年輕疏散星團 NGC 6910 之光度、運動與動力

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摘要

本研究針對年輕疏散星團 NGC 6910，以中央大學鹿林前山天文台一米望遠鏡進行光度觀測，獲得星團光度、星際吸收與紅化、距離與年齡等參數。以美國海軍天文台星表 B1.0（USNO－B1.0）之數據，進行恆星計數統計，以及星團運動與動力方面的分析，以推算星團的半徑、密集度等參數。

在對 NGC6910 中心區域進行 CCD Johnson UBV 三波段光度觀測，UBV 三波段之光度誤差分別爲 0.056, 0.028 與 0.021 星等，紅化爲 E(B－V) = 1.11±0.16。將修正紅化後的星團星色—星等圖（CMD）與恆星演化等時模型〈isochrones〉擬合的結果顯示，NGC 6910 的年齡約爲 3.98 百萬年至一千萬年之間，距離模式爲 10.88。

根據 USNO－B1.0 中 POSS－I 103a－O blue sensitive plates 測定星等，星團 1°×1°範圍內的座標作爲資料庫，進行恆星計數統計分析。結果顯示 NGC 6910 的表面恆星數量密度分佈符合金氏模式(King 1962)，當距離爲 1500pc 時，核心半徑（r_c）2.48 pc，潮汐半徑（r_t）26.13 pc， k=12.50 stars/pc^2。Oort 常數採用 A = 14.4±0.8 km s^{-1} kpc^{-1} 、B = -12.4±0.6 km s^{-1} kpc^{-1} (Feast and Whitelock 1997)，則星團總質量約爲 6400 $M_\odot$。

The Photometry, Kinematics and Dynamics of Young Open Cluster NGC 6910

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Abstract

Based on the Johnson UBV CCD photometry of a young open cluster NGC 6910 with 1.0-m telescope at Lulin Observatory of National Central University, the magnitude, extinction, reddening, distance and age of clusters are derived. The USNO－B1.0 catalogue is used for star counting method of King model.

In the photometric calibration, it shows the standard errors 0.056 mag in U, 0.028 mag in B and 0.021 mag in V. The reddening E(B－V) is determined to be

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1.11±0.16 mag. The age of NGC 6910 is estimated, using well isochrones fit, to be 4~10 Myrs and its distance modulus is 10.88.

The magnitudes and coordinates in the USNO－B1.0 catalogue are derived from the POSS－I 103a－O blue sensitive plates. The analysis of the star counting is based on the images within the area 1°×1° centered at the cluster. The results show that the radial distribution of the stellar number density for NGC 6910 is consistent with the King's model. The best fit gives core radius (r_c) 2.48 pc, tidal radius (r_t) 26.13 pc and k=12.50 stars/pc^2. By adopting the Oort's constants A = 14.4±0.8 km s^{-1} kpc^{-1}, B = -12.4±0.6 km s^{-1} kpc^{-1} (Feast and Whitelock 1997), the mass of NGC 6910 is estimated to be about 6400 $M_\odot$.

關鍵字（Keywords）：疏散星團（open cluster）、恆星計數（star count）、金氏模式（King model）

1. Introduction

In this paper, the young open cluster NGC 6910 is studied in terms of combining Johnson UBV CCD photometry and star counting method to derive its fundamental parameters: size, reddening, distance, age and mass.

NGC 6910 is located in the field of RA (2000): 20^h 23^m 12^s, Dec (2000): +40°46′ 42″ (ℓ=78°.68, b =+2°.01), the seriously obscured region in Cygnus (Delgado 2000). The field is near the bright star γ Cyg, in the proximity of the compact OB association Cyg OB2. The field of NGC 6910 is the part of the complex, mixing region, which contains clusters, associations, clouds, dusts and star formation region RSF 2 Cyg (Shevchenko 1989).

