Bull. Astr. Soc. India (2003) **31**, 9–18

Study of open cluster NGC 2509

S. Sujatha[1,2] and G.S.D. Babu[1,3]
[1]*M.P. Birla Institute of Fundamental Research, Bangalore 560 001, India*
[2]*Mount Carmel College, Bangalore 560 052, India*
[3]*Indian Institute of Astrophysics, Bangalore 560 034, India*

Received 11 November 2002; accepted 20 January 2003

Abstract. We present the first CCD photometric observations of the open cluster *OCl* 630 (NGC 2509) in *UBVRI* filters. It is a fairly nearby cluster at a distance of 912±15 pc, and is placed in the direction of the Puppis constellation as part of the Orion arm in our Galaxy. The age of this cluster is estimated to be $\sim 8\times10^9$ years. This cluster is found to be older than M67, but younger than NGC 188, both of which are well known old clusters. Thus, being an old cluster, it is an unsuitable candidate for tracing the spiral arm of our Galaxy.

Keywords : Open cluster, photometry, distance, age.

1. Introduction

In 1915, Melotte identified the cluster NGC 2509 (*OCl* 630, Mel 81, RA2000 : 08h 00m 48s, Dec2000 : $-19° \; 03' \; 30''$, l : 237°.86, b : N 05°.83) and found it to be spread over an angular diameter of 4 arcmin. Later in 1918, Charlier obtained its distance to be 1130 parsec. After about a decade Trumpler (1930) estimated the distance of the cluster to be 3050 pc, while Collinder (1931) and Barhatova (1950) gave the figures as 2700 pc and 1820 pc respectively. Barhatova also mentioned that the angular diameter of the cluster is about 10 arcmin. Later, Ruprecht (1966) classified this cluster as II 1 p, in the Trumpler system of classification. The members of the cluster were estimated to be 56 by Raab (1922) and 30 stars by Collinder (1931).

The late Prof. M.K. Vainu Bappu had proposed a study of open clusters for using them as tools in understanding the structure of our Galaxy, which was carried out to some extent by Babu (1983, 1985, 1987). Though the galactic latitude of open cluster NGC 2509 is about 6°, it has been chosen from among the selection of a few not-well-studied open clusters as an attempt to explore its suitability in the study of galactic structure.

