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UBVRI CCD photometric studies of open clusters Berkeley 15, Czernik 18 and NGC 2401

S. Sujatha[1,2*], G.S.D. Babu[1] and Sharath Ananthamurthy[3]

[1] *M.P. Birla Institute of Fundamental Research, Bangalore - 560001, India.*

[2] *Mount Carmel College, Bangalore - 560052, India.*

[3] *Jnana Bharathi, Bangalore University, Bangalore - 560056, India.*

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Abstract. CCD photometric observations of three open clusters Berkeley 15 (= OCl 414), Czernik 18 (= OCl 426) and NGC 2401 (= OCl 588), obtained for the first time in UBVRI filters down to V = 20 mag, are presented here. They are located at distances of 1259, 955 and 3467 parsecs with their respective ages estimated as ~5 x 10^9 years, ~ 0.8 to 1 x 10^9 years and ~ 1 x 10^9 years. While OCl 414 and OCl 426 are in the direction of the Auriga - Perseus constellations, OCl 588 is placed in the direction of Ophiuchus constellation in our Galaxy. The clusters studied here are of intermediate and old age category.

Keywords : Open clusters, distances, ages

1. Introduction

Continuing the earlier work done by us (Sujatha and Babu, 2003a; 2003b, hereafter referred to as Paper I and Paper II respectively), we have obtained the first CCD photometric UBVRI observations of three open clusters, Berkeley 15 (= OCl 414), Czernik 18 (= OCl 426) and NGC 2401 (= OCl 588). These not-so-well-studied clusters are selected from the catalogue given by Alter et al. (1970) and their basic data is tabulated in Table 1. No other data is available for these clusters at the site WEBDA (http://obswww.unige.ch/webda/). Since they are classified as poor clusters, they are visually examined in the POSS charts and the central condensation of stars of all the three clusters were respectively found to be fitting into the field of view of the telescope. The finding charts of the central condensations for these clusters are shown in Figs 1, 2 and 3

*e-mail : sreesuji@hotmail.com

Table 1. Basic data of the open clusters Berkeley 15, Czernik 18 and NGC 2401.

Name	OCl No.	RA (2000) h m s	Dec (2000) deg m s	l	b	Trumpler class
Berkeley 15	414	05 02 05	+44 30 00	$162^o.33$	N $01^o.61$	II 2 p
Czernik 18	426	04 28 00	+30 56 00	$168^o.29$	S $12^o.30$	IV 2 p
NGC 2401	588	07 29 24	-13 58 00	$229^o.67$	N $01^o.85$	II 3 p

respectively and the identification numbers for the individual stars are introduced for the first time.

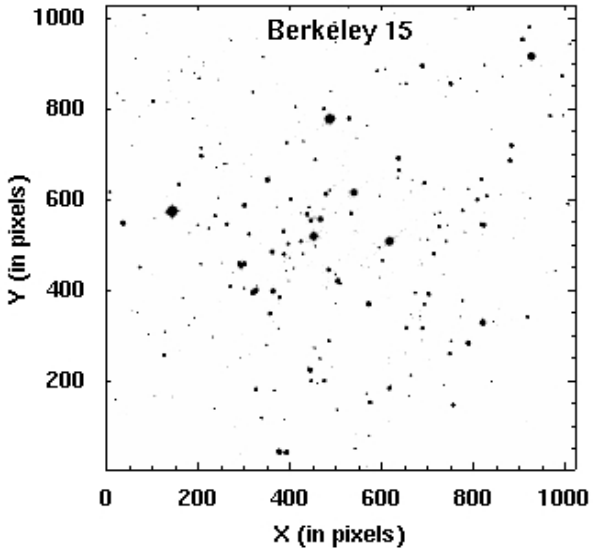

Figure 1. Finding chart for the field of open cluster Berkeley 15 (OCl 414) reproduced from the CCD frame taken in the V-filter. North is towards the top and East is towards the left of the figure.

2. Observations and reductions

The clusters were observed on 13 and 14 December 2001, with the 1.02 m telescope at the Vainu Bappu Observatory of Indian Institute of Astrophysics at Kavalur. Standard UBVRI filters along with 1k CCD were used at the Cassegrain focus of the telescope, the image scale being 0.315 arcsec/pixel. The well-known open cluster M67 (NGC 2682) was also observed on each of the above-mentioned dates for the calibration of the instrument. The exposure times for U-filter were generally longer compared to the other filters. Unfortunately, the U filter, which was used here, was of rather poor quality. Due to this fact, many faint stars in the respective fields of the

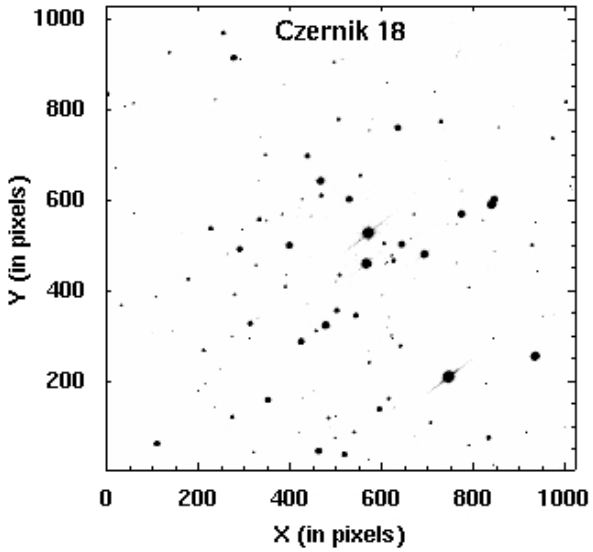

Figure 2. Finding chart for the field of open cluster Czernik 18 (OCl 426) reproduced from the CCD frame taken in the V-filter. North is towards the top and east is towards the left of the figure.

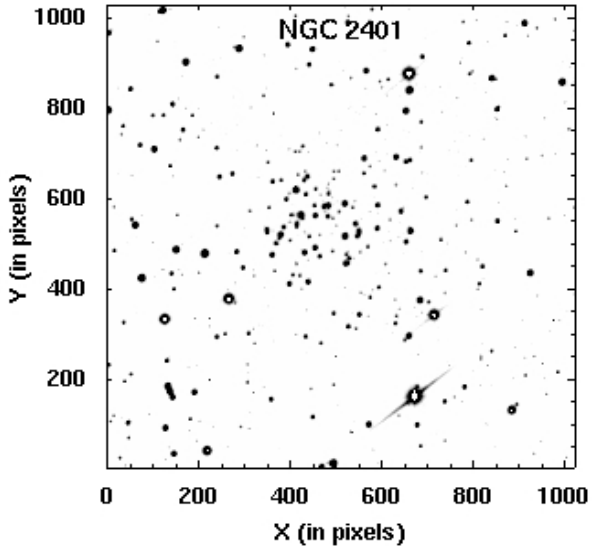

Figure 3. Finding chart for the field of open cluster NGC 2401 (OCl 588) reproduced from the CCD frame taken in the V-filter. North is towards the top and East is towards the left of the figure.