NGC 6910 is a very young cluster with an age of 7~13 Myrs (Dias et al. 2002, Delgado and Alfaro 2000, Vansevicius 1989, Hagen 1970 and Markarjan 1951). Photoelectric, photographic and CCD photometry for the stars in NGC 6910 have been studied by many astronomers such as Becker and Stock (1948), Hoag, et al. (1965), Onegina (1956), Mathews (1963), Tifft (1958), Vansevicius (1989), Delgado and Alfaro (2000). The spectral classifycation of bright stars are also obtained by many researchers, Morgan W.W., Code A.D., Whitford (1955), Hiltner (1956), Hoag and Applequist (1965), Walborn (1971), Sowell (1987), Tifft (1958) and Yoss (1961).

In section 2, the observations, data reductions and photometric calibration are described. Color-Magnitude Diagrams (CMD), Two-Color Diagrams (TCD) and isochrones fitting are discussed in section 3. The spatial distribution of the stars and King's model are presented in the section 4. Finally, the results and discussion are summarized in section 5.

2. Observations, Data Reduction and Photometric Calibration

2.1. Observations

The observation of Johnson UBV photometry (Table 1) was carried with 1m telescope at the Lulin Observatory of National Central University on 2003 August 3. The Princeton Instruments VersArray: 1300B (PI 1300B) CCD with 1340x1300 pixels (20×20 μm/pixel) is used. The scale is 0.515″ per pixel in the focal plane. The area of the whole CCD image covers a squared field of 11.50′ ×11.15′. At 1 MHz readout speed, the CCD readout noise is 8 e^- rms.

Table 1. Observation Log of 2003 August 3

Region	Filter	Exposure time(s)	Date and Time (UT)
NGC6910	U	600	17:49
R.A.=$20^h23^m08^s$	B	60	16:37
Dec.=+40° 46′30″	V	60	17:36

2.2. Data Reductions

At the end of the observations, the bias and flat－field frames were taken at twilight. The Cyanogen MaxIm DL Version 3.0 package was used to subtract the bias, dark frames and to correct for the flat field.

Data reductions of the cleaned frames were done with the standard IRAF (NOAO) routines. The stellar instrumental magnitude and position of each star are derived in terms of DAOFIND, PHOT, Point Spread Function (PSF) fitting and AllSTAR tasks of IRAF DAOPHOT II package (Stetson 1987). The PSF was obtained for each frame using several uncontaminated stars.

The photometric calibration obtained using IRAF DAOPHOT II package (Stetson 1987) is given in Fig. 1.

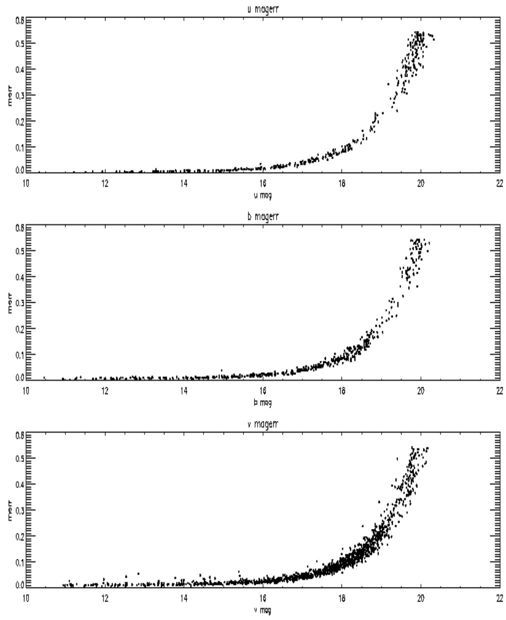

Fig. 1: The internal photometric errors of NGC 6910 from IRAF result

2.3 Photometric Calibration

The CCD UBV magnitudes of 41 stars measured by Delgado (2000) were used for the photometric calibration. The equations of photometric calibration are:

$$U - u = 0.211\,(U - B) + 1.262,$$

$$\sigma_U = 0.056,$$

$$B - b = -0.026\,(B - V) + 1.631,$$

$$\sigma_B = 0.028,$$

$$V - v = -0.078\,(\mathrm{B} - \mathrm{V}) + 1.878,$$

$$\sigma_V = 0.021,$$

where the u, b, v are instrumental magnitudes and U, B and V are the reference magnitudes from the data by Delgado (2000). The photometry and

