JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
38: 423 ~ 428, 2005

KINEMATICAL FOCUS ON NGC 7086

A. L. TADROSS
National Research Institute of Astronomy & Geophysics, 11421-Helwan, Cairo, Egypt.
E-mail: altadross@mailer.eun.eg & altadros@nriag.sci.eg
(Received October 11, 2005; Accepted November 7, 2005)

ABSTRACT

The main physical parameters; the cluster center, distance, radius, age, reddening, and visual absorbtion; have been re-estimated and improved for the open cluster NGC 7086. The metal abundance, galactic distances, membership richness, luminosity function, mass function, and the total mass of NGC 7086 have been examined for the first time here using Monet et al. (2003) catalog.

Key words : Galaxy: open clusters and associations — individual: NGC 7086 — astrometry — Stars: luminosity function — mass function — Stars: Kinematics

I. INTRODUCTION

The open cluster NGC 7086, Figure 1, is situated very near to the disk of the Milky Way at 2000.0 coordinates $\alpha = 21^h\ 30.45^m$, $\delta = +51°\ 36'$, $\ell = 94.41°$, $b = 0.22°$. It classified as I2m type by Trumpler (1930). The main photometric observations of NGC 7086 were presented by Hoag et al. (1961) using the U.S. Naval Observatory which did not lead to a reliable distance determination. Hassan (1967) has studied the three color photometry of 156 stars in the region of the cluster NGC 7086 to improve the distance determination. The apparent diameter of the cluster has been estimated between 7.5 and 9.1 arcmin. Hassan's estimated distance is found to be 1170 pc. He classified about 70 stars as physical members and another 20 ones as uncertain members. It is still doubtful that the open cluster NGC 7086 have some physical members lie within the cluster region. Recently, Balog and Kaszás (1997) observed the color-magnitude diagram of NGC 7086 through Johnson B and V filters using CCD. Therefore, the aim of this study is to estimate the most physical parameters of NGC 7086, which depending on the membership richness using the observations of Balog and Kaszás (1997) and the spatially unlimited catalog of Monet et al.(2003), USNO-B1*, which presents positions, proper motions, magnitudes in various optical pass-bands.

In the next sections, observational data, color-magnitude diagram *(CMD)* and physical parameters, geometric properties, membership analysis, luminosity function *(LF)*, and the mass function *(MF)* of the cluster are examined.

II. OBSERVATIONAL DATA

According the catalog of Monet et al. (2003), the data were obtained from scans of Schmidt plates taken for the various sky surveys during the last 50 years.

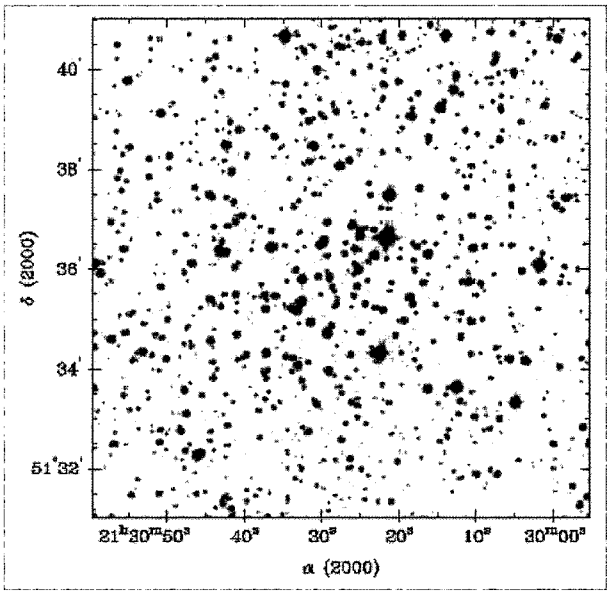

Fig. 1.— The image of NGC 7086 as taken from Digitized Sky Surveys *(DSS)*; *(http://cadcwww.dao.nrc.ca/cadcbin/getdss)*. North is up, east on the left.

USNO-B is believed to provide all-sky coverage, completeness down to V=21 mag. On this context, the genuine size (the true projected area) of the cluster can be determined regardless on the available photometry. So after determine the true area of the cluster, membership filtration can be done on the stars restricting in that area. Stars with largest proper motions have been removed because they are likely to be foreground stars instead of cluster members. Identifying foreground stars is useful in cleaning up the color-magnitude diagrams and estimating the amount of field star contamination. On the other hand, the background field star cannot readily be distinguished from member stars