Table 2. Journal of observations.

Date	Object	Filter	UT	Airmass	Exp. Time (sec)	Date	Object	Filter	UT	Airmass	Exp. Time (sec)
13 Dec 2001	OCl 414	I	15 22	1.538	1500	14 Dec 2001	OCl 426	I	17 10	1.064	180
		I	15 52	1.408	900			I	17 18	1.064	300
		I	16 12	1.348	600			R	17 27	1.064	180
		I	16 26	1.308	300			R	17 32	1.054	360
		R	16 41	1.278	180			V	17 41	1.054	600
		R	16 46	1.268	300			V	17 54	1.064	480
		V	16 55	1.248	300			B	18 06	1.064	600
		V	17 03	1.238	240			B	18 19	1.074	1200
		B	17 13	1.228	300			U	18 44	1.094	1800
		B	17 22	1.218	720						
		B	17 37	1.198	1200		M67	U	19 27	1.264	900
		U	18 03	1.188	2700			B	19 47	1.194	420
		U	18 52	1.198	2700			V	19 57	1.164	300
								V	20 07	1.136	180
	M67	I	19 48	1.208	45			R	20 13	1.124	90
		I	19 52	1.198	90			I	20 17	1.114	90
		R	19 56	1.178	60						
		R	20 00	1.168	90		OCl 588	U	20 35	1.124	2400
		V	20 04	1.158	180			B	21 34	1.154	1800
		V	20 10	1.138	120			V	22 08	1.214	1500
		B	20 15	1.128	300			R	22 39	1.304	300
		B	20 23	1.108	420			I	22 50	1.354	300
		U	20 33	1.088	900						

clusters could not be observed. Thus the number of stars, which could be actually taken up for reductions were perforce, limited to the transparency characteristics of the U filter. The journal of observations is given in Table 2.

These observations, corrected for atmospheric extinction, were standardized with the help of calibration constants obtained from the observations of M67 in the same manner as done in our earlier work (Sujatha and Babu, Papers I and II). The transformation equations along with the coefficients are given below.

Transformation equations for the observations on 13 December 2001 are

$$(B - V) = 0.757(b - v)_o - 0.356$$
$$(V - vo) = -0.046(B - V) - 3.730$$
$$(U - B) = 1.040(u - b)_o - 3.337$$
$$(V - R) = 1.166(v - r)_o - 0.094$$
$$(V - I) = 1.144(v - i)_o + 0.030$$
$$(B - I) = 0.876(b - i)_o - 0.346$$

Transformation equations for the observations on 14 December 2001 are

$$(B-V) = 0.965(b-v)_o - 0.910$$
$$(V-vo) = -0.130(B-V) - 3.925$$
$$(U-B) = 0.903(u-b)_o - 2.975$$
$$(V-R) = 1.019(v-r)_o - 0.108$$
$$(V-I) = 1.144(v-i)_o + 0.030$$
$$(B-I) = 1.060(b-i)_o - 1.063$$

The IRAF and DAOPHOT packages were used for reducing the data down to V = 20 mag. All the individually standardized magnitudes V and the colours (B-V) , (U-B) , (V-R) , (V-I) and (B-I) of the stars in each cluster are listed respectively in Tables 3–5. The uncertainties in magnitudes and colours are as given below.

$$V : 0.01 \ to \ 0.02 mag$$
$$(B-V) : 0.02 \ to \ 0.03 mag$$
$$(U-B) : 0.05 \ to \ 0.07 mag$$
$$(V-R) : 0.005 \ to \ 0.01 mag$$
$$(V-I) : 0.005 \ to \ 0.01 mag$$
$$(B-I) : 0.005 \ to \ 0.01 mag$$

The larger errors were mainly applicable to the fainter stars ($m_{vis} > 15$) and for the observations through the U filter.

Table 3. The standardised UBVRI photometric data for individual stars in the open cluster Berkeley 15 (OCl 414).

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
1	919.988	912.403	12.776	1.180	1.585	1.060	2.036	3.437
2	681.81	891.973	15.245	0.504	1.270	0.824	1.585	2.727
3	744.112	852.418	15.399	0.295	0.991	0.558	1.165	2.082
4	94.917	813.852	16.343	0.037	1.273	0.861	1.754	2.860
5	405.157	801.037	17.239	-0.028	1.540	1.103	2.126	3.453
6	467.859	797.101	16.703	-0.833	1.078	0.762	1.575	2.497

Table 3. Continued.