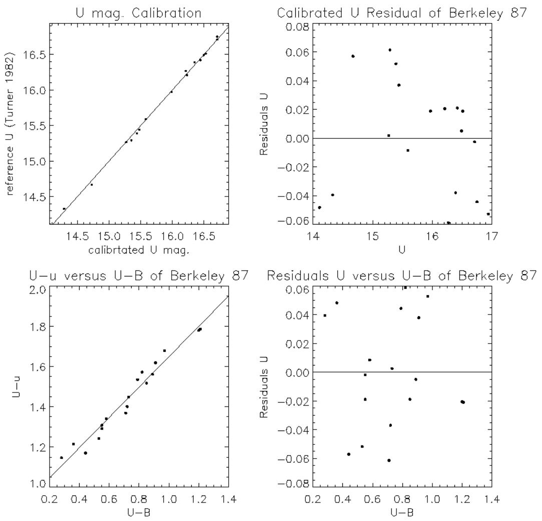

Fig. 2: The photometric calibration and residuals in U band of NGC 6910

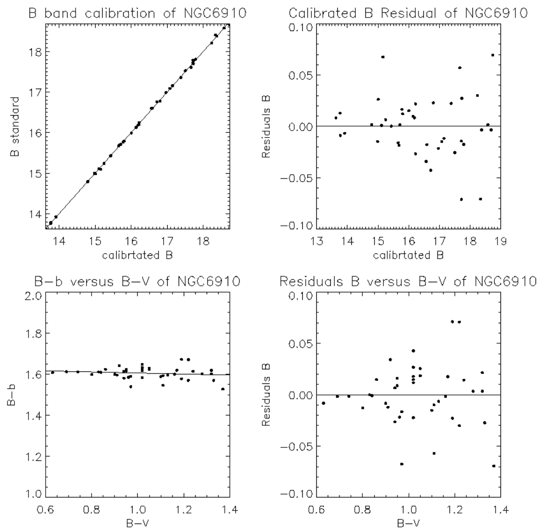

Fig. 3: The photometric calibration and residuals in B band of NGC 6910.

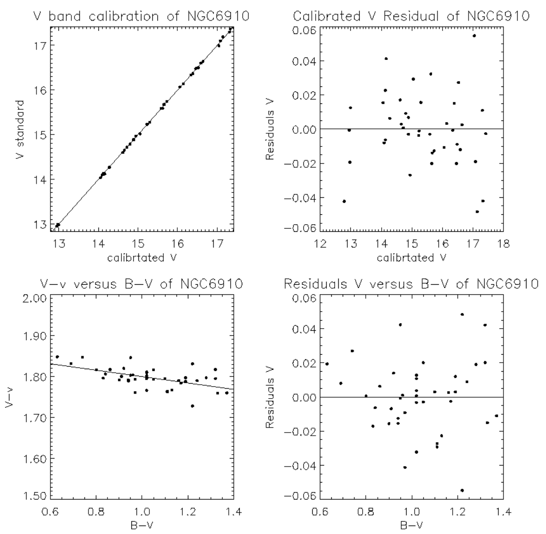

Fig. 4: The photometric calibration and residuals in V band of NGC 6910

residuals in each band are plotted in Fig. 2~4. There is no noticeable trend in the residuals of the photometric calibration.

