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Spectral classification and reddening in the young open cluster NGC 6913

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Abstract. Spectroscopic observations have been made for the young open cluster NGC 6913. In total, the spectra of 100 stars of the cluster, having membership probability greater than 50%, have been obtained and classified. Reddening is estimated on the basis of spectral classification. The variable extinction across NGC 6913 is analyzed and discussed. From the spectroscopic observations, it is found that the spectral type distribution in our sample covers from O7 to K3. There are only 2 O-type stars in this OB association. 40 and 33 percent of the total stars are B and A type stars respectively, and the F, G, K stars amount to 25 percent.

An extreme variation of extinction is found across the young open cluster NGC 6913. The distribution of extinction in the region is correlated with the effective temperature of the stars for stars earlier than F8. It is found that extinction in the cluster center is relatively homogeneous, but very large. The north and south of this cluster have the largest extinction. The eastern and western parts seem to be low reddening regions. A mean distance modulus of 10.17 ± 0.14 mag. is derived for the cluster, which corresponds to a distance of 1.08 kpc.

A large part of the values of interstellar reddening of the stars in NGC 6913 from spectral classification are quite different from those taken from photometry (especially for early B and F type stars); the largest discrepancy amounts to 1.48 mag.. Depending on a reddening method, a total amount of 30% of the stars with membership probability greater than 50% can be evaluated to be probable "non-members" of the cluster.

In addition, some interesting objects are found in this study. Further observations for these stars will be made in the future.

Key words: stars: fundamental parameters – ISM: dust, extinction – Galaxy: open clusters and associations: general

1. Introduction

The young open cluster NGC 6913 (M29) (20h23m.9, +38.32(2000)) is located in the Cygnus OB1 association. In 1973, Sanders computed the probabilities of cluster membership for 228 stars in the field of NGC 6913, based on relative proper motions (Sanders 1973). He found there are 105 stars with probabilities greater than 50% out of 228 stars in the field. Before 1980, only a small part of the stars had UBV photoelectric values. Much more complete UBV photoelectric photometry was done by Joshi et al. (1983), using the 104-cm Sampurnanand reflector of the Uttar Pradesh State Observatory. The standard deviations of their observations were better than $\pm$ 0.025 mag. in (U-B), (B-V) and V magnitudes (Joshi et al. 1983). From their photometric study, the distance modulus to the cluster is obtained to be 10.85, which corresponds to a cluster distance 1.5 kpc. It also was found that the cluster stars have ages between 0.3 to 1.75 Myr with a few even younger than 0.3 Myr. This means that NGC 6913 is a very young open cluster.

Since the cluster is so young, it should have many stars in the pre-main-sequence phase. Many published and upcoming papers by different authors show galactic clusters containing stars young enough to be still surrounded by circumstellar disks. The presence of such disks has now been inferred around pre-main-sequence stars of masses ranging from 0.1 to 25$M_{\odot}$. Circumstellar disks and mass loss of the stars are the two factors affecting the observational results. Another factor is the intracluster extinction due to the remaining star-forming molecular cloud. All of them contribute to the non-uniform extinction across a cluster, which has been studied by Sagar (1987).

The study of interstellar matter inside open clusters, especially very young open cluster, is quite important for a thorough understanding of the star formation processes (e.g. Burki 1975; Wallenquist 1975, 1979; Roth 1988). On the basis of the presence of non-uniform extinction in young open clusters and associations, Elmegreen & Lada (1977) proposed the sequential star formation process theory, which predicted that massive stars in open clusters should be younger than low-mass stars.

Although many people have done statistical research on this topic, little work has been done wholly based on precise spectroscopic data. Some studies of extinction of open clusters were done with photometric data, only partially calibrated with spectroscopy. The photometric data sometimes were not accurate. Actually, in the case of the variable extinction across a cluster, photometric observation is insufficient. It is too difficult to obtain accurate spectral type from photometric data. This will

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cause incorrect values for reddening and position in the H-R diagram. Besides, spectroscopy provides a powerful means for characterizing stars which appear to have unusual properties. A stellar spectrum is indicative of significant amounts of activity associated either with the star itself or with the presence of circumstellar material. Circumstellar material can be identified from the spectrum not only with emission lines but also without emission lines (Hillenbrand et al. 1993). Hence, spectroscopic observation is indispensable.

If one wants to study intracluster extinction, one should have a complete sample of cluster members, for which three sets of data must be available, i.e. (i) reliable cluster membership; (ii) precise photometric data; (iii) accurate spectral classification.

To study extinction inside the very young open cluster, we select those stars which have a membership probability greater than 50% in Sanders' star table of NGC 6913. We carry out spectroscopic classification for 100 stars of the NGC 6913 field. Even for those stars whose proper motions are in agreement with the average for the cluster, there could still be a non-negligible fraction of non-member stars (e.g. Crawford et al. 1977).

2. Observations and results

2.1. Observations and data reduction

The spectroscopic observations were carried out between June 7 and June 11 in 1994 with the 2.16 m telescope at Xinglong station of Beijing Astronomical Observatory, equipped with a thin Tektronix 512$\times$512 CCD and a UNIVASAL spectrograph. A grating with a dispersion of 195Å/mm was used. The spectral resolution is 5.26Å/pixel, and the wavelength coverage is from 4205 to 6898Å.

The stars were selected from Sanders' list of NGC 6913. All the stars in the sample have a membership probability greater than 50%. A membership probability of 50% guarantees that most of the non-cluster members have been removed. We will discuss the problem of membership in Sect. 3 of this paper. A cross identification between Sanders' finding chart and ST Atlas was made so as to get the accurate coordinates of the stars.

The spectroscopic data were reduced on a Sun sparc-2 workstation with the ESO Midas package. Every spectrum was corrected from the CCD flat and dark by using the usual methods. The contamination of the nearby sky was subtracted.

2.2. Results

Fig. 1 shows the reduced spectra that we plot in order of spectral type. Three of them were found to be emission spectra, i.e. #33, 125 and 151. One emission line star (#159) in Mermilliod's catalogue (Mermilliod 1986) does not show emission lines in its spectrum. Fig. 1 is available as supplementary data in electronic form.