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
7	480.076	774.444	12.460	-0.094	0.612	0.415	0.708	1.294
8	522.292	775.852	15.701	0.359	1.166	0.497	1.181	2.298
9	960.737	782.121	16.060	–	1.811	1.287	2.506	4.058
10	989.914	782.503	17.920	–	1.213	0.839	1.868	2.877
11	876.83	716.104	15.458	0.097	1.002	0.560	1.153	2.085
12	200.498	692.881	15.613	0.653	1.271	0.874	1.780	2.877
13	448.567	684.588	17.062	–	1.798	1.222	2.457	4.006
14	629.477	688.002	15.448	1.846	1.756	1.184	2.316	3.849
15	873.115	683.05	15.523	0.298	1.115	0.715	1.445	2.441
16	344.26	640.003	15.166	0.175	1.049	0.663	1.368	2.304
17	630.749	660.984	16.820	–	1.422	0.998	1.790	3.060
18	686.05	633.235	16.404	0.246	0.953	0.604	1.189	2.056
19	471.621	609.031	15.503	0.894	1.227	0.771	1.400	2.535
20	532.645	612.498	13.912	0.318	0.876	0.539	1.106	1.904
21	782.211	620.179	17.815	-0.268	1.390	0.882	1.702	2.956
22	810.351	641.574	16.783	0.603	1.080	0.664	1.405	2.370
23	801.685	596.604	16.118	0.173	0.982	0.572	1.180	2.084
24	822.469	604.712	16.819	0.599	1.062	0.638	1.339	2.297
25	395.36	597.219	16.732	0.408	1.079	0.709	1.430	2.387
26	136.404	570.711	11.562	-0.025	0.804	0.545	0.783	1.573
27	294.128	584.326	15.388	0.017	1.100	0.695	1.436	2.416
28	769.598	572.652	16.921	0.168	0.973	0.596	1.241	2.120
29	431.157	564.34	15.439	0.378	0.990	0.657	1.339	2.215
30	526.046	567.012	16.374	0.487	1.028	0.655	1.320	2.244
31	439.044	550.4	15.415	0.417	0.957	0.631	1.295	2.142
32	459.422	553.475	14.784	0.238	0.919	0.574	1.206	2.031
33	230.516	560.864	16.748	0.344	1.443	1.017	1.977	3.227
34	192.738	539.88	17.133	1.037	1.290	0.815	1.640	2.792
35	255.969	542.761	16.105	0.885	1.173	0.718	1.530	2.572
36	216.683	533.409	17.436	0.170	1.235	0.902	1.808	2.857
37	174.415	522.452	18.301	–	1.519	0.930	2.059	3.377
38	304.559	520.059	16.731	0.177	1.140	0.697	1.430	2.458
39	379.064	527.334	16.292	0.429	1.006	0.593	1.253	2.167
40	718.601	536.83	16.660	–	1.648	1.177	2.311	3.721
41	815.368	540.934	14.931	0.282	0.980	0.610	1.224	2.115
42	719.98	568.96	17.880	0.797	1.229	1.011	1.732	2.791
43	444.778	515.686	13.346	0.128	0.897	0.541	0.988	1.837
44	610.113	504.49	13.107	0.300	0.875	0.550	1.192	1.968
45	417.183	504.496	16.479	0.684	1.041	0.631	1.340	2.274
46	389.381	499.411	16.910	0.048	1.166	0.780	1.530	2.564
47	449.284	494.213	17.863	-1.116	1.107	1.292	2.514	3.250
48	354.493	481.355	15.195	0.306	0.979	0.616	1.271	2.150
49	380.663	475.909	16.502	-0.161	1.073	0.723	1.393	2.352
50	422.247	477.711	18.084	–	1.466	0.921	1.744	3.076
51	587.827	491.679	17.577	-0.303	1.469	0.546	1.586	2.958
52	694.082	507.951	18.300	–	1.450	0.929	1.796	3.097
53	733.935	505.256	17.823	-0.057	1.358	0.842	1.812	3.002
54	285.392	452.502	14.283	0.321	1.039	0.627	1.295	2.237
55	199.033	454.682	17.553	0.550	1.566	1.036	1.996	3.384
56	65.59	447.69	16.487	0.134	1.113	0.726	1.474	2.460
57	29.588	544.892	14.363	0.989	1.838	1.329	2.569	4.138
58	706.947	477.484	16.233	0.329	1.031	0.633	1.286	2.221
59	477.793	442.54	16.030	0.355	0.975	0.646	1.278	2.150
60	492.275	431.065	16.045	0.722	1.104	0.800	1.588	2.536
61	497.782	416.975	15.236	0.362	1.123	0.724	1.479	2.476
62	263.741	404.941	16.484	0.316	1.085	0.714	1.454	2.413
63	318.448	395.746	14.223	0.183	1.009	0.635	1.307	2.212
64	355.927	394.542	14.908	0.171	1.002	0.623	1.287	2.189
65	370.815	380.921	15.870	0.292	1.015	0.647	1.386	2.280

Table 3. Continued.

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
66	666.464	391.389	17.439	–	1.202	0.856	1.638	2.689
67	695.799	388.533	15.541	0.116	1.061	0.709	1.341	2.298
68	564.794	366.739	15.057	0.385	1.032	0.622	1.297	2.230
69	686.791	366.311	17.314	0.741	1.081	0.828	1.598	2.518
70	769.645	374.273	17.341	0.309	1.353	0.949	1.852	3.027
71	349.456	345.531	15.959	0.617	1.229	0.798	1.505	2.618
72	813.89	325.649	14.012	0.617	1.121	0.680	1.191	2.252
73	911.578	338.384	16.647	0.238	1.772	1.324	2.565	4.059
74	648.39	313.778	16.361	-0.243	1.018	0.665	1.342	2.249
75	681.79	312.887	15.867	0.279	1.004	0.657	1.312	2.210
76	368.623	312.396	18.085	–	1.370	1.022	1.933	3.109
77	478.402	285.918	17.191	1.608	1.115	0.740	1.581	2.543
78	745.058	284.38	17.173	0.317	1.177	0.740	1.506	2.558
79	782.123	280.245	14.925	-0.026	1.049	0.680	1.374	2.310
80	681.732	286.291	18.772	–	1.290	1.064	2.012	3.077
81	741.554	256.943	15.850	-0.009	1.063	0.635	1.303	2.272
82	446.962	270.06	17.785	–	1.347	0.966	1.919	3.072
83	458.995	246.229	17.640	3.037	1.249	0.923	1.742	2.823
84	342.305	275.386	17.450	-1.298	2.060	1.337	2.663	4.466
85	437.289	220.5	15.011	0.236	1.007	0.621	1.275	2.186
86	468.491	197.138	15.893	0.425	1.042	0.668	1.353	2.286
87	440.008	197.215	16.469	2.037	1.194	0.814	1.632	2.674
88	656.922	208.468	17.145	1.020	1.321	0.996	1.876	3.009
89	610.073	180.33	15.385	0.193	1.006	0.614	1.262	2.174
90	319.092	179.136	15.535	0.024	1.043	0.636	1.307	2.252
91	119.663	253.474	16.166	–	2.013	1.428	2.776	4.499
92	568.624	149.731	15.609	0.378	1.045	0.635	1.311	2.257
93	749.207	143.438	15.699	0.279	1.282	0.900	1.720	2.843
94	331.993	115.484	16.566	-0.027	1.029	0.576	1.209	2.160
95	228.376	135.621	17.588	–	1.510	0.926	1.859	3.215
96	381.244	111.465	18.466	1.090	1.349	0.993	1.949	3.097
97	369.724	40.792	13.792	0.098	1.011	0.632	1.260	2.178
98	385.957	39.031	14.085	0.032	1.020	0.657	1.359	2.265
99	595.082	462.533	17.638	–	1.247	0.935	1.708	2.794
100	589.299	425.766	18.604	-0.569	1.517	0.803	1.728	3.122
101	479.926	617.667	15.566	1.781	1.245	0.780	1.402	2.557
102	435.416	580.489	16.921	1.474	1.139	0.879	1.779	2.724
103	416.839	566.626	16.292	0.798	1.014	0.646	1.379	2.273
104	439.044	550.4	15.410	0.418	0.957	0.634	1.293	2.141
105	466.947	577.633	19.310	–	1.491	1.444	2.259	3.499
106	589.63	605.75	18.340	–	1.279	1.089	2.139	3.162
107	494.173	567.812	19.335	-2.025	1.604	0.727	1.585	3.114
108	150.92	631.177	16.297	1.204	1.661	1.287	2.477	3.863
109	251.205	675.3	17.478	–	1.430	1.048	1.985	3.219
110	233.047	668.134	18.412	-1.552	1.661	1.130	2.116	3.587