3. CMD, TCD and Isochrones Fitting

All stars calibrated in the previous section are presented in V vs. (B−V) color-magnitude diagram (Fig. 5) and (B − V) vs. (U − B) two-color diagram (Fig. 6). The magnitudes of those bright stars with saturated images are substituted by the CCD magnitudes measured by the Delgado (2000).

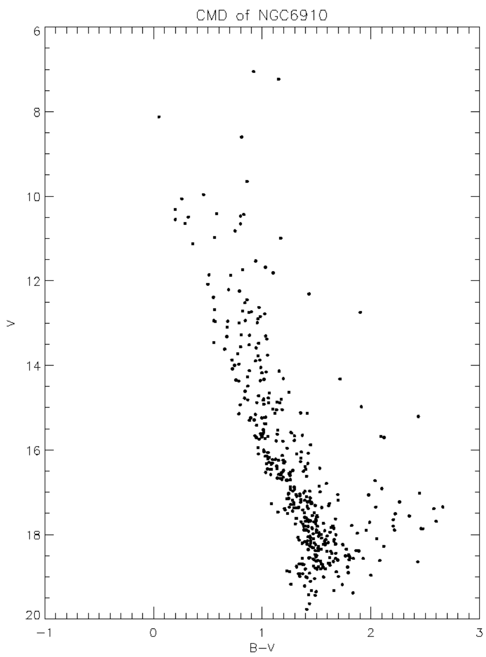

Fig. 5: CMD of NGC 6910

In order to calculate the reddening, five main sequence stars with spectral types of O and B (Table 2) are selected from the paper of Hoag and Applequist (1965). Their intrinsic color indices listed in Table 2 are quoted from the work of Schmidt-Kaler (1982). From the data in Table 2, we derive an average of

$$\alpha = \frac{E(U-B)}{E(B-V)} = 0.75.$$

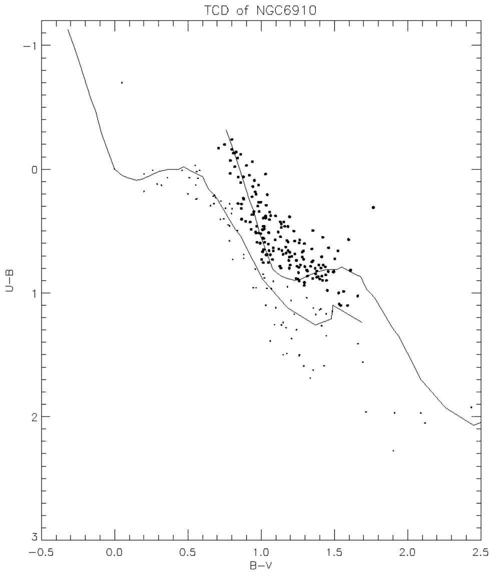

Fig. 6: The TCD of NGC 6910 with zero－reddening (left) and E(B－V)=1.11 (right) curves of all stars. The 180 likely members are marked with big dots, other foreground stars (un－reddening) with small dots.

Table.2. The spectral type and colors for the selected dwarfs in NGC 6910.

No.	MK Type	U－B	B－V	Q	E(B－V)
D014	O95V	-0.24	0.80	-0.84	1.08
D013	B05V	-0.14	0.83	-0.76	1.08
D018	B1 V	-0.20	0.75	-0.76	1.00
D021	B1 V	-0.17	0.71	-0.70	0.94
D024	B1 V	-0.13	0.82	-0.75	1.07

With U, B and V magnitudes, each star's reddening free parameter *Q* can be derived from $Q \equiv (U-B) - \frac{E(U-B)}{E(B-V)}(B-V)$. For early type main sequence stars ($Q<-0.5$) with the relation $(B-V)_0 = 0.332Q$ (Johnson and Morgan,1953), we derive their true color excess $E(B-V)$ in the range of 1.11±0.16 mag. Due to the $R_v \equiv A_v/E(B-V)$ is nearly a constant 3.1, the extinction A_v of each star can be found. And the intrinsic apparent magnitude V_0 is obtained directly from $V-A_v$.