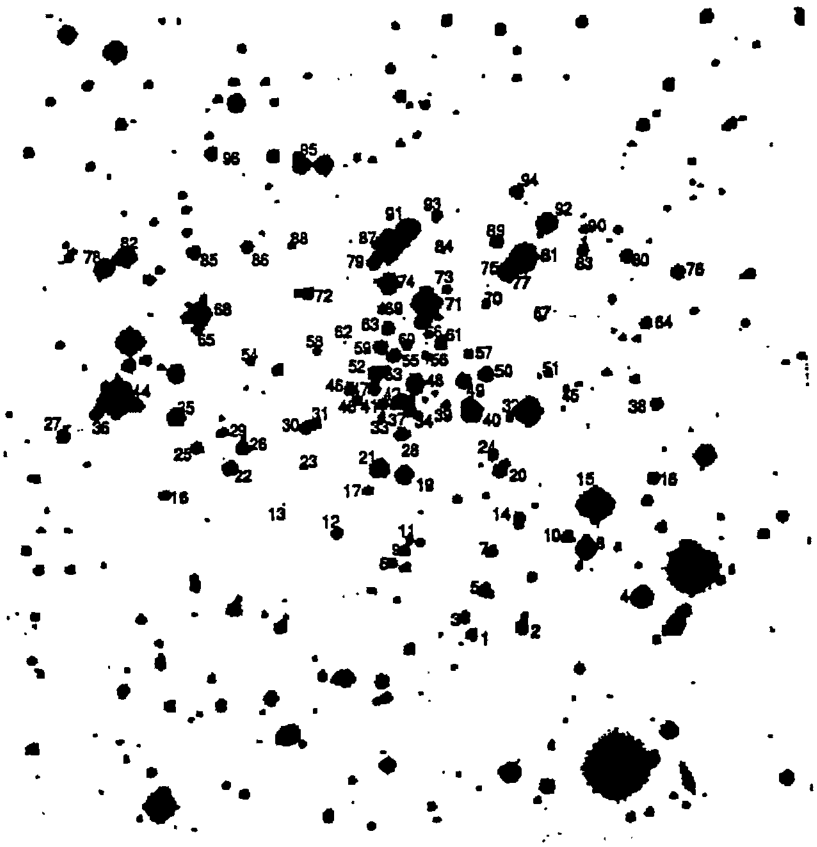

Figure 1. Finding chart for the field of open cluster OCl 630 (NGC 2509) reproduced from the CCD frame taken in the V-filter. The identification numbers are introduced in the present work. North is to the top and east is to the left of the chart.

The first *UBVRI* photometric observations of this cluster and the results are presented in this paper. The finding chart is as shown in Fig. 1, and the identification numbers are introduced in this paper.

2. Observations and Reductions

The CCD photometry of the stars in the central region of this cluster was done on 13 December 2001, using standard *UBVRI* filters at the Cassegrain focal plane of the 102 cm telescope of Vainu Bappu Observatory, Kavalur (78° 50′ E longitude, 12.5° N latitude). Liquid nitrogen cooled 1 K

CCD (Charge Coupled Device) was used along with an online computer to collect the data. A number of bias and flat field frames were also taken during the observing runs. In addition to this, the well-known cluster M67 (NGC 2682) was also observed for the calibration of the instrument. The practice of obtaining at least two frames for each filter was followed during the observations. The exposure times for U filter were generally much longer than for the other filters.

The data collected was reduced and analysed using the IRAF (Image Reduction and Analysis Facility) package for photometric reductions. A total of 96 stars down to $V = 18.3$ mag were selected for analysis in the field of the cluster. The instrumental magnitudes, corrected for atmospheric extinction, were standardized with the help of calibration constants obtained from the observations of open cluster M67. A total of 13 stars were chosen in the field of M67 and their magnitudes as well as the colour indices were matched with the values given by Francic (1989). The uncertainities in V, B-V, U-B, V-R and V-I are found to be in the range of 0.01 to 0.02, 0.02 to 0.03, 0.04 to 0.06, 0.005 to 0.01 and 0.005 to 0.01 respectively. The larger errors were mainly applicable to the fainter ($M_v > 15$) stars.

The colour-magnitude diagrams (CMDs) of the cluster V vs (B-V), V vs (V-R) and V vs (V-I) show a broad main sequence as well as the post main sequence ascertaining it as a cluster. These CMDs are shown in Fig 2.

3. Reddening

The colour – colour diagram of the selected 96 stars in this field, with (B-V) against (U-B), is as shown in Fig. 3, in which the scatter could be due to the presence of some non-member field stars. Further, it may be noted in this diagram that there are no stars bluer than (B-V) =0.5 mag, which gives an indication that the cluster probably belongs to the old category. In view of this, some of the stars having (B-V) > 0.9 mag could be belonging to the evolved stage of the cluster. Therefore, that part of the diagram was not specifically considered in its analysis.

In this figure, the stars with $0.5 < (B\text{-}V) < 0.9$ mag seem to show a small shift from the unreddened main sequence (Schmidt-Kaler, 1982). By shifting that curve on to the observed stars in such a way that the shift is parallel to the reddening line, the colour excesses $E(B\text{-}V)$ and $E(U\text{-}B)$ of the cluster stars are found to be 0.15 mag and 0.108 mag respectively.

The total visual absorption A_v has been calculated from the expression $A_v = R.E(B\text{-}V)$, where R is the value of total to selective absorption which is taken as 3.25 (Moffat and Schmidt-Kaler, 1976). Thus,

$$A_v = 0.488 \text{ mag.}$$

All the individually corrected magnitudes and the colours are listed in Table 1.