Table 4. The standardised UBVRI photometric data for individual stars in the open cluster Czernik 18 (OCl 426).

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
1	247.743	965.286	16.106	0.445	1.152	0.453	1.609	2.663
2	129.855	923.005	17.421	-0.158	1.192	0.416	1.537	2.640
3	270.933	911.21	14.901	0.412	0.920	0.305	1.297	2.119
4	499.733	775.357	17.435	1.496	0.969	0.391	1.480	2.342

Table 4. Continued.

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
5	574.138	775.644	19.243	-2.262	1.212	0.840	2.232	3.305
6	628.966	756.401	15.348	0.278	0.952	0.312	1.316	2.172
7	722.79	770.025	16.687	-0.036	1.205	0.421	1.592	2.705
8	848.641	757.911	18.152	-0.161	1.357	0.522	1.775	3.041
9	995.859	813.935	17.335	0.200	1.535	0.650	2.105	3.542
10	329.665	734.885	19.153	-0.231	1.132	0.657	2.059	3.058
11	965.996	733.131	17.153	0.514	1.235	0.520	1.748	2.882
12	339.906	696.412	17.824	-2.558	1.355	0.584	1.926	3.179
13	431.068	694.229	16.226	0.384	1.224	0.450	1.632	2.764
14	460.404	639.211	14.560	0.441	0.726	0.156	0.996	1.627
15	546.773	651.226	17.850	-0.156	1.208	0.568	1.970	3.059
16	461.415	607.238	17.137	0.624	1.116	0.411	1.535	2.555
17	522.713	598.581	15.257	0.626	0.936	0.324	1.339	2.176
18	767.161	617.761	18.847	–	1.676	0.575	1.952	3.556
19	839.046	599.177	13.568	0.375	0.773	0.177	1.043	1.722
20	419.697	599.013	18.681	–	1.151	0.670	2.022	3.044
21	376.454	566.207	18.442	–	1.369	0.359	1.470	2.772
22	767.568	566.122	14.494	0.369	0.730	0.157	0.980	1.617
23	563.909	523.876	12.676	0.557	1.011	0.447	1.515	2.421
24	326.306	554.232	16.725	–	1.267	0.464	1.637	2.815
25	219.975	533.943	16.152	0.387	1.089	0.346	1.409	2.408
26	392.043	496.579	15.085	0.671	1.246	0.448	1.620	2.775
27	598.264	501.031	17.726	-0.651	1.548	0.561	1.890	3.358
28	637.064	498.652	15.112	0.522	0.853	0.254	1.186	1.942
29	283.452	488.85	15.534	0.802	0.967	0.298	1.292	2.165
30	319.373	453.378	18.335	-1.289	1.088	0.558	1.702	2.678
31	559.097	456.834	13.505	0.540	0.728	0.182	1.051	1.681
32	615.645	474.257	17.002	–	1.326	0.526	1.713	2.950
33	619.703	463.338	16.930	–	1.166	0.517	1.719	2.780
34	686.708	477.222	14.241	0.433	0.816	0.223	1.137	1.856
35	921.287	497.853	17.283	-0.456	1.166	0.455	1.662	2.728
36	814.093	552.752	19.162	–	1.046	0.744	2.130	3.030
37	664.637	565.866	18.519	–	1.368	0.448	1.719	3.001
38	604.179	542.682	19.105	-2.926	2.909	-0.459	0.829	3.868
39	738.354	542.969	19.637	–	3.153	0.283	1.727	4.967
40	257.481	478.144	19.260	-2.544	3.265	0.598	1.974	5.320
41	757.79	458.551	18.994	–	2.261	0.626	2.053	4.290
42	501.394	431.49	17.589	4.114	1.183	0.511	1.691	2.773
43	383.019	405.931	18.008	1.816	1.410	0.538	1.764	3.090
44	171.894	422.814	17.311	–	1.475	0.540	1.930	3.314
45	272.64	387.971	17.643	-0.431	1.614	0.542	1.879	3.420
46	100.925	383.705	17.979	-0.156	1.169	0.346	1.492	2.573
47	24.888	364.435	17.532	–	1.168	0.354	1.431	2.515
48	495.321	353.261	16.079	-0.066	1.010	0.334	1.380	2.294
49	537.104	342.015	16.080	-0.046	1.219	0.445	1.632	2.758
50	471.356	320.556	14.291	0.438	0.757	0.163	1.047	1.708
51	417.77	284.69	14.919	0.316	0.868	0.228	1.174	1.948
52	450.048	308.311	17.750	-1.655	1.289	0.285	1.456	2.671
53	322.723	337.46	18.370	–	1.094	0.258	1.418	2.422
54	306.709	324.68	15.880	0.194	0.975	0.295	1.285	2.168
55	266.9	297.076	18.351	-0.736	1.132	0.348	1.301	2.355
56	204.991	264.835	17.006	-0.257	0.906	0.275	1.229	2.040
57	610.023	338.363	19.329	-1.614	1.393	0.600	1.844	3.144
58	605.059	316.755	19.316	-1.337	1.279	0.398	1.526	2.725
59	614.719	298.449	18.508	–	1.295	0.620	1.951	3.137
60	634.145	275.006	17.390	2.212	1.180	0.445	1.619	2.703
61	566.118	263.889	19.364	2.105	1.432	0.512	1.678	3.034
62	566.211	238.536	17.754	-1.783	1.056	0.379	1.403	2.367
63	783.68	404.473	18.506	-1.433	1.372	0.457	1.790	3.072
64	739.327	206.689	11.901	0.025	0.577	0.103	0.726	1.213
65	928.17	252.19	13.158	0.070	0.607	0.089	0.855	1.366

Table 4. Continued.