The distance modulus with extinction term A_v is given as

$$m_v - M_v = 5\log d - 5 + A_v,$$

where the $m-M$ is distance modulus, *d* is distance in pc and A_v is extinction.

In this paper, the theoretical isochrones (Bertelli 1994) is adopted. This model considers convective core overshoot, thus it is more appropriate to the evolutionary track fitting of a young cluster.

The intrinsic magnitude M_V versus the intrinsic color index $(B-V)_0$ is plotted in Fig. 7. The best fits show the isochrones curves of distance modulus 10.88, corresponding to 1500 pc, with the metal abundance z=0.02, log(Age)=7.0 (curve on right) and log(Age)=6.6 (on left).

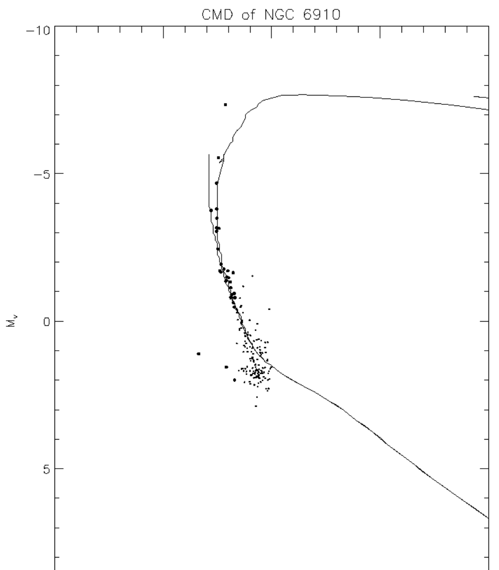

Fig. 7: The plot of the intrinsic magnitude M_v versus the intrinsic color index $(B-V)_0$. The 30 stars are well fitted with the isochrones curves of z=0.02, log(age) = 6.6 (left) and log(age) = 7.0 (right). The stars $Q < -0.5$ are plotted in big dots, others are in small dots.

4. Star Counting and King's Model

Due to our observations only cover the central area of the cluster, so the database for King model is taken from the USNO－B1 catalogue (Monet et al. 2003) within a 60′×60′ region. In the field of NGC 6910, the completeness of B band in the USNO－B1.0 catalogue locates at mag. 18.5 (Fig. 8).

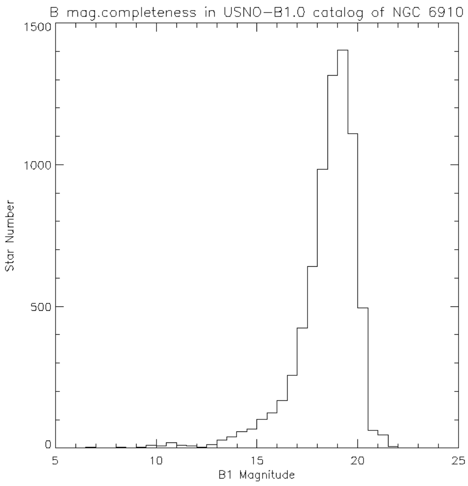

Fig. 8: The stars number histogram of USNO－B1.0 catalogue (Monet et al. 2003) in POSS－I 103a－O blue sensitive plates magnitude of NGC 6910 field.

The center of the cluster is determined by fitting the star number density with a function that includes member stars in Gaussian and field stars in constant distribution as below:

$$f(z) = Ke^{\frac{-z^2}{2}} + f,$$

$$z = \left(\frac{x - x_c}{\sigma}\right)^2 + \left(\frac{y - y_c}{\sigma}\right)^2,$$

where K is amplitude constant, f is number density of field stars, and x_c, y_c is the center of cluster. Using the method described above, we obtain the center of NGC 6910 which is located at RA $20^h\ 22^m\ 57^s$, Dec 40° 44′ 48″ (epoch 2000.0).