Table 1 presents the results of our spectral classification as well as other observational data for NGC 6913. The method we used to make the spectral classification has been described by Shi & Hu (1999). They discussed the MK standards and an extension of the MK classification to the yellow-red region based on CCD spectra, obtained with the 2.16 m telescope of BAO, of 125 MK standards covering the spectral types from O to M and luminosity classes from V to I. They listed the main features for spectral classification in the yellow-red region. We also refer to the Library of stellar spectra observed by Jacoby et al. (1984) to classify the 100 cluster stars. Besides, we observed some standard MK stars to compare accuracy with our program stars. We find that the accuracy of classification is better than one spectral subclass. The values of V, (B-V), (U-B) and Ep(B-V) are taken from Joshi's photoelectric UBV photometry. The values of $(B\text{-}V)_0$, $(U\text{-}B)_0$, E(B-V) and E(U-B) in this table are calculated from the spectral type.

The distribution of spectral type of the stars we observed is shown in Fig. 2. From Figs. 1 and 2, it can be seen that there is a broad spectral type distribution in our sample, which covers spectral type O7 to K3. There are only 2 O-type stars in the OB association. Most of the stars belong to B or A type, namely 40 and 33 percent of the total number of stars respectively. And the F, G, K stars make up 15, 6, 4 percent respectively.

3. Study of reddening and extinction of NGC 6913

3.1. Comparison among the different observational data

Many E(B-V) values derived from our spectral classification are different from those based on photometry (Ep(B-V)). Some show a very large difference. 32 stars have absolute values of (E(B-V)-Ep(B-V)) greater than 0.3 mag., the largest one of as much as 1.48 mag. (#219)! We find that the stars with large absolute values of (E(B-V)-Ep(B-V)) are mainly some early B type stars and most of the F type stars. The values for Ep(B-V) of the B type stars are far lower than for E(B-V), and the values for Ep(B-V) of the F type stars are higher than for E(B-V). These results are mainly due to the effect of reddening and the uncertainty of the photometric classification; moreover, they have different R values. The difference shows the importance of the spectroscopic observations in studying young star clusters which include many pre-main sequence stars.

In addition, For the same cluster, Crawford et al. (1977) selected a small sample to do four-color and Hβ photometry. They found the disagreement between the distance modulus derived from the photometry alone and from that using spectral types. What is particularly striking is that they never found it in their previous cluster work. This indicates once more that to study the clusters with large variable extinction, using the photometric method only is insufficient.

3.2. The distance modulus and H-R diagram

In order to construct the physical H-R diagram for NGC 6913, the distance modulus must be known accurately. The distance of NGC 6913 estimated by various authors ranges from 0.8 kpc to 2.8 kpc. Up to now a relatively dependable value of the distance is (1.5 ± 0.12) kpc, corresponding to a distance modulus 10.85 ± 0.15 mag (Joshi et al. 1983). This is obtained by fitting the ZAMS given by Allen onto the unevolved part of the cluster

Table 1. Observational data for the young open cluster NGC 6913 (M29).
(1) Col.1,6, star numbers and membership probability taken from Sanders (1973).
(2) Col.2,3,4,5, photoelectric UBV magnitudes and colours of the stars in NGC 6913,taken from Joshi et al. (1983).
(3) Col.7,8,9,10,11, spectral classification from our observations, corresponding intrinsic colours and the adopted values of the reddening.
(4) Col.12, spectral types shown in BICDS (1986).