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
66	608.931	159.054	17.220	–	1.295	0.410	1.542	2.757
67	620.215	138.136	19.502	–	2.141	1.678	3.835	5.811
68	588.717	135.438	15.888	1.174	1.418	0.527	1.781	3.114
69	345.223	155.683	14.917	0.097	0.963	0.285	1.284	2.154
70	207.885	190.629	18.096	-2.049	0.768	0.359	1.247	1.906
71	267.064	118.105	16.249	0.236	1.018	0.357	1.382	2.305
72	477.01	115.774	17.210	0.536	1.193	0.376	1.475	2.584
73	480.35	95.958	19.738	–	2.164	0.933	2.291	4.405
74	533.048	84.423	17.378	–	1.340	0.498	1.695	2.948
75	491.447	72.471	18.032	-1.398	1.280	0.377	1.599	2.794
76	512.183	35.441	15.406	0.027	0.951	0.271	1.254	2.113
77	455.952	43.099	14.705	0.308	1.151	0.366	1.448	2.512
78	313.379	40.16	17.754	–	1.247	0.324	1.466	2.634
79	103.141	59.42	14.904	-0.108	1.005	0.300	1.337	2.250
80	700.731	106.066	17.493	-1.043	1.085	0.353	1.416	2.410
81	663.664	77.092	19.000	-2.141	1.211	0.582	1.719	2.830
82	783.807	55.64	17.662	-0.637	0.875	0.441	1.528	2.283
83	826.94	72.475	15.942	-0.113	1.043	0.369	1.458	2.403
84	909.217	85.014	18.006	-0.620	1.190	0.413	1.688	2.777
85	991.395	95.523	18.659	-0.753	1.522	0.689	1.967	3.400
86	489.365	901.289	17.854	0.981	1.052	0.411	1.464	2.419
87	507.018	907.397	18.784	–	1.539	0.288	1.376	2.871
88	762.775	926.005	18.071	-0.766	1.318	0.493	1.754	2.979
89	755.694	914.415	18.106	0.634	1.175	0.502	1.751	2.819

Table 5. The standardised UBVRI photometric data for individual stars in the open cluster NGC 2401 (OCl 588).

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
1	167.326	900.974	13.664	-0.109	0.215	-0.114	0.244	0.370
2	436.631	895.379	15.667	-0.124	0.645	0.134	0.828	1.383
3	235.689	869.054	16.013	-0.171	0.604	0.112	0.842	1.351
4	561.221	881.528	14.710	0.726	1.486	0.539	1.661	3.078
5	654.801	875.302	11.395	0.821	0.950	0.674	1.422	2.267
6	787.791	875.72	16.161	0.114	0.810	0.179	0.891	1.622
7	655.835	838.189	13.465	0.733	1.131	0.328	1.266	2.322
8	648.246	792.916	14.472	0.091	0.219	-0.121	0.239	0.370
9	181.799	784.087	16.690	1.286	0.700	0.095	0.812	1.428
10	161.222	751.144	15.617	-0.046	0.792	0.183	0.938	1.646
11	586.896	752.352	15.885	0.072	0.277	-0.075	0.423	0.604
12	681.743	769.192	16.622	0.051	0.766	0.183	0.959	1.637
13	98.361	708.222	14.259	-0.229	0.580	0.087	0.644	1.141
14	234.992	711.178	16.049	0.695	0.856	0.192	0.961	1.737
15	240.897	647.278	15.583	0.070	0.623	0.099	0.716	1.255
16	269.098	654.255	15.919	-0.014	0.597	0.071	0.738	1.247
17	346.896	680.129	17.088	0.104	0.479	0.046	0.678	1.063
18	556.961	688.093	15.093	0.330	0.340	-0.022	0.437	0.685
19	626.646	690.944	15.118	0.392	0.766	0.215	0.950	1.628
20	648.505	681.323	15.421	0.161	0.296	-0.059	0.393	0.596
21	556.411	655.477	16.767	0.356	0.360	-0.058	0.502	0.768
22	601.937	661.371	18.245	-	0.907	0.174	1.134	1.954
23	490.908	660.221	16.528	0.678	0.913	0.230	1.219	2.039
24	501.615	660.512	16.621	1.350	1.052	0.319	1.209	2.182

Table 5. Continued.