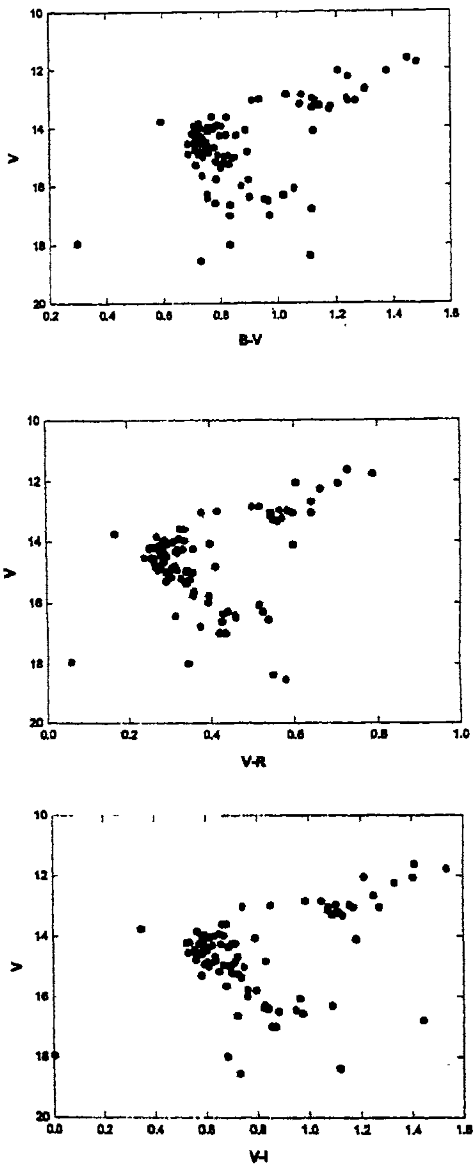

Figure 2. The colour-magnitude diagrams of the open cluster *OCl* 630 are shown from top to bottom as *V* vs (*B*-*V*), *V* vs (*V*-*R*) and *V* vs (*V*-*I*). All of them indicate a broad main sequence as well as the post main sequence ascertaining it as a cluster.

Table 1. The observational data for individual stars in the open cluster *OCl* 630 corrected for interstellar extinction.

ID	X	Y	V_0	M_v	$(U\text{-}B)_0$	$(B\text{-}V)_0$	$(V\text{-}R)_0$	$(V\text{-}I)_0$
1	592.146	246.426	14.799	4.999	−0.121	0.591	0.292	0.613
2	655.134	255.661	13.862	4.062	−0.073	0.737	0.399	0.794
3	582.512	266.679	14.731	4.931	−0.186	0.640	0.318	0.671
4	806.091	287.608	12.850	3.050	0.586	1.118	0.642	1.275
5	606.597	298.93	14.809	5.009	−0.104	0.698	0.355	0.749
6	491.834	332.975	15.006	5.206	0.347	0.662	0.328	0.703
7	617.073	344.541	14.610	4.810	−0.040	0.744	0.411	0.834
8	736.727	346.031	12.644	2.844	0.151	0.877	0.499	0.988
9	508.537	347.169	14.960	5.160	0.562	0.634	0.303	0.655
10	713.35	360.088	14.392	4.592	−0.163	0.563	0.262	0.572
11	514.599	360.486	14.772	4.972	0.264	0.665	0.341	0.693
12	423.234	369.218	14.273	4.473	−0.182	0.601	0.294	0.606
13	366.467	371.239	17.743	7.943	−0.616	0.146	0.057	0.005
14	650.544	382.718	14.033	4.233	0.164	0.670	0.356	0.714
15	749.474	398.926	11.566	1.766	1.390	1.333	0.790	1.536
16	206.234	415.157	15.035	5.235	−0.131	0.681	0.348	0.727
17	463.257	418.348	15.557	5.757	0.285	0.635	0.356	0.765
18	823.024	428.495	14.635	4.835	−0.177	0.599	0.307	0.631
19	509.5	436.664	13.089	3.289	0.645	0.968	0.551	1.091
20	628.833	439.821	13.795	3.995	0.243	0.581	0.310	0.634
21	477.097	445.184	12.842	3.042	0.676	0.976	0.544	1.076
22	289.375	448.018	13.393	3.593	0.057	0.673	0.336	0.683
23	382.596	449.409	16.793	6.993	−0.338	0.683	0.420	0.873
24	620.126	459.048	14.691	4.891	0.077	0.538	0.304	0.598
25	246.684	471.084	14.378	4.578	−0.224	0.604	0.285	0.587
26	305.691	471.148	13.727	3.927	−0.018	0.654	0.321	0.657
27	76.19	484.927	14.047	4.247	−0.302	0.704	0.334	0.703
28	505.913	485.129	14.168	4.368	0.085	0.570	0.289	0.606
29	279.716	490.563	15.786	5.986	0.029	0.721	0.394	0.765
30	386.592	495.127	13.635	3.835	0.072	0.577	0.271	0.568
31	399.292	499.474	13.755	3.955	0.105	0.607	0.286	0.584
32	641.301	504.293	16.580	6.780	-	0.966	0.374	1.444
33	481.856	506.402	15.170	5.370	0.266	0.653	0.341	0.740
34	528.227	506.937	14.240	4.440	0.334	0.574	0.281	0.557
35	220.89	508.085	12.832	3.032	0.282	0.761	0.378	0.744
36	119.106	511.999	14.639	4.839	0.147	0.610	0.279	0.713
37	517.45	512.958	13.749	3.949	−0.006	0.558	0.289	0.597
38	827.272	515.017	14.346	4.546	−0.175	0.581	0.265	0.570
39	563.606	517.341	16.160	6.360	3.844	0.751	0.429	0.827
40	594.759	510.074	12.771	2.971	0.715	0.967	0.564	1.104
41	483.182	520.305	14.623	4.823	0.040	0.582	0.267	0.607
42	501.229	521.195	13.991	4.191	−0.018	0.550	0.261	0.583
43	452.363	525.685	14.562	4.762	0.224	0.561	0.281	0.563
44	146.843	530.383	11.424	1.624	1.454	1.301	0.727	1.412
45	714.897	534.345	16.429	6.629	−0.072	0.685	0.427	0.723
46	441.636	538.214	14.594	4.794	0.054	0.598	0.312	0.641
47	472.484	538.971	14.347	4.547	0.033	0.536	0.255	0.532