star #	V (mag.)	B-V (mag.)	U-B (mag.)	Ep(B-V) (mag.)	p (%)	spectral type	$(B-V)_0$ (mag.)	$(U-B)_0$ (mag.)	E(B-V) (mag.)	E(U-B) (mag.)	remarks
2	12.04	0.53	0.07	0.63	72	A0IV	-0.02	-0.02	0.55	0.09	
7	13.01	0.84	-0.08	1.07	86	B0III	-0.30	-1.08	1.14	1.00	
9	13.39	0.71	1.01	0.73	81	A2IV	0.05	0.06	0.66	0.95	
11	12.86	0.64	0.24	0.71	79	F2III	0.34	0.09	0.30	0.15	
15	9.03	0.61	-0.34	0.87	81	O7I	-0.32	-1.14	0.93	0.8	
17	13.38	0.57	0.21	0.63	86	A3IV	0.09	0.08	0.48	0.13	
24	13.07	1.39	0.55	0.80	83	B2III	-0.25	-0.85	1.64	1.40	
26	10.33	0.60	-0.17	0.80	82	B2V	-0.25	-0.85	0.85	0.68	
28	12.97	1.85	0.33	0.75	67	K2III	1.16	1.17	0.69	-0.84	
32	12.20	0.41	0.47	0.35	84	F5III	0.43	0.09	-0.02	0.38	
33	13.28	0.69	0.31	0.75	82	A0IVe	-0.02	-0.02	0.71	0.33	
36	13.41	0.74	0.35	0.79	62	A2IV	0.05	0.06	0.69	0.29	
37	10.62	1.57	1.74	0.86	66	K0III	1.01	0.86	0.56	0.88	
40	13.60	0.80	0.47	0.83	71	A8III	0.23	0.11	0.57	0.36	
42	13.23	1.01	-	0.80	68	F9III	0.60	0.13	0.41		
47	10.91	0.42	0.25	0.43	58	B8III	-0.10	-0.33	0.52	0.58	
49	13.28	0.83	0.69	0.75	73	A2IV	0.05	0.06	0.78	0.63	
51	13.59	0.56	0.03	0.68	77	F8III	0.60	0.13	0.04	-0.10	
52	13.40	0.63	0.21	0.70	87	A0IV	-0.02	-0.04	0.65	0.25	
54	13.25	0.78	0.32	0.85	88	A6IV	0.20	0.10	0.58	0.22	
55	10.16	0.55	-0.14	0.73	86	B3III	-0.25	-0.85	0.80	0.71	
58	13.14	0.51	0.04	0.61	85	B0II	-0.30	-1.08	0.81	1.12	
61	11.96	0.52	0.11	0.60	61	A8IV	0.23	0.09	0.29	0.02	
64	13.03	0.83	0.04	0.99	83	B5IV	-0.17	-0.57	1.00	0.61	
66	12.61	0.88	0.68	0.75	78	A2V	0.05	0.06	0.83	0.62	
69	9.33	0.54	-0.29	0.75	84	B2IV	-0.24	-0.86	0.78	0.57	
71	12.77	0.74	0.06	0.89	78	B7IV	-0.13	-0.43	0.87	0.49	
73	12.09	0.51	-0.04	0.64	89	B4III	-0.19	-0.65	0.70	0.61	
76	13.67	0.80	0.25	0.90	89	B9IV	-0.07	-0.19	0.87	0.44	
87	10.78	0.38	0.09	0.44	87	A6III	0.18	0.12	0.20	-0.03	
92	13.62				47	G0III	0.65	0.15			
96	12.98	0.61	0.56	0.63	81	A2IV	0.05	0.06	0.56	0.50	
98	11.40	0.55	0.21	0.61	66	F0III	0.28	0.10	0.27	0.11	
101	12.81	1.71	-	0.76	83	G7II	0.92	0.70	0.79		
102	13.57	0.76	0.23	0.86	73	F0III	0.28	0.10	0.48	0.13	
104	13.11	1.77	1.51	0.83	85	K0III	1.01	0.86	0.76	0.65	
105	13.70	0.77	1.15	0.79	70	B4IV	-0.20	-0.65	0.97	1.80	
107	12.64	0.44	0.20	0.47	87	A2V	0.05	0.06	0.39	0.14	
108	11.82				82	A2V	0.05	0.06			
110	11.98	0.67	0.16	0.77	82	B6V	-0.15	-0.50	0.82	0.66	
111	13.84	0.76	0.19	0.87	86	F4III	0.40	0.09	0.36	0.10	
115	13.19	0.75	0.04	0.91	88	B4V	-0.20	-0.65	0.95	0.69	
116	13.75	0.70	0.20	0.79	68	F4II	0.38	0.15	0.32	0.05	
119	13.50	1.02	0.46	0.80	84	A7III	0.20	0.12	0.82	0.34	
120	12.74	1.02	0.50	0.80	87	A8III	0.23	0.11	0.79	0.39	
121	13.32	1.36	0.51	0.79	88	B4V	-0.19	-0.65	1.58	1.16	
123	12.18	0.44	0.33	0.67	87	A8IV	0.23	0.07	0.21	0.26	
124	12.20	0.72	-0.03	0.90	77	B3V	-0.21	-0.71	0.93	0.68	
125	9.47	0.87	-0.34	1.15	83	B0IIIe	-0.30	-1.09	1.17	0.75	B0Ipe
126	12.22	0.79	0.12	0.94	82	B4V	-0.19	-0.65	0.98	0.77	
130	12.07	0.89	0.11	0.92	87	B4IV	-0.19	-0.65	1.08	0.76	
131	13.17	0.58	0.05	0.70	78	F3IV	0.39	0.03	0.19	0.02	

Table 1. (continued)

star #	V (mag.)	B-V (mag.)	U-B (mag.)	Ep(B-V) (mag.)	p (%)	spectral type	$(B-V)_0$ (mag.)	$(U-B)_0$ (mag.)	E(B-V) (mag.)	E(U-B) (mag.)	remarks
133	12.90	0.79	0.27	0.88	86	B4IV	-0.19	-0.65	0.98	0.92	
135	8.57	0.43	0.08	0.16	76	F0III	0.28	0.10	0.15	-0.02	F0III
136	13.53	1.08	0.54	0.80	88	B4II	-0.18	-0.77	1.26	1.31	
139	9.35	0.80	-0.14	1.08	79	B0II	-0.28	-1.09	1.08	0.95	B0II,VAR.
140	11.37	0.87	0.15	-	42	B2IV	-0.24	-0.86	1.11	1.01	B2IV
141	13.15	1.06	0.32	0.80	88	A0II	-0.02	-0.15	1.08	0.47	
142	12.90	0.84	0.19	0.97	89	B4IV	-0.19	-0.65	1.03	0.84	
143	11.88	1.09	0.41	0.88	87	B1II	-0.27	-0.97	1.36	1.38	
144	13.50	0.68	0.62	0.68	59	F8III	0.54	0.10	0.14	0.52	
147	10.24	0.70	-0.13	0.98	83	B0III	-0.30	-1.09	1.00	0.96	B0
148	11.80	0.46	0.10	0.53	83	A8II	0.21	0.11	0.25	-0.01	
149	8.93	0.78	-0.18	1.08	78	O7II	-0.32	-1.14	1.10	0.96	O7V-O9II
151	12.49	1.31	0.36	0.80	74	B5e	-0.16	-0.59	1.47	0.95	
152	12.54	0.76	0.08	0.91	88	B3IV	-0.20	-0.73	0.96	0.81	
153	12.96	1.32	0.41	0.88	86	B6III	-0.14	-0.52	1.46	0.93	
155	8.91	0.78	-0.20	0.80	79	B6II	-0.14	-0.63	0.92	0.43	
157	8.84	0.92	-0.05	1.13	57	B0I	-0.23	-1.09	1.15	1.04	B0I,VAR.
159	8.89	0.83	-0.10	1.11	72	B0I	-0.23	-1.09	1.06	0.99	B0I-II,Be
166	13.67	0.81	0.50	0.52	87	B7III	-0.13	-0.43	0.94	0.93	
167	11.84	1.06	0.85	0.52	71	G6III	0.86	0.63	0.20	0.22	
168	13.20	1.67	1.35	0.52	79	G5III	0.86	0.63	0.81	0.72	
169	10.79	0.49	0.05	0.58	88	A6III	0.17	0.09	0.32	-0.04	
171	12.35	0.52	0.13	0.59	70	A6III	0.17	0.12	0.35	0.01	
174	10.11	0.18	-0.28	0.31	63	B4II	-0.19	-0.65	0.37	0.37	
175	13.77				62	A3V	0.08	0.10			
176	12.80	0.53	0.07	0.63	58	A5IV	0.15	0.11	0.38	-0.04	
179	13.84	1.01	1.04	0.52	88	K3III	1.29	1.44	-0.28	-0.40	
181	13.68	0.61	0.09	0.72	81	F1III	0.30	0.10	0.31	-0.01	
182	10.47	0.18	-0.58	0.42	72	B6II	-0.14	-0.52	0.32	-0.06	
184	12.63	1.08	0.24	0.65	86	B3V	-0.21	-0.71	1.29	0.95	
185	12.70	0.55	0.03	0.67	75	A2IV	0.05	0.06	0.50	-0.03	
187	11.38	0.63	-0.09	0.81	65	A6III	0.17	0.12	0.46	-0.21	
191	13.32	0.56	0.16	0.63	86	A8IV	0.23	0.11	0.33	0.05	
192	11.53	1.43	0.20	0.65	88	B2IV	-0.25	-0.85	1.68	1.05	
198	13.56				87	G9III	1.00	0.80			
199	12.77	0.76	0.03	0.93	72	F5IV	0.43	0.02	0.33	0.01	
203	12.36				74	F3III	0.37	0.09			
204	12.37	0.45	0.10	0.52	75	A5IV	0.15	0.09	0.30	0.01	
208	12.22	0.49	-0.06	0.62	77	A6IV	0.17	0.10	0.32	-0.16	
209	12.08	0.43	0.12	0.54	89	A2IV	0.05	0.06	0.38	0.06	
214	11.14	0.32	0.04	0.38	59	A4IV	0.12	0.10	0.20	-0.06	
215	13.34	1.03	-	0.38	68	G3III	0.79	0.49	0.24		
216	12.33	0.66	0.14	0.77	86	F5III	0.43	0.09	0.23	0.05	
217	12.93	0.71	0.06	0.86	84	A8III	0.23	0.11	0.48	-0.05	
219	11.90	1.63	0.46	0.38	86	B2V	-0.23	-0.92	1.86	1.38	
221	12.42	0.64	0.19	0.46	58	A1IV	0.02	0.03	0.62	0.16	
222	12.84	0.45	0.07	0.38	58	B8V	-0.10	-0.33	0.55	0.40	
228	12.28				89	B4IV	-0.19	-0.65			