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
25	356.95	637.213	15.909	0.242	0.370	-0.016	0.506	0.783
26	375.69	640.198	16.482	0.362	0.425	0.008	0.459	0.800
27	412.502	652.637	16.706	2.516	0.834	0.198	0.871	1.629
28	432.666	647.769	15.260	0.187	0.551	0.029	0.611	1.078
29	427.556	642.22	15.353	0.137	0.519	0.055	0.625	1.056
30	490.562	643.41	16.998	0.217	0.771	0.129	0.859	1.550
31	408.167	618.123	14.362	-0.307	0.194	-0.107	0.222	0.326
32	429.83	609.013	16.300	0.263	0.453	0.024	0.503	0.872
33	462.154	608.337	17.461	-	0.835	0.055	0.783	1.549
34	451.239	621.04	16.785	0.324	0.702	0.111	0.804	1.423
35	393.321	610.464	15.385	-0.348	0.262	0.033	0.309	0.482
36	386.881	597.956	16.044	0.324	0.431	-0.102	0.462	0.809
37	479.182	610.234	16.323	0.363	0.470	-0.025	0.525	0.910
38	579.562	626.059	16.478	0.730	0.466	0.110	0.699	1.067
39	626.784	629.695	17.326	-0.580	0.839	0.234	1.412	2.136
40	349.221	580.061	16.943	0.074	0.523	0.007	0.578	1.017
41	307.461	572.022	17.120	-0.194	0.724	0.101	0.892	1.529
42	448.379	584.016	16.460	0.954	0.402	-0.075	0.476	0.790
43	398.143	563.288	16.188	-0.533	0.408	0.132	0.528	0.844
44	418.523	562.315	14.051	-0.407	0.191	-0.105	0.230	0.330
45	410.145	543.440	15.605	-0.166	0.288	-0.085	0.315	0.516
46	394.247	548.112	16.361	0.320	0.661	0.001	0.540	1.134
47	450.37	561.433	15.461	-0.040	0.300	-0.072	0.322	0.535
48	477.998	584.102	14.866	0.003	0.299	-0.082	0.399	0.606
49	477.691	559.573	15.820	0.373	0.423	-0.060	0.544	0.876
50	488.248	556.329	15.909	0.630	0.504	-0.077	0.397	0.828
51	502.319	570.165	17.135	-	0.646	-0.134	0.578	1.152
52	514.545	588.04	14.903	-0.067	0.238	-0.098	0.288	0.436
53	536.891	593.86	17.121	0.879	0.703	0.108	0.653	1.284
54	532.016	580.01	16.594	-0.998	0.548	0.132	0.397	0.877
55	538.027	543.511	15.411	0.016	0.265	-0.109	0.320	0.496
56	544.603	521.626	14.888	0.222	0.379	-0.035	0.445	0.736
57	515.116	515.671	14.539	-0.331	0.166	-0.126	0.207	0.282
58	585.637	533.265	15.579	0.652	0.954	0.359	1.273	2.134
59	459.952	519.145	18.119	-0.581	0.775	0.134	1.026	1.709
60	427.176	525.69	16.934	0.256	0.759	0.023	0.847	1.526
61	437.298	515.845	16.664	0.447	0.769	0.065	0.888	1.574
62	449.999	490.439	15.276	0.054	0.692	0.168	0.882	1.484
63	487.979	482.905	17.169	0.158	0.567	0.032	0.719	1.196
64	459.985	471.388	16.161	-0.036	0.535	0.024	0.638	1.086
65	426.678	479.629	15.275	-0.232	0.237	-0.100	0.304	0.450
66	395.348	506.869	17.143	0.053	0.559	0.075	0.706	1.175
67	344.702	529.237	15.346	0.091	0.466	0.002	0.562	0.940
68	374.156	518.909	14.658	-0.337	0.236	-0.108	0.256	0.405
69	364.031	500.598	15.853	0.069	0.351	-0.052	0.499	0.755
70	344.702	529.237	15.346	0.091	0.466	0.002	0.562	0.940
71	565.136	493.202	16.850	0.620	0.718	0.097	0.801	1.438
72	517.2	455.473	14.954	0.063	0.350	-0.015	0.529	0.782
73	409.156	454.731	17.281	2.253	0.855	0.068	0.842	1.626
74	355.957	474.661	15.282	-0.108	0.572	0.102	0.694	1.179
75	361.556	439.532	17.296	-0.431	0.656	0.208	0.963	1.520
76	235.572	538.773	16.576	-0.213	0.716	0.096	0.787	1.423
77	148.51	563.085	17.086	-0.052	0.722	0.136	0.850	1.487
78	208.429	477.342	13.129	-0.027	0.424	-0.044	0.387	0.732
79	278.623	481.528	15.648	-0.282	0.301	-0.101	0.323	0.537
80	261.001	377.563	12.110	-0.696	0.228	0.035	0.481	0.604
81	120.962	332.421	12.100	-0.160	0.563	0.160	0.735	1.206
82	70.918	423.168	13.342	-0.513	0.129	-0.190	0.081	0.125
83	434.456	415.086	15.497	-0.155	0.254	-0.079	0.330	0.491
84	393.721	410.571	15.500	0.436	0.843	0.194	0.912	1.678
85	401.467	430.536	16.333	0.192	1.127	0.376	1.405	2.446

Table 5. Continued.

ID	X	Y	V	(U-B)	(B-V)	(V-R)	(V-I)	(B-I)
86	416.694	429.254	16.469	-	1.565	0.534	1.719	3.218
87	586.767	584.6	15.731	0.323	0.343	-0.033	0.467	0.717
88	637.431	571.36	15.611	-0.015	0.396	0.024	0.628	0.925
89	658.179	527.435	14.778	-0.179	0.228	-0.048	0.349	0.481
90	648.707	503.421	15.724	0.169	0.540	0.083	0.654	1.107
91	692.225	602.303	16.568	-0.123	0.759	0.239	1.090	1.751
92	603.637	454.324	17.461	0.771	0.642	0.199	0.974	1.514
93	782.614	591.885	16.202	0.023	0.674	0.129	0.860	1.444
94	791.485	552.551	17.420	-0.034	0.592	0.046	0.763	1.265
95	758.813	540.631	17.551	-0.385	0.930	0.340	1.519	2.336
96	724.858	508.539	16.807	1.749	0.456	-0.046	0.648	1.009
97	680.589	439.04	16.243	0.339	0.891	0.267	1.042	1.851
98	589.314	403.123	16.398	0.036	0.835	0.208	0.947	1.701
99	570.373	381.122	16.686	-0.338	0.515	0.114	1.041	1.438
100	490.483	345.55	16.307	0.300	0.730	0.144	0.885	1.529
101	546.531	342.643	15.682	0.184	0.935	0.288	1.079	1.933
102	678.958	374.175	14.300	0.594	1.136	0.408	1.356	2.410
103	735.004	440.528	16.429	0.054	0.707	0.165	0.920	1.536
104	848.319	549.345	15.529	1.006	1.257	0.445	1.485	2.662
105	888.366	527.32	16.978	-0.314	0.613	0.135	0.936	1.447
106	815.371	449.131	15.950	-0.068	0.423	-0.005	0.528	0.861
107	919.971	434.384	14.077	0.258	1.037	0.327	1.173	2.132
108	709.582	341.618	12.032	0.380	1.178	0.419	1.394	2.493
109	654.853	295.297	14.561	-0.281	0.272	-0.112	0.296	0.481
110	627.51	340.265	16.509	0.596	0.767	0.145	0.913	1.595
111	625.553	323.061	16.179	1.085	1.073	0.278	1.144	2.145
112	539.387	312.232	16.638	-0.052	0.772	0.225	0.828	1.522
113	522.609	316.232	15.850	0.181	0.482	0.025	0.594	0.987
114	462.785	279.495	16.630	-0.214	0.653	0.073	0.777	1.344
115	428.954	294.365	16.153	-0.083	0.391	-0.052	0.450	0.753
116	808.825	410.853	16.100	-0.380	0.710	0.060	0.783	1.412
117	218.774	317.425	17.883	-	0.950	0.163	0.881	1.766
118	253.254	300.625	16.470	0.172	0.612	0.184	0.662	1.193
119	235.178	293.522	15.827	0.191	0.595	0.104	0.709	1.218
120	304.466	301.428	16.133	0.039	0.646	0.111	0.801	1.358
121	317.719	278.974	17.286	-0.321	0.966	0.192	1.004	1.899
122	353.953	155.226	15.425	-0.276	0.648	0.129	0.794	1.355
123	128.03	184.112	13.439	-0.226	0.352	-0.042	0.436	0.698
124	440.727	178.388	17.283	-0.022	1.070	0.334	1.182	2.177
125	490.865	188.317	17.092	0.308	0.748	0.134	0.978	1.635
126	444.746	116.091	15.714	-0.086	0.543	0.053	0.665	1.120
127	567.163	99.447	14.534	-0.281	0.658	0.077	0.680	1.260
128	667.487	162.138	10.913	-0.994	-0.297	0.355	0.445	-0.005
129	776.448	182.41	15.510	0.208	0.887	0.242	0.982	1.790
130	879.869	131.087	12.947	-0.740	0.196	-0.052	0.340	0.437
131	292.288	446.395	15.943	-0.014	0.810	0.174	0.885	1.617
132	315.075	441.288	17.394	-	1.279	0.383	1.334	2.547
133	316.412	429.011	17.200	-	1.369	0.079	0.988	2.325
134	420.59	400.014	17.850	-0.325	0.380	0.180	0.714	0.986
135	485.934	521.019	18.846	0.867	1.624	0.038	0.656	2.298
136	496.395	540.032	17.987	-	1.022	0.057	0.956	1.915
137	519.139	475.206	15.707	-0.579	0.357	-0.006	0.540	0.800
138	548.341	481.363	17.477	0.470	0.819	-0.093	0.693	1.449
139	613.732	552.768	17.636	-	0.666	-0.133	0.590	1.185
140	423.025	715.261	16.329	0.659	0.602	0.148	0.916	1.417
141	406.904	703.696	16.467	0.110	0.590	0.149	0.893	1.383
142	393.041	709.177	17.270	-	0.667	0.106	0.831	1.409
143	415.92	704.001	16.134	-0.207	0.597	0.107	0.885	1.384
144	569.831	670.575	17.308	0.060	0.772	0.212	0.911	1.599
145	790.901	684.47	16.608	-0.339	0.768	0.182	0.931	1.613
146	681.846	713.081	17.288	0.548	0.731	0.164	0.912	1.555

