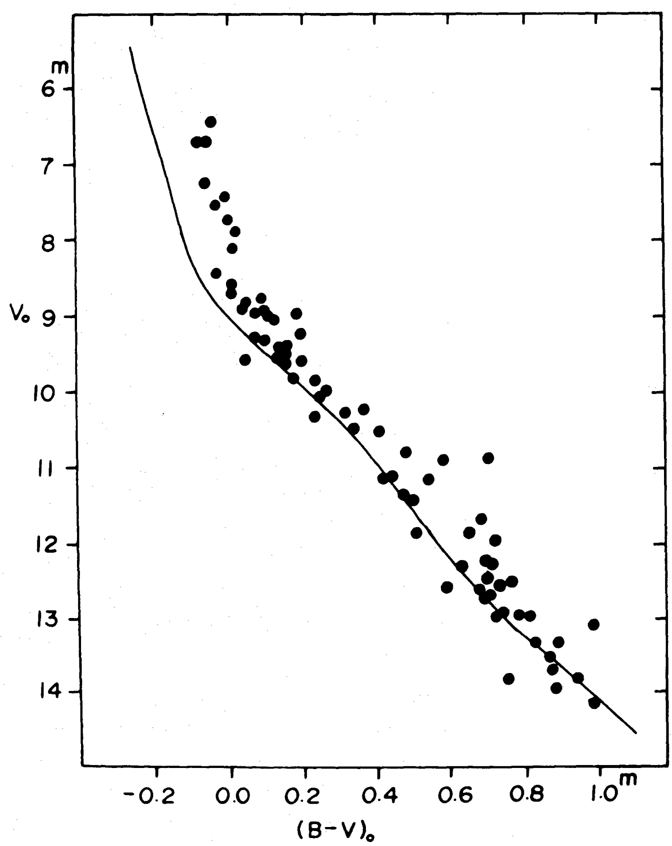

Figure 2. V, $(B-V)_0$ diagram of M39.

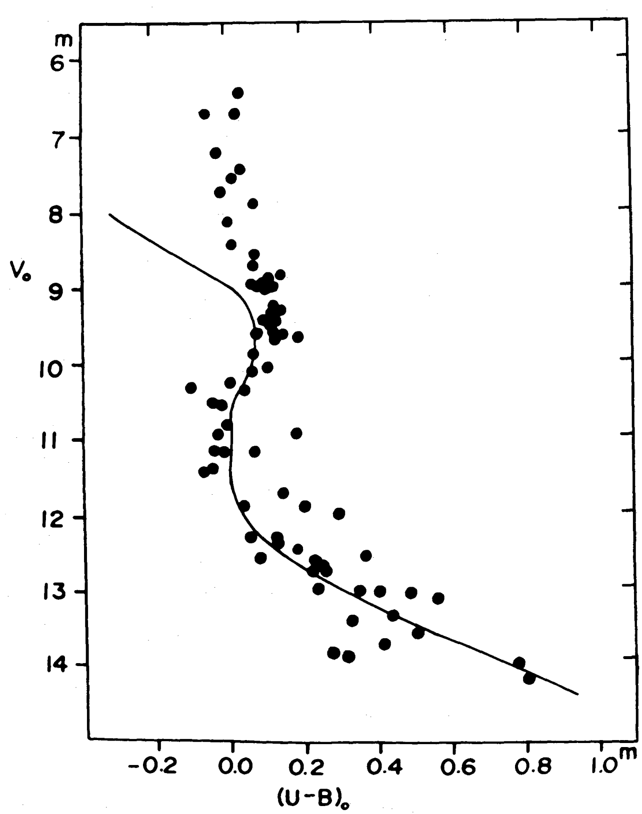

Figure 3. V, $(U-B)_0$ diagram of M39.

found to be 7.40±0.2 mag. This corresponds to a distance of 300±30 pc. For this cluster Johnson (1953) has given a distance of 275±30 pc and McNamara & Sanders (1977) have given 265 pc. Abt & Levato (1976) have estimated the distance to be 360 pc, which is higher than the present study presumably due to the fact that fewer cluster stars have been used for distance determination.