http://cdsweb.u-strasbg.fr/viz-bin/VizieR?-source=I/284

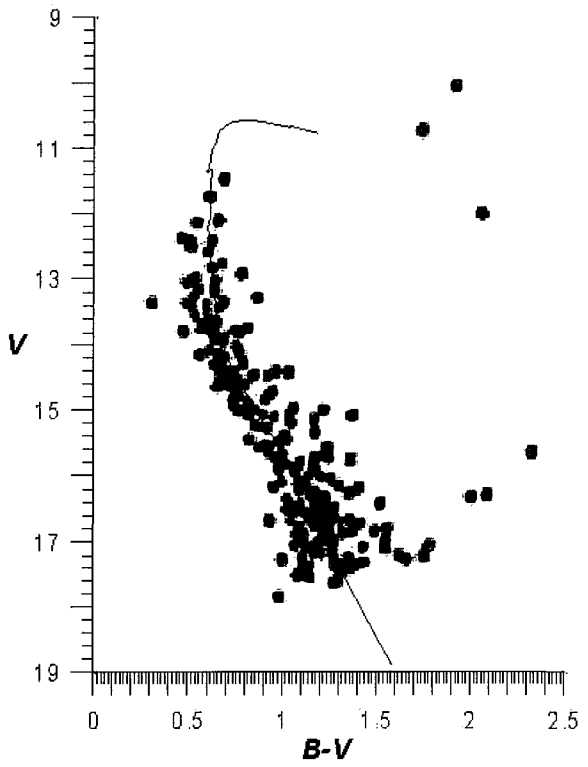

Fig. 2.— The CMD of Balog and Kaszás (1997) fitted with the ZAMS of Girardi et al. (2000) of log$t$ = 8.20 yr and metal abundance of 0.02. V–M_v, and E(B-V) are found to be 12.9 ± 0.10, and 0.72 ± 0.07 mag respectively.

by proper motions. However, USNO-B catalog demonstrates a pronounced excess of zero proper motions objects, which helps in determining the membership richness of the cluster, see *Gáspár* et al. (2003).

III. PROPERTIES OF NGC 7086

(a) CMD and Physical Parameters

Several fittings have been applied on the *CMD* of Balog and Kaszás (1997) using Girardi et al. (2000) isochrones of different ages and metal abundances. These isochrones are fitted to the lower envelope of the points matching the main sequence, turn-off point, and red giant positions, as showing in Figure 2. The overall shape of the *CMD* is found to be well reproduced with isochrones of age = 1.58 $\times 10^8$ yr, and metal abundance of 0.02. On this respect, the reddening is estimated simultaneously with the apparent distance modulus, which are found to be E(B-V) = 0.72 ±0.07 and $V - M_v = 12.9 \pm 0.10$ mag. The resulting total visual absorption is then $A_v = 2.16$ mag where the value of the ratio $A_v/E(B-V)$ is taken to be 3.0, following Garcia et al. (1988). The true distance modulus is then $(V - M_v)_o = 10.74 \pm 0.10$ mag, corresponding to a distance of 1400 ± 65 pc. The distances of the cluster from the galactic plane, Z, and from the galactic center, R_g, are found to be 5.38 pc and 8.72 kpc respectively.

(b) Geometric Properties

The cluster center is define as the location of maximum stellar density of the cluster's area. About 4000 stars are found within a preliminary radius of 10 arcmin for NGC 7086 using USNO-B1 catalog. The cluster center is found by fitting Gaussian to the profiles of star counts in right ascension and declination, as shown in Figure 3. Using this method, see Tadross (2005), the cluster center is found to lie at α= 322.6212 ± 0.004 and δ= 51.5864 ± 0.002 degrees. This new center is found to differ from WEBDA† by 2 sec in right ascension and 50 arcsec in declination.

Within 25 concentric shells in equal incremental steps of 0.4 arcmin from the cluster center, star count and surface density distribution are performed out to the cluster area. The whole area is covered and the density of the field stars reaches enough stability, i.e. the difference between the observed density profile and the background one is almost equal zero, as shown in Figure 4. From the slow drop off distribution and its tail, the cluster radius is defined at r=5.5 arcmin (≈ 2.2 pc).

IV. LUMINOSITY AND MASS FUNCTIONS OF NGC 7086

(a) Membership Analysis

It is noticed that, using USNO-B1 catalog, the region of NGC 7086 is very stellar crowded. So, our sample has been divided into two main groups: Stars with zero proper motions (~ 2800 stars) and stars with different proper motion values (~ 1200 stars), see Figure 5. The second group has been divided into two subgroups: Inner stars (~ 925 ones) and Outer stars (~ 275 ones). The inner stars (~ 23% of the whole sample) have ($\mu_\alpha cos\delta \,\&\, \mu_\delta$) lie between 0 and ±40 mas/yr, which are taken into account. While the outer stars (~ 7% of the whole sample) have $-40 \geq (\mu_\alpha cos\delta \; or/and \; \mu_\delta) \geq +40$ mas/yr, which are excluded from our sample because they have the highest motions in the cluster's area and expecting to be foreground stars.

For stars with zero proper motions (~ 70% of the whole sample), the stellar density distribution has been performed. From the damping profile of the distribution and its tail, the radius can be taken at r=3′, as shown in the left panel of Figure 6. This radius is included within the estimated radius of the cluster and contains about 310 stars.

To decrease the background contaminations, the

†http://obswww.unige.ch/webda/navigation.html