main sequence present in the (V_0, $(B-V)_0$) and (V_0, $(U-B)_0$) diagrams respectively.

We obtained the cluster distance by means of the ZAMS fitting method. Three main-sequence stars (#124, 126 and 130) satisfied the strict conditions, i.e. membership probability around 80% (or more), OB type stars, location within the central region, $0.70 < E(U-B)/E(B-V) < 0.80$ (normal reddening law) and a value of E(B-V) not too high compared with other OB stars in this cluster. After fitting to the ZAMS locus, a mean distance modulus of 10.17 ± 0.14 mag. is derived, which corresponds to a distance of 1.08 kpc.

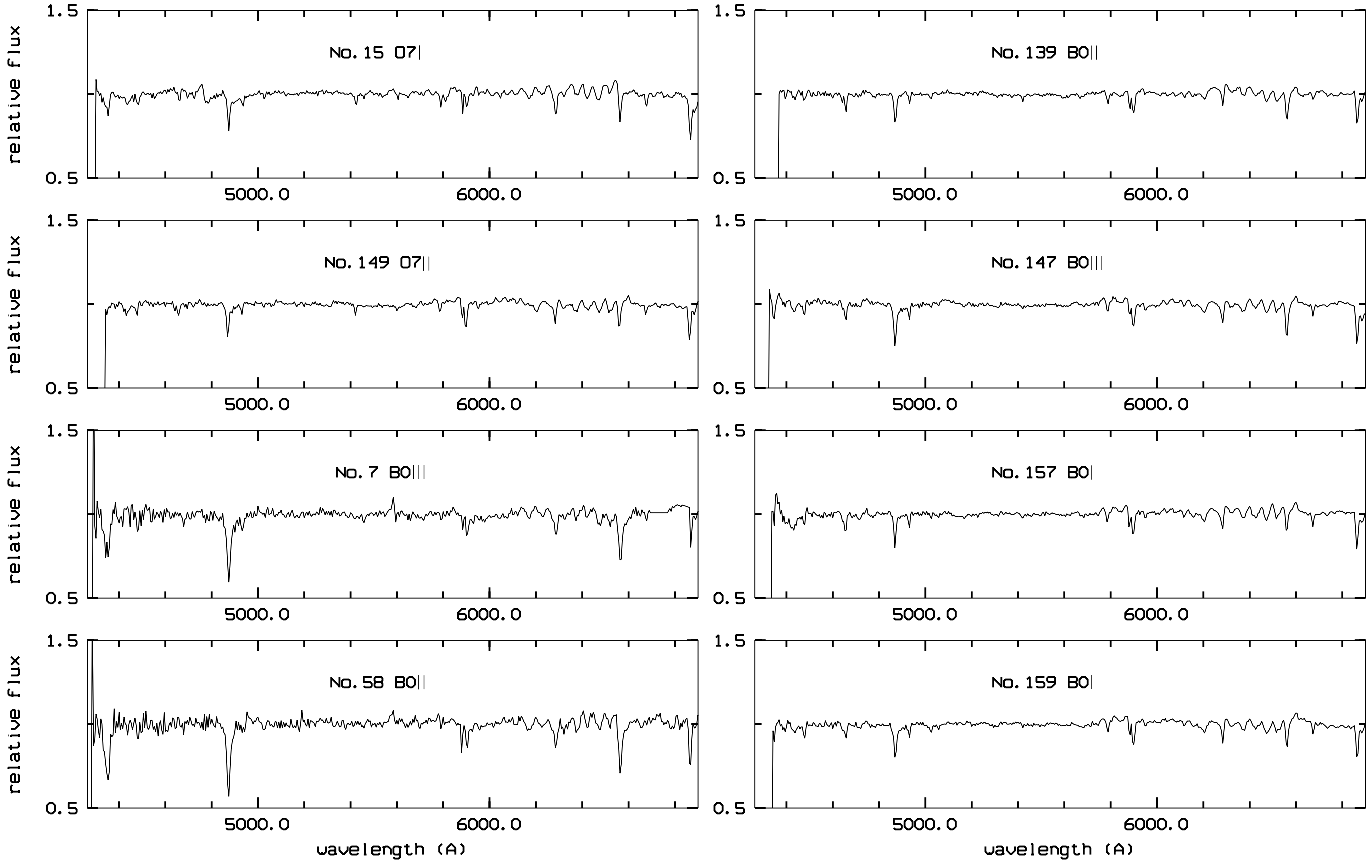

Fig. 1. The spectra of 100 stars in NGC 6913, all of which have membership probability greater than 50% Here we show only eight spectra, the others are available electronically.[2]