With the cluster center, we derive the radial stellar density from the center outward to the radius of 30′. The number density of stars is calculated by the number of stars in an increasing concentric ring radius with a width of 2′ around the cluster center (see Table 3) and dividing by the corresponding projected area. For each annulus, we take the mean of its inner and outer radii as the radius of the i^{th} annulus R_i. S_i is the corresponding area of the annulus. N_i is the total stars number within the annulus. Then the star number density f_i and the associated error ε_i, assuming a Poisson law error in the star counts, are derived simply by

$$f_i = \frac{N_i}{S_i},\ \varepsilon_i = \frac{\sqrt{N_i}}{S_i}$$

Table 3. The annulus and density distribution of stars in NGC 6910.

Annulus	Inner Radius(′)	Outer Radius(′)	Area of rings (arcmin^2)	star Counts	Number density (stars/ arcmin^2)
1	0	2	12.57	31	2.47
2	2	4	37.70	80	2.12
3	4	6	62.83	107	1.70
4	6	8	87.97	109	1.24
5	8	10	113.10	122	1.08
6	10	12	138.23	131	0.95
7	12	14	163.36	145	0.89
8	14	16	188.50	165	0.88
9	16	18	213.63	168	0.79
10	18	20	238.76	176	0.74
11	20	22	263.89	228	0.86
12	22	24	289.03	197	0.68
13	24	26	314.16	218	0.69
14	26	28	339.29	188	0.55
15	28	30	364.42	233	0.64

King (1962) derived an empirical dynamical model to express the relation of r_c, r_t and the star number density as a function of radius r:

$$f(r) = k\left[\frac{1}{\sqrt{1+\left(\frac{r}{r_c}\right)^2}} - \frac{1}{\sqrt{1+\left(\frac{r_t}{r_c}\right)^2}}\right]^2$$

where $f(r)$ gives the number density distribution of stars in projection, depending on the radius r from the cluster center. The parameter k is a normalization related to the total number of stars in the cluster center. r_c is the core radius that is defined to be the radius at which the star density has dropped to half the central value, and r_t is the tidal radius where $f(r)$ approaches the value of zero.

The concentration (c) of the cluster is defined as $c = \log\left(\frac{r_t}{r_c}\right)$. It is a distance independent parameter of cluster's morphology with more physical significance.

The theoretical tidal radius of open cluster is approximately (Oort, J. H 1959, King 1962) given as follows:

$$r_t = \left[\frac{GM_c}{4A(A-B)}\right]^{1/3}$$

where the A, B are Oort′s constants, G is the gravitational constant and M_c is the mass of cluster. This provides a way to estimate the mass of cluster.

In our work, we adopt the Oort's constants A = 14.4±0.8 km s^{-1} kpc^{-1} and B = -12.4±0.6 km s^{-1} kpc^{-1}, which are obtained from the proper motion of Cepheids that measured by Hipparcos satellite (Feast & Whitelock 1997).

For NGC 6910, the three constants, r_c, r_t and k, of King′s model are derived to be k = 2.38 (stars/arcmin^2), r_c = 5′.68, and r_t = 59′.89. With the distance of the cluster 1500 pc, these quantities correspond to k = 12.50 (stars/pc^2), r_c = 2.48 (pc), r_t = 26.13(pc). The field stars number density is 0.64 (stars/arcmin^2).

The relationship established from King's model is plotted against the stellar number density (the field number density as a constant is subtracted) in Fig. 9. The uncertainties are derived from Poission statistics.