Table 1. continued.

ID	X	Y	V_0	M_v	$(U\text{-}B)_0$	$(B\text{-}V)_0$	$(V\text{-}R)_0$	$(V\text{-}I)_0$
48	524.879	543.594	12.957	3.157	0.476	0.927	0.544	1.075
49	585.026	545.485	13.758	3.958	0.334	0.622	0.336	0.673
50	613.473	551.949	13.907	4.107	0.778	0.971	0.597	1.184
51	692.557	553.371	16.362	6.562	−0.175	0.632	0.539	0.977
52	473.537	556.498	13.392	3.592	0.133	0.619	0.325	0.667
53	486.927	559.226	13.705	3.905	0.178	0.637	0.325	0.654
54	316.337	571.604	16.799	6.999	−0.288	0.820	0.434	0.858
55	499.609	576.634	14.033	4.233	0.198	0.555	0.252	0.524
56	538.355	576.906	16.203	6.403	0.331	0.605	0.458	0.844
56	593.056	577.536	15.436	5.636	0.809	0.587	0.358	0.682
58	402.597	584.947	16.294	6.494	−0.014	0.814	0.461	0.884
59	482.615	588.184	13.935	4.135	0.038	0.567	0.274	0.593
60	516.25	590.135	15.084	5.284	0.207	0.566	0.292	0.584
61	558.658	590.629	14.102	4.302	0.258	0.577	0.315	0.627
62	436.455	593.686	18.182	8.382	−1.280	0.961	0.549	1.118
63	491.131	609.388	14.110	4.310	0.099	0.586	0.283	0.587
64	817.907	609.846	14.330	4.530	−0.277	0.559	0.261	0.560
65	248.397	610.336	14.470	4.670	0.429	0.629	0.264	0.725
66	535.209	615.052	14.150	4.350	0.196	0.591	0.319	0.689
67	684.165	618.374	17.792	7.992	-	0.683	0.345	0.685
68	253.105	628.434	12.468	2.668	1.029	1.151	0.641	1.252
69	484.278	632.456	16.074	6.274	1.201	0.605	0.441	0.831
70	614.804	636.472	15.869	6.069	1.341	0.904	0.517	0.968
71	541.641	637.727	12.049	2.249	1.017	1.091	0.662	1.331
72	391.535	652.006	14.052	4.252	0.117	0.566	0.275	0.575
73	566.536	654.32	16.244	6.444	-	0.803	0.313	0.950
74	492.211	661.474	13.036	3.236	0.764	1.032	0.570	1.117
75	641.863	673.734	13.130	3.330	0.853	1.028	0.560	1.130
76	855.87	669.839	13.831	4.031	−0.225	0.624	0.298	0.619
77	662.99	690.918	11.847	2.047	1.099	1.056	0.604	1.213
78	131.603	683.467	12.794	2.994	0.003	0.785	0.416	0.854
79	473.577	687.709	14.326	4.526	0.000	0.588	0.239	0.590
80	792.206	689.472	14.001	4.201	−0.010	0.574	0.251	0.540
81	662.99	690.918	11.847	2.047	1.099	1.056	0.604	1.213
82	160.144	696.296	12.773	2.973	0.785	1.087	0.584	1.159
83	738.864	697.605	14.741	4.941	0.026	0.679	0.343	0.702
84	561.499	698.521	18.345	8.545	−0.820	0.582	0.580	0.730
85	246.292	701.893	13.893	4.093	0.056	0.610	0.292	0.593
86	313.882	707.52	14.065	4.265	0.067	0.649	0.319	0.662
87	493.071	707.672	11.870	2.070	1.400	1.228	0.705	1.406
88	371.597	708.501	16.101	6.301	1.439	0.869	0.526	1.091
89	628.603	709.235	14.464	4.664	0.237	0.602	0.288	0.639
90	739.943	722.678	15.576	5.776	0.163	0.747	0.396	0.798
91	518.93	727.184	12.646	2.846	0.657	0.931	0.517	1.051
92	692.635	731.273	12.854	3.054	1.000	1.091	0.597	1.172
93	553.758	741.1	14.718	4.918	0.152	0.575	0.273	0.595
94	655.698	768.32	13.883	4.083	0.180	0.603	0.286	0.595
95	385.478	803.047	13.024	3.224	0.861	0.993	0.571	1.107
96	270.946	818.05	13.555	3.755	−0.049	0.443	0.168	0.351