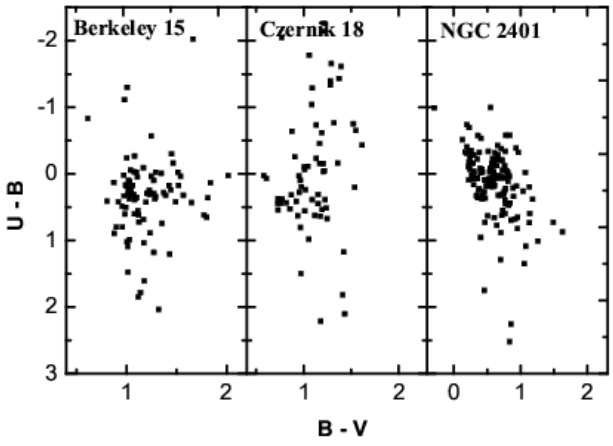

Figure 4. The (B-V) vs (U-B) diagrams for the clusters Be 15, Cz 18 and NGC 2401. The unwieldy scatter in the diagrams could be due to the absence of blue stars and/or poor quality of U filter.

3. Reddening

An attempt was made to obtain the colour excesses through the (B-V) vs (U-B) diagrams of these clusters. However it was noticed that the S/N ratio for the data obtained through the U filter used in this work was very poor, which resulted in an unwieldy scatter in the colour - colour diagrams as shown in figure 4. This could be attributed either to the low quality of the U filter and/or to the absence of blue stars in these clusters. With this in view the E(B-V) values were obtained by employing the technique given by Natali et al. (1994), through the colour - colour diagrams of (B-V) vs (B-I) for the selected stars in the field of each cluster as shown in figure 5. Thus the reddening corrected $(B\text{-}V)_o$ values were obtained by applying E(B-V) to the standardized (B-V) values. Then the V magnitudes were also corrected to obtain the reddening corrected V_o magnitudes by applying the total visual absorption A_v as it was done in Paper I (Sujatha and Babu, 2003a).

4. Results and Discussion

The distance moduli (V_o-M) of these clusters have been determined by fitting the relevant zero age main sequences (ZAMS) onto the respective $(B\text{-}V)_o$ vs M_v, $(V\text{-}R)_o$ vs M_v and $(V\text{-}I)_o$ vs M_v diagrams as shown in figure 6. The distance D of each cluster is then calculated by using the standard expression $\log D = 0.2(V_o\text{-}M) + 1$. While the distances of Be 15 and Cz 18 are in the range of about 1 kpc, the distance of NGC 2401 is much farther at more than 3 kpc. Then in order to obtain the respective ages of the clusters, the post main sequence isochrones given by Girardi et al. (2000) are superimposed on to the HR diagrams along with the ZAMS as shown in figure 6. It may be noted in these diagrams that there is a clear indication of the absence of blue stars in these clusters and all the three clusters are found to be of intermediate and old age category.

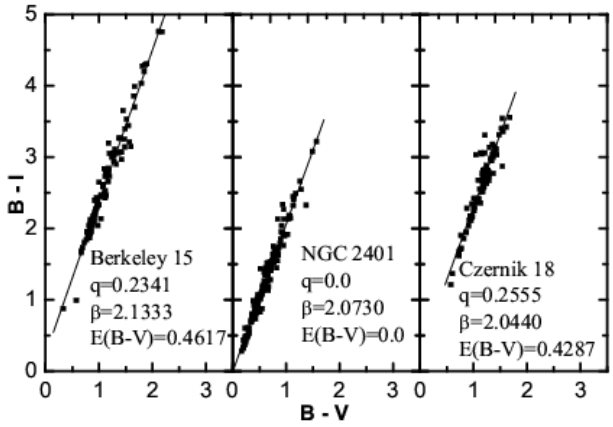

Figure 5. The (B-V) vs (B-I) diagrams of the stars in the fields of open clusters Be 15, Cz 18 and NGC 2401 respectively. Employing the technique given by Natali et al. (1994), the colour excesses E(B-V) for each cluster is obtained. The solid line is the least square fit for the respective diagrams.

Table 6. The physical parameters of the clusters as obtained in this work.