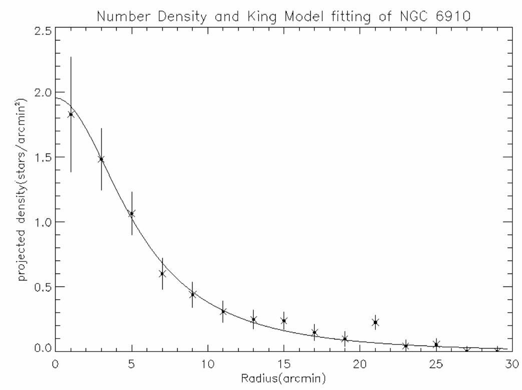

Fig.9: The King profile respect to stellar number density (the field stars number density is subtracted) of NGC 6910. The uncertainties are derived from Poission statistics.

The concentration $c = \log\left(\frac{r_t}{r_c}\right)$ = 1.02. The King model profile respect to stellar number density in logarithm form is plotted in Fig. 10.

From the above parameters, the cluster mass is estimated to be about 6,390 $M_\odot$.

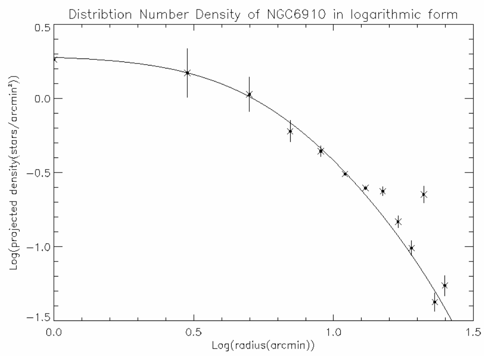

Fig. 10: The King model profile (solid line) respect to stellar number density in logarithm form of NGC 6910.

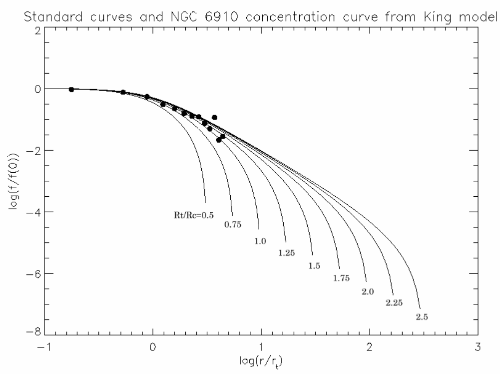

Fig. 11: The standard curve and NGC 6910 (c=1.10) concentration curves.

5. Results and Discussions

The physical parameters of the young open cluster NGC 6910 has been derived based on the CCD Johnson UBV photometry and position. The reddening towards the NGC 6910 is found to be $E(B-V)=1.11\pm0.16$ mag, which agrees with previous studies of other investigators. $\alpha=0.75$ is between the value 0.78 (Delgado and Alfaro 2000) and 0.69 (Landolt 1992). The average extinction 3.54 agrees with the value 3.65 given by Vansevicius (1989). The distance modulus $(m-M)_0=10.88$ is between the listed values by Dias (2002) and Lynga (1987). The isochrones fitting indicates the age of NGC 6910 is $(7\pm3)\times10^6$ years, which agrees with the values of previous study of other investigators.

The result in this research may affected by few factors that are discussed as follows:

(a) Lack of faint stars for model fitting. Suffering from the serious extinction, faint members of young open clusters are difficult to be detected in the optical. The infrared observations or IR data, such as 2MASS All-Sky Catalog of Point Sources (Cutri et al. 2003) are important to the study of young open clusters.

(b) Errors in photometric calibration. In our observation, the photometry is not calibrated with standard stars. Instead, we used the magnitudes measured by the work of other researchers.

(c) Isochrones fitting errors. NGC 6910 is so young and don't have low mass dwarfs that make the isochrones fitting uncertain. Another difficulty in isochrones fitting is the fitting results will be affected by the abundance parameters Y and Z. In this study, the value of Z is assumed to be 0.02.

(d) Membership. NGC 6910 locates at the low latitude of Galactic disk, mixed with a large amount of field stars. In the future work, with kinematics method, such as proper motion statistics, we can recognize the members more effectively.

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