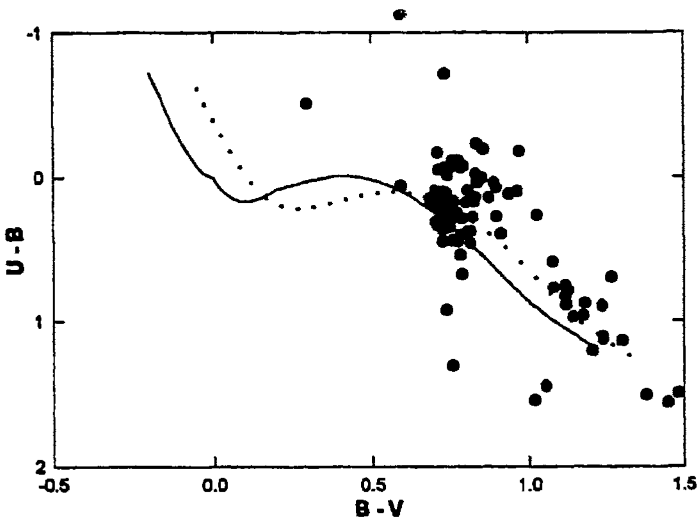

Figure 3. The $(B\text{-}V)$ vs $(U\text{-}B)$ diagram of the stars in the field of the open cluster *OCl* 630. The solid line is the main sequence (MS) for the unreddened stars (Schmidt-Kaler, 1982), while the dotted line represents the MS when it is fitted to the observations by shifting it parallel to the reddening line.

4. 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 $(B\text{-}V)_o$ vs V_o diagram and the value of distance modulus $(V_o - M)$ is found to be 9.8 ± 0.04 mag (Fig. 4). Then the distance D to the cluster is calculated by using the standard expression $\log D = 0.2(V_o - M) + 1$, from which the value of D is estimated as 912 ± 15 pc.