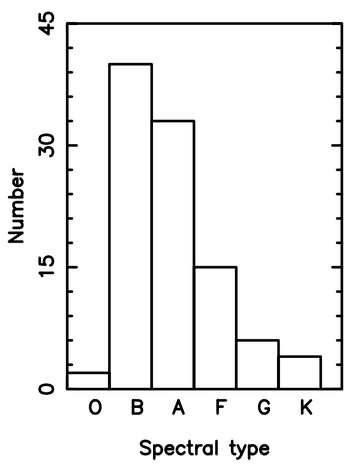

Fig. 2. The number distribution of spectral type of the stars observed in NGC 6913.

Fig. 3 is the H-R diagram constructed by using the dereddened $(B-V)_0$ on the basis of our spectroscopic classification and the V magnitudes, where the ZAMS line is evaluated based on the distance modulus of 10.17. The ((U-B), (B-V)) colour-colour diagrams of NGC 6913 are plotted in Fig. 4, in which the zero-age main sequence line, III and Ib type luminosity line are drawn. In this diagram, the reddening line is also plotted with a slope of 0.72.

On the basis of the above two diagrams, we found that most of the stars in the cluster are still in the pre-main-sequence stage. They have an abnormal reddening slope. Only 10% of the stars in this open cluster approximately satisfy the normal interstellar reddening law. This problem is usual in star forming regions and very young star clusters.

3.3. *Membership of NGC 6913*

Crawford et al. (1977) did four-colour and Hβ photometry for 25 stars in NGC 6913 and found that of stars called members by Sanders, 14 stars were real members and 6 probable non-members. Since some of the stars with membership probability greater than 50% in the cluster field are non-member stars, we can try to identify those possible non-members of the cluster in the full field.

In order to rule out most of the possible foreground stars, a reddening method is used. Considering the distance of NGC 6913 to be 1.08 kpc, to avoid removing the real cluster members, a distance of 1.0 kpc is used to do the preliminary work. Neckel & Klare (1980) (hereafter NK) gave the galactic distribu-

[2] Other spectra are available electronically with the on-line publication at http://link.springer.de/link/service/00230

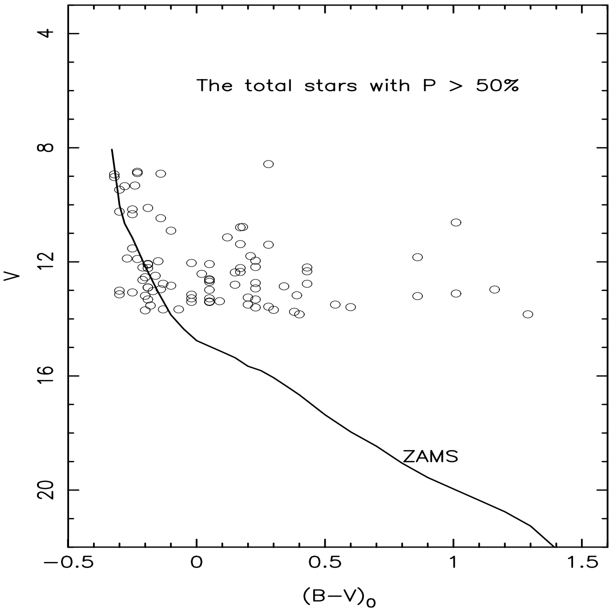

Fig. 3. The H-R diagram of NGC 6913 constructed by using the dereddened values of (B-V)$_0$ derived from our spectral classification. A mean distance modulus of 10.17 mag. is used in the diagram.

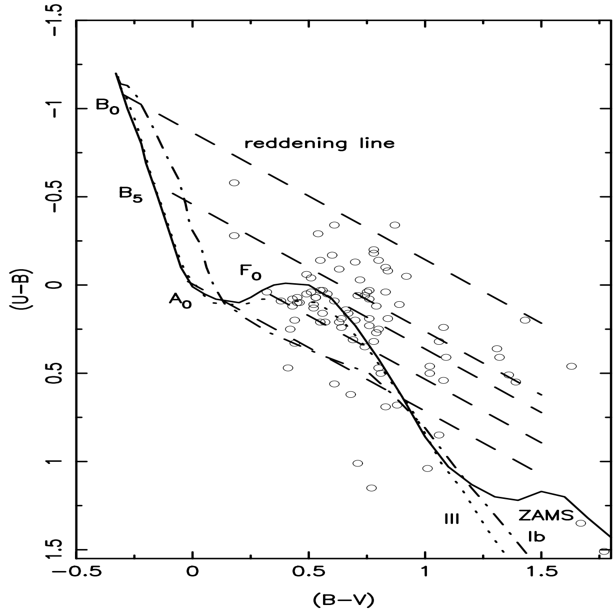

Fig. 4. The (U-B)$_0$ versus (B-V)$_0$ and the (U-B) versus (B-V) colour-colour diagrams of NGC 6913, in which the reddening line is plotted with a slope 0.72. The zero-age main sequence line, III and Ib type luminosity line are drawn.

tion of the interstellar extinction in the galactic belt $|b| \leq 7^o.6$ and presented reliable Av(r)-relations of 325 fields. As NGC 6913 is at galactic coordinate l=76.92, b=+0.61, from the NK relation between distance and optical extinction Av in different regions of sky a value of Av of about 2.0 is derived (field 286(76/+1) in NK), corresponding to a value of E(B-V)=0.65 if we assume R=3.1. Therefore, those stars with E(B-V) less than 0.65 could be foreground stars. These comprise two fifths of the stars Sanders lists as members. Clearly, most of the OB stars remain in the list and most later-type stars are removed.