Cluster	E(B-V) In mag	Dist. Modulus in mag	Distance in pc	Age in years
Berkeley 15	0.462	10.5	1259 ± 135	~ 5 x 10^9
Czernik 18	0.430	9.9	955 ± 110	~ 0.8 - 1 x 10^9
NGC 2401	0.0	12.7	3467 ± 410	~ 1 x 10^9

The distances and ages of the respective clusters are found to be same in their corresponding HR diagrams. The results are tabulated in table 6.

4.1 Berkeley 15 (Be 15, OCl 414):

In 1960, Setteducati listed this group of stars as a cluster in the Berkeley Catalogue and indicated its angular diameter as 9 arcmin (*cf.* Alter et al., 1970). It is classified as II 2 p by Ruprecht (1966) in the Trumpler system of classification.

In the present work, the colour excess E(B-V) has been found to be 0.462 mag based on which the distance modulus is determined as 10.5 mag. Using this value, the distance is calculated to be 1259± 135 parsecs. The post main sequence isochrones superimposed on its HR diagram indicate an age of ~ 5 x 10^9 years. The smallest $(B\text{-}V)_o$ on its main sequence is + 0.50 mag which also gives the age of this cluster as 5 x 10^9 years by using the relationship given by Allen (2000). This cluster is in the direction of the Auriga - Perseus constellations.

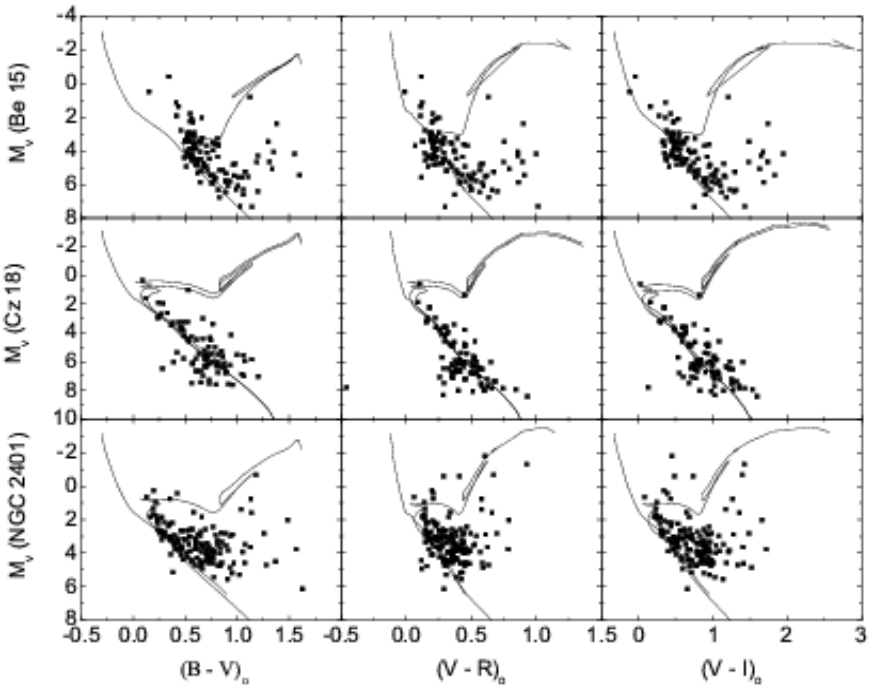

Figure 6. The colour-magnitude diagrams $(B-V)_o$ vs M_v, $(V-R)_o$ and M_v and $(V-I)_o$ and M_v of the open clusters Be 15, Cz 18 and NGC 2401 along with the relevant zero age main sequences (ZAMS) and appropriate isochrones. See text for details of distances and ages of the respective clusters.

4.2 Czernik 18 (Cz 18, OCl 426):

The earliest study of this cluster was done by Czernik (1966) who mentioned that it is spread over an angular diameter of 10 arcmin. This cluster is classified as IV 2 p in the Trumpler system of classification (Ruprecht, 1966).

Correcting for the reddening of E(B-V) = 0.430 mag obtained in the present work, the distance of this cluster is calculated to be 955 ± 110 parsecs on the basis of its distance modulus of 9.9 mag. The HR diagram of this cluster with a superimposition of post main sequence isochrones indicates an age of ~ 0.8 - 1 x 10^9 years. The turn off point with the smallest $(B-V)_o$ on its main sequence is found to be + 0.26 mag and this also gives the age of this cluster as 1 x 10^9 years by using the relationship given by Allen (2000) which agrees well with that obtained through the isochrones. As in the case of Be 15, this cluster is also in the direction of the Auriga - Perseus constellations.

4.3 NGC 2401 (OCl 588):

This group of stars was first listed as a cluster by Trumpler (1930), who gave its angular diameter as 2 arcmin. He also estimated its distance to be 5150 pc, while Collinder (1931) gave the distance as 10000pc. Almost two decades later Barhatova (1950) found the distance as 2700pc and also gave its angular diameter as 5 arcmin. It has been classified in the Trumpler system as II 3 p by Ruprecht (1966).

Since the interstellar reddening in the direction of this cluster is found to be 0.0 mag, no extinction correction has been applied to the observations in the present work. The distance modulus is then determined to be 12.7 mag and thereby the distance is calculated as 3467 ± 410 parsecs. The post main sequence isochrones on its HR diagram indicate an age of ~ 1 x 10^9 years. The smallest $(B-V)_o$ on its main sequence is + 0.27 mag which also gives the age of this cluster as 1 x 10^9 years by using the relationship given by Allen (2000). This cluster is located in the direction of Ophiuchus constellation in our Galaxy.

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References

Allen C.W., 2000, *Astrophysical Quantities,4 edn*, Publishers, Springer Verlag, New York.
Alter G., Balazs B., Ruprecht J., 1970, *Catalogue of Star Clusters and Associations*, Publishers,Akademiai, Budapest.
Barhatova K.A., 1950, *AZh*, **27**, 182.
Czernik, 1966, *Act. Ast.*, **16**, 94.
Girardi L., Bressan A., Bertelli G., Chiosi C., 2000, *A&AS*, **141**, 371.
Natali et al., 1994, *A&A*, **289**, 756.
Ruprecht J., 1966, *BAC*, **17**, 34.
Sujatha S., Babu G.S.D., 2003a, *BASI*, **31**, 9 (Paper I).
Sujatha S., Babu G.S.D., 2003b, *BASI*, **31**, 379 (Paper II).
Trumpler, R.J., 1930, *LOB*, **14**, 154.