5. Age of the cluster

The HR-diagram of this cluster, shown in Fig.5, is plotted for the true distance modulus of 9.8 mag. The post main sequence isochrones given by Bertelli et al (1994) are sùperimposed along with the ZAMS (Schmidt-Kaler, 1982), which clearly indicate that the stars of the cluster generally follow the isochrone of 8×10^9 yrs. However, the turn off point from the main sequence, being $(B - V)_o = 0.57$ mag, indicates the age of 5×10^9 yrs by using the relationship given by Allen (1981).

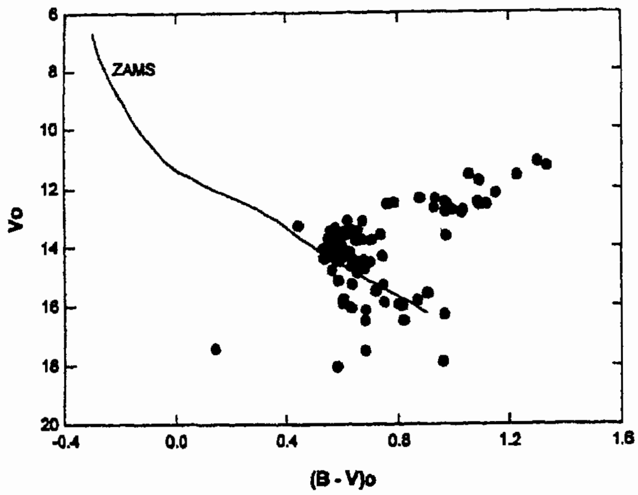

Figure 4. The (*B-V*) vs *V* magnitude diagram of the stars in the field of *OCl* 630. The solid curve represents the zero age main sequence (Schmidt-Kaler, 1982), which is shifted to match the observations.

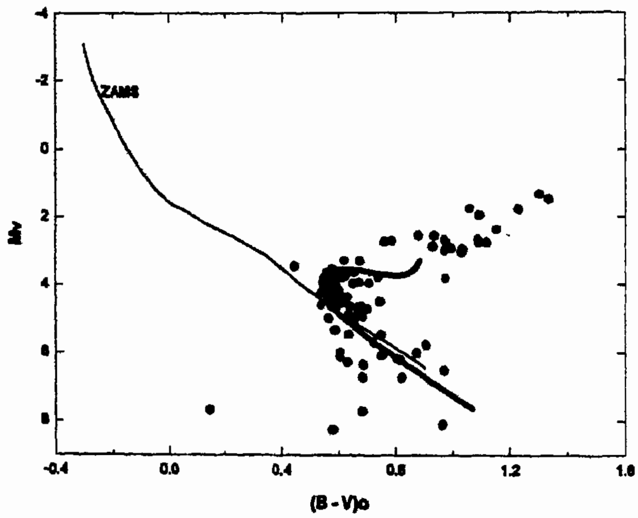

Figure 5. The HR diagram of *OCl* 630 (NGC 2509) corrected for the true distance modulus of 9.8 mag. The ZAMS is taken from Schmidt-Kaler (1982) and the thick curve represents the isochrone of age 8×10^9 years given by Bertelli *et al.* (1994).

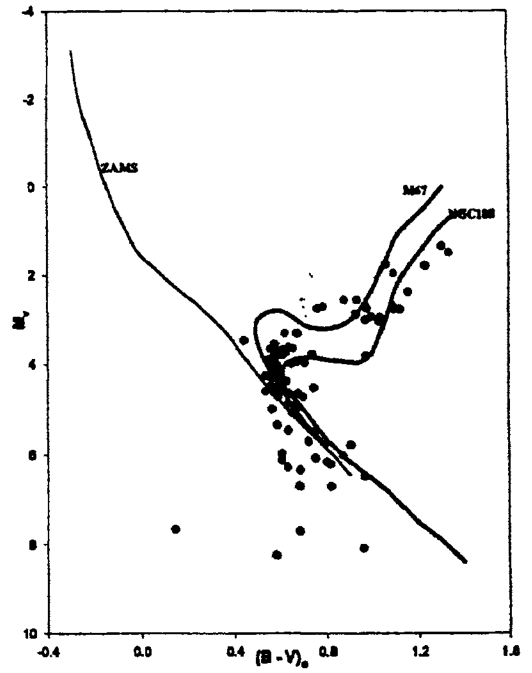

Figure 6. The open cluster *OCl* 630 is compared with the post main sequences of the well known old open clusters M67 and NGC 188. The ZAMS is the same as in Fig. 5.