Even so, the value of ΔE(B-V) 1.03 in the cluster is still very large. Extremely non-uniform reddening across NGC 6913 can still be inferred.

However, there is something very important to which we should pay special attention. In NK, the extinction in this region at a distance below 0.8 kpc is only about 0.1 mag., and sharply increases to over 2 mag. from about 0.8 kpc to 1.1 kpc. This could be caused by the high reddening star clusters. Therefore, the stars with E(B-V) smaller than 0.65 discussed above are not definitely non-members of the cluster, Some of which could be members lying on the edge of the cluster. We can use a mean value of the extinction of 1.0 mag. (with an E(B-V) value of 0.32) to judge whether a star is a real non-member of NGC 6913. Those stars with E(B-V) values between 0.32 and 0.65 are possibly either members or non-members. Based on thi principle, the percentage of non-members in Sanders' list of members amounts to $\sim 20\%$. Supposing that half the stars with reddening values between 0.32 and 0.65 are non-members of the cluster, a total amount of 30% of the stars with membership probability greater than 50% can be assumed to be non-members, coincident with the proportion of non-members evaluated by Crawford.

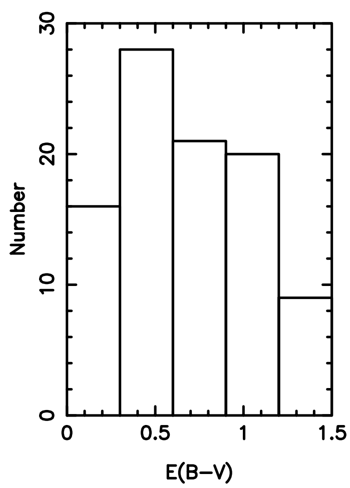

Fig. 5. The number distribution of E(B-V) of the stars with P>50% in NGC 6913 field.

3.4. Reddening and extinction across the NGC 6913 field based on the Sanders' cluster members ($>50\%$ membership probability)

The number distribution of E(B-V) is presented in Fig. 5. We note that there are 9, 20, 21, 28 and 16 stars respectively corresponding to $E(B-V) \geq 1.2$, between 0.9 and 1.2, between 0.6 and 0.9, between 0.3 and 0.6, as well as <0.3 mag. The average value of E(B-V) is 0.71 with ΔE(B-V) = E(B-V)$_{\max}$ - E(B-V)$_{\min}$ = 1.82 mag. (the two negative reddening values are excluded here). It has been pointed out by Burki that ΔE(B-V) greater than 0.11 is an indication of the presence of nonuniform

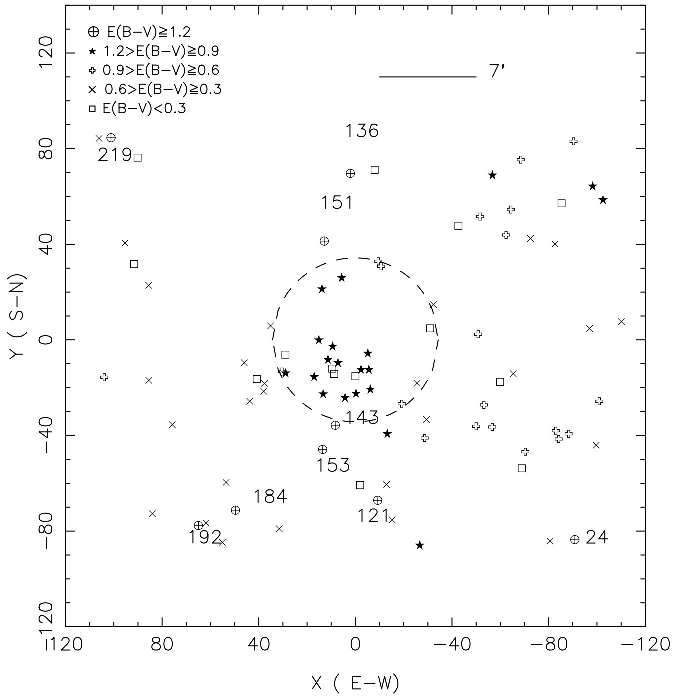

Fig. 6. The spatial distribution of extinction across NGC 6913, in which the diameter of the circle is two times the Lyngå diameter of 12′.

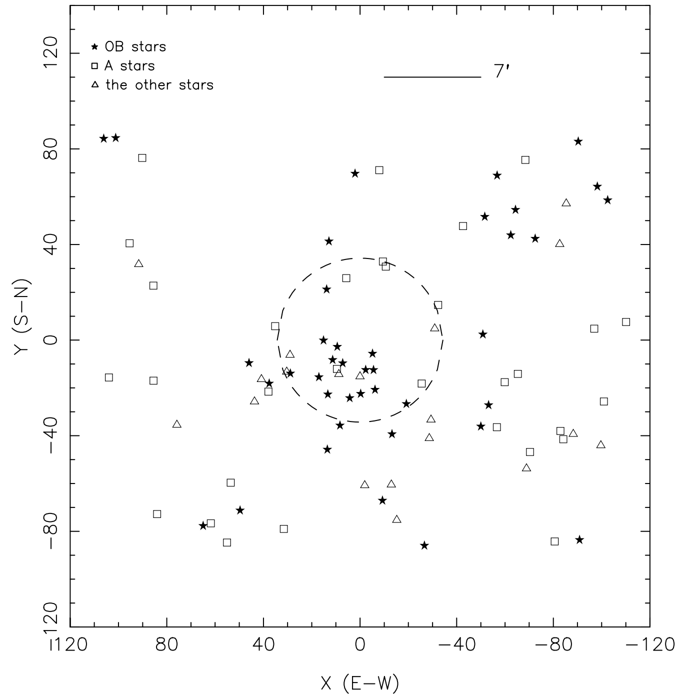

Fig. 7. The spatial distribution of the stars with high mass and relatively low mass respectively; the meaning of the circle is the same as in Fig. 8.

extinction across the cluster (Burki 1975). Thus the extremely variable reddening across NGC 6913 can be inferred.