7 Colour–magnitude diagram

The colour–magnitude diagram [M_V, $(B-V)_0$] for the 74 members of M39 has been plotted in Fig. 4 for a true distance modulus of 7.40 mag, and $E(B-V)=0.03$ mag. The dotted curve is the zero-age main sequence shifted by 0.75 mag upwards in order to take into account binary effects, etc. From the colour–magnitude diagram the following inferences can be drawn:

(1) The colour–magnitude diagram, presumably complete up to $M_V=6.35$ mag (see Section 3), extends from $M_V=-1.0$ to 6.75 mag, in which a well-defined cluster main sequence is clearly visible. It is worth noting that the population density of cluster members for stars fainter than $M_V \approx 2.25$ mag is less than that of brighter stars. Such a decrease in the luminosity function of the unevolved main-sequence stars has also been noticed by van den Bergh & Sher (1960) for NGC 1970, 1960 and 2362 at Mpg~2.0, 2.5 and 1.9 mag respectively. However, in this respect the luminosity function of the unevolved main-sequence stars of these clusters is quite different in comparison to the luminosity function of other well studied clusters. It is difficult to explain such behaviour in these clusters with existing theories of star formation. Consequently they deserve attention from the theoretical point of view.

(2) An evolutionary effect in the cluster is clearly visible. Stars having colours in the range -0.07 mag$<(B-V)_0<0.02$ mag and brighter than $M_V=1.0$ mag have moved off the zero-age main sequence. No cluster member has yet reached the red-giant phase of the stellar evolution.

(3) The spectral type of the brightest member of the cluster, having $M_V=-0.95$ mag

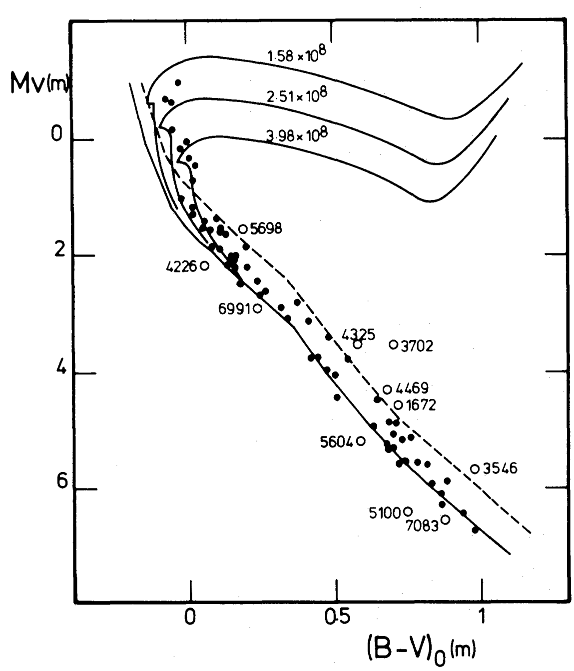

Figure 4. M_V, $(B-V)_0$ diagram of M39. The dotted curve is the zero-age main sequence shifted by 0.75 mag upwards Open circle represents peculiar stars.

Table 3. Distribution of stars in M39.

B magnitude range (mag)	Number by Platais (1984)		Number discussed in this study	
	Probable members	Probable field stars	Probable members	Peculiar stars
6.0 to 11.0	38	4	38	3
11.0 to 14.8	34	11	33	7
14.8 to 16.7*	9	8	3	1

*There is a large difference between the probable field stars and peculiar stars, which may be due to fact that out of 9 probable members only 3 have *UBV* photoelectric data.

$(B-V)_0=-0.03$ mag and $(U-B)_0=0.02$ mag obtained in the present study, is B9.5 (Abt & Levato 1976).

(4) Stars numbered 1672, 3546, 3702, 4325, 4469 and 5698 are situated well above the zero-age main sequence while stars numbered 4226, 5100, 5604, 6991 and 7083 are well below the zero-age main sequence. These positions are peculiar from the standpoint or stellar evolution. In Table 3 we have compared the predicted number of field stars listed in column 3 in the various groups by Platais (1984) with the number of peculiar stars listed in column 5 in the present study. This comparison indicates that the possibility cannot be ruled out that all 11 peculiar stars are field stars. Therefore, it is suggested that their membership should also be checked by radial velocity measurements.

8 Age of the cluster stars

We have used the isochrones for population I stars given by Maeder & Mermilliod (1981). By fitting the isochrones to the stars evolving off the zero-age main sequence in the cluster $[M_V, (B-V)_0]$ diagram (Fig. 4) we infer that the age of the cluster star lies between 2.0×10^8 and 4.0×10^8 yr. For this cluster an age of 7×10^8 yr has been estimated by McNamara & Sanders (1977), which is based on the turn-off point in the colour–magnitude diagram.

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