6. Discussion

The distance of 912 pc appears to be small as compared to the earlier estimates by Charlier (1918), Trumpler (1930), Collinder (1931) and Barhatova (1950). Yet it may be considered as a fairly reliable estimate, because, even though the cluster is placed in the direction of Puppis constellation as part of the Orion arm in our Galaxy, the relatively less interstellar extinction of $E(B-V) = 0.15$ mag, clearly indicates that the cluster is not too far away. It is worth noting here that as the distance increases along the Orion spiral arm the interstellar content is also expected to increase giving rise to greater extinction values. However, the age of this cluster, being around 8×10^9 yrs puts it into the category of old clusters, making it an unsuitable candidate for tracing the spiral arm. Further, its latitude of 6° away from the central plane of the disc is very likely due to its drifting away from its place of origin during this period.

Neverthless, as an old cluster, it can be compared with that of the other well studied old clusters M67 and NGC 188 as shown in Fig. 6. In this figure we can clearly see that the stars of open cluster *OCl* 630 lie between the observed post main sequences of M67 and NGC 188. Sandage (1961), using Hoyle's (1959) models, estimated the ages of M67 and NGC 188 as 9-10

$\times 10^9$ and 16×10^9 years, while hastening to add the statement that these ages should be reduced by a factor of 2. Later, VandenBerg (1985), by fitting the more realistic isochrones (VandenBerg, 1985) has shown the ages of M67 and NGC 188 to be 5×10^9 and 10×10^9 years respectively. In addition, considering the turn off points of both these clusters as well as *OCl* 630, we can say that the cluster is younger than NGC 188 and older than M67.

7. Conclusions

The open cluster *OCl* 630 is found to be an old cluster with an age of $\sim 8 \times 10^9$ years, being younger than NGC 188 and older than M67. Its distance is estimated to be 912±15 pc, which places it in the Orion arm in the direction of Puppis constellation. However, being an old cluster, it is an unsuitable candidate for tracing the spiral arm of our Galaxy.

Acknowledgements

We are grateful to Drs. Padmakar Parihar and D.K. Sahu of CREST/IIA, Mr. K. Jayakumar and Mr. S. Pukalenthi of VBO for their help at various stages of this work. One of us (SS) is grateful to Dr. Sharath Ananthamurthy of Bangalore University for his guidance and encouragement. SS also wishes to thank the Indian Institute of Astrophysics for the telescope time at Vainu Bappu Observatory, Kavalur and the M.P. Birla Institute of Fundamental Research, Bangalore, for providing the necessary facilities in carrying out this work.

References

Allen C.W., 2000, *Astrophysical Quantities*, 4 edn, Springer Verlag, New York.
Babu G.S.D., 1983, *JAA*, **4**, 235.
Babu G.S.D., 1985, *JAA*, **6**, 61.
Babu G.S.D., 1987, *JAA*, **8**, 219.
Barhatova K.A., 1950, *AZh*, **27**, 182.
Bertelli *et al.*, 1994, *A & AS*, **106**, 275.
Charlier, 1918, *LdM*, **S2**, N19, 18.
Collinder P., 1931, *LdAn*, **2**, 1.
Francic S.P., 1989, *AJ*, **98**, 888.
Hoyle F., 1959, *MNRAS*, **119**, 124.
Melotte, 1915, *Mem. RAS*, **60**, 181.
Moffat A.F.J. and Schmidt-Kaler, 1976, AA, **48**, 115.
Raab, 1922, *LdM*, **S2**, N30, 39.
Ruprecht J., 1966, *BAC*, **17**, 34.
Sandage A., 1961, *ApJ*, **135**, 349.
Schmidt-Kaler Th., 1982, in Landolt-Bornstein, Numerical Data and Functional Relationships in science and technology, Eds K. Schaifers and H.H. Voigt, Group VI, 2, 19.
Trumpler, R.J., 1930, *LOB*, **14**, 154.
VandenBerg D.A., 1985, *ApJs*, **58**, 711.