Fig. 6 shows the spatial distribution of extinction across the NGC 6913 field, in which the diameter of the circle is 12′, corresponding to twice the possible smallest cluster diameter given by Lyngå (1987). From this figure, we find that most of the nine stars with E(B-V) greater than 1.2 lie on the edge of the field. Most of the stars with E(B-V) between 0.9 and 1.2 are concentrated in the central area. All of the stars except one with E(B-V) between 0.6 and 0.9 lie in the western part (right-hand side of the figure) of the cluster. Those with relatively small values of E(B-V) are distributed randomly over the entire cluster region. It is clear that the region with the largest mean value of extinction is in the central part. The western region comes second.

On the same scale as Fig. 6, Fig. 7 shows the spatial distribution of those stars with high mass and relatively low mass respectively. Surprisingly, it was found that the distribution of OB stars coincides very well with the distribution of large colour excess across the field. All nine stars with E(B-V) greater than 1.2 are B-type stars. From Figs. 6 and 7, clearly the surroundings of the massive stars seem to be more obscure than those of the low-mass stars.

Fig. 8 shows $(B-V)_0$ versus E(B-V). It clearly shows a dependence of E(B-V) on spectral type. For those stars earlier than F8 (i.e. $(B-V)_0$ less than 0.6), the colour excess increases together with the effective temperature of the stars. But the stars with spectral type later than F8 seem to show reversed characteristics. Because the number is too small, we cannot confirm the latter point. A similar result for the whole field was obtained

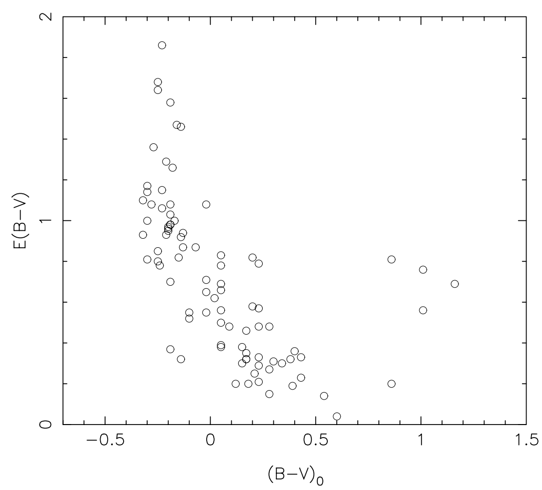

Fig. 8. $(B-V)_0$ versus E(B-V).

by Sagar (1987). In order to understand if the tendency is caused by a systematic error in Joshi's observations, we have compared the data for the open cluster NGC 6823 (both NGC 6823 and 6913 show a tendency like Fig. 8 in Sagar's paper), observed by Sagar & Joshi (1981) using the same instruments, with the data observed by other people (e.g. Guetter 1992; Stone 1988). We find that all of them have the same trend. Therefore, the trend should be reflection of reality.

3.5. The interstellar diffuse bands in the stellar spectra

The correlation between interstellar reddening and the interstellar diffuse bands has been proven by Greenberg & Chlewicki

(1983). A cluster is a very good sample to check this relationship. There are many different types of stars in a cluster. By comparing the intensity of the IDBs in the spectra of stars of different types, the relation between IDBs and the stellar parameters (e.g. temperature, luminosity etc.) could be derived.

The IDBs appear distinctly in the spectra shown in Fig. 1 (e.g. at 6284Å etc.). Although in a low resolution spectrum it is difficult to measure the equivalent width of the relatively weak IDBs, the spectra of early type stars in NGC 6913 clearly show relatively strong absorption of the interstellar diffuse bands, and the low-mass late-type stars show relatively weak absorption, or even no absorption. This means that the strength of the IDBs is well correlated with effective temperature of stars.

Krelowski et al. (1998) stated that IDBs are not all of the same origin and usually quite well correlated to E(B-V). In our present work a correlation between spectral type and E(B-V) of NGC 6913 has been shown, thus the IDBs also correlate well with the reddening, in agreement with Krelowski's conclusion.

4. Discussions of individual stars

4.1. Emission line stars

Three stars show emission spectra in our sample, i.e. # 33, 125 and 151; of these only #125 (HD229221, BD+38 4062) has been previously classified as B0Ipe (Morgan et al. 1953). Roman (1951) classified #125 as B0IIe. Morgan et al. (1953) classified it B0Iabpe in the study for a group of blue giants. Based on its spectrum, we classify it B0IIIe. Its mass could be around 8-10 $M_{\odot}$; this would make it an intermediate mass star. Because it is a member of NGC 6913, it could be a Herbig Be star candidate. As the value of E(B-V) of #125 is 1.17, a dense circumstellar disk is thus inferred. In addition, Wang & Hu (1996) found that the H_{α} spectrum of #125 underwent a peculiar variation, from a single emission line to one composed of three components, i.e. emission + absorption + filled emission. They concluded that this could be explained by a model of a central star + asymmetrical circumstellar disk or clump + outer layer of dust. The star could have planets forming around it.

#33 shows Hα in medium-strong emission and Hβ and Hγ in absorption. Its spectral type is A0Ve. The value of E(B-V) equals 0.71. It seems to be a classical AeBe star.

#151 shows a very large value of E(B-V) (1.47). It is classified as B5e. The Intensity of the Hα emission line is very high. It could have a thick envelope. The star is also inferred to be a pre-main-sequence star with intermediate mass (Herbig Ae/Be star).

4.2. The stars with peculiar colour excess

There are a few stars with peculiar colour excess, i.e. #28, 51, 179, 187 and 32, some of which show negative values of E(B-V). In addition, some stars show relatively low positive colour excess values.

#28 is classified as a K2III star. It has very strange observed colours (B-V) and (U-B). The value of the former is the highest in all the cluster stars, attaining to 1.85, and the value of the latter is relatively low (0.33). The intrinsic colours of (B-V) and (U-B) are 1.16 and 1.17 separately. Thus a value of E(U-B)=-0.84 is derived. If the spectral type of #28 is earlier than G2 to make the value of E(U-B) greater than zero, then the value of E(B-V) would be greater than 2.5! In this case, #28 would be a variable star with large light variations and with a extremly thick envelope (the UBV photometry was carried out 11 years ago). Otherwise, if it is not a variable star, and the photoelectric photometry in UB bands is reliable, then it must be a extremely " blue-enhancing " star. It should be paid close attention to and should be observed further.

#32 has E(B-V) just below zero, and #51 and 187 have a relatively large negative E(U-B) colour excess. Both E(B-V) and E(U-B) of #179 appear large negative values. #131, 135 and 144 have low positive values of colour excess (less than 0.2). What causes the very low or even negative values for the colour excess?

Clearly, all of these stars except one (#187) have a spectral type later than F0 (#187 is a late A type star). There are three possible explanations for this phenomenon. (1) Six out of the seven non-early-type stars have relatively low V photometric values. It is difficult for a 1-meter class telescope to measure the faint blue light of the late-type stars by using photoelectric methods; this could cause a large uncertainty of the photometry in the blue bands. (2) Young stars sometimes show spectral blue veiling and ultraviolet excess. These effects make the (B-V) colour too blue compared with its spectral type and a negative value of colour excess E(B-V) for the star will be observed if the blueing effect of the blue continuum is greater than the reddening effect of interstellar absorption. A few stars in the Orion nebula (NGC 1976) have been observed to have such values (Walker 1983). (3) They are possible variables with large light variations.

Here two stars are worthy of special mention, i.e. #135 and 179. #135 has a membership probability of 76%. It lies in the central area of the cluster. It is a very luminous F0III star. Its V magnitude is 8.57, which makes it one of the brightest stars in the NGC 6913 field. Nearly all of the stars in the field with large V magnitude are early-type stars (OB stars). The value of E(B-V) is very small (0.15), much smaller than the other stars with large V magnitude. #135 might not be a member of the cluster, probably a foreground star.

#179 has a high membership probability in this area (88%). Its V magnitude is 13.84 mag. Its position is not far away from the central region. Although it is a K-type star, the value of its reddening is negative! It must be a variable star.

4.3. The possible variable stars with large amplitude

Comparing with Joshi's photometry, we found a few stars to have more than 0.4 magnitude difference in Vilnius photometry on V band, namely # 40, 119, 120, 123, 136, 141 and 155, which have values of Vilnius V magnitude 13.09, 12.76, 13.59, 13.53, 12.20 13.60 and 13.16 respectively (ref. Vilnius photometry database, Mermilliod 1995). Most of them are A type stars. Two of them are B type stars. Especially, there is a remarkable variation for another B star # 155, which changes from 8.91 mag. in Joshi's photometry to 13.16 mag. in Vilnius' photometry! If no identification mistake was made, it should be a very interesting variable star.

5. Conclusions

Spectroscopic observations have been made for the young open cluster NGC 6913. Spectra of 100 stars having membership probability greater than 50% are obtained and classified. Reddening is estimated on the basis of spectral classification. The variable extinction across NGC 6913 is analyzed and discussed. The results of our study can be summarized as follows.

1. From the spectroscopic observations, it is found that the spectral type distribution in our sample covers from O7 to K3. There are only 2 O-type stars in this OB association. 40 and 33 percent of the total stars are B and A type stars respectively, and the F, G, K stars amount to 25 percent.
2. Many of the values of interstellar reddening from spectral classification are quite different from those taken from photometry (especially for early B and F type stars), in which the largest discrepancy is 1.48 mag.. This further demonstrates that correct spectral classification is extremely important for the study of reddening and extinction of stars. Hence, it is necessary to make spectroscopic observations first before studying interstellar extinction of young open cluster. Photometry only is insufficient.
3. The extreme variation of extinction across NGC 6913 is shown. The distribution of extinction in the region is correlated with the effective temperature of the stars in the case of the stars earlier than F8. This could mean that the more luminous new formed stars have a higher mass loss rate.
4. It is found that extinction in the cluster center is relatively homogeneous, but very large. In this cluster, the north and south have the largest extinction. The east and west seem to be low reddening regions.
5. A mean distance modulus of the cluster of 10.17 ± 0.14 mag. is derived, which corresponds to a distance of 1.08 kpc.
6. Based on a reddening method, a total amount of 30% of the stars with membership probability greater than 50% can be derived to be probable "non-members" of the cluster.
7. Some interesting objects are found in this study. Further observations for these stars will be made in the future.

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References

Burki G., 1975, A&A 43, 37
Crawford D.L., Barnes J.V., Hill G., 1977 AJ 82, 606
Elmegreen B.G., Lada C.J., 1977, ApJ 214, 725
Greenberg M., Chlewicki G., 1983, ApJ 272, 563
Guetter H.H., 1992, AJ 103, 197
Hillenbrand L.A., Massey P., Strom S.E., Merrill K.M., 1993, AJ 106, 1906
Jacoby G.H., Hunter D.A., Christian C.A., 1984, ApJS 56, 257
Joshi U.C., Sanwal B.B., Sagar R., 1983, PASJ 35, 405
Krelowski J., Galazutdinov G.A., Musaev F.A., 1998, ApJ 493, 217
Lyngå G., 1987, Catalogue of open cluster data. Computer based catalogue available through CDS, Strasbourg, France
Mermilliod J.C., 1986, BICDS
Mermilliod J.C., 1995, Database on open clusters, version 2.0.
Morgan W.W., Whitford A.E., Code A.D., 1953, ApJ 118, 318
Neckel Th., Klare G., 1980, A&AS 42, 251
Roman N.G., 1951, ApJ 114, 492
Roth M., 1988, MNRAS 233, 773
Sagar R., Joshi U.C., 1981, Ap&SS 75, 465
Sagar R., 1987, MNRAS 228, 483
Sanders W.L., 1973, A&AS 9, 221
Shi H.-M., Hu J.-Y., 1999, Acta Astrophys. Sin. vol. 19, no. 2, 193
Stone R.C., 1988, AJ 96, 1389
Walker M.F., 1983, ApJ 271, 642
Wallenquist Å., 1975, Uppsala Astr. Obs. Ann. Band 5, # 8
Wallenquist Å., 1979, Uppsala Astr. Obs. Ann. Band 5, # 10
Wang J.-J., Hu J.-Y., 1996, Chin. Astro. Astrophys. 20, no. 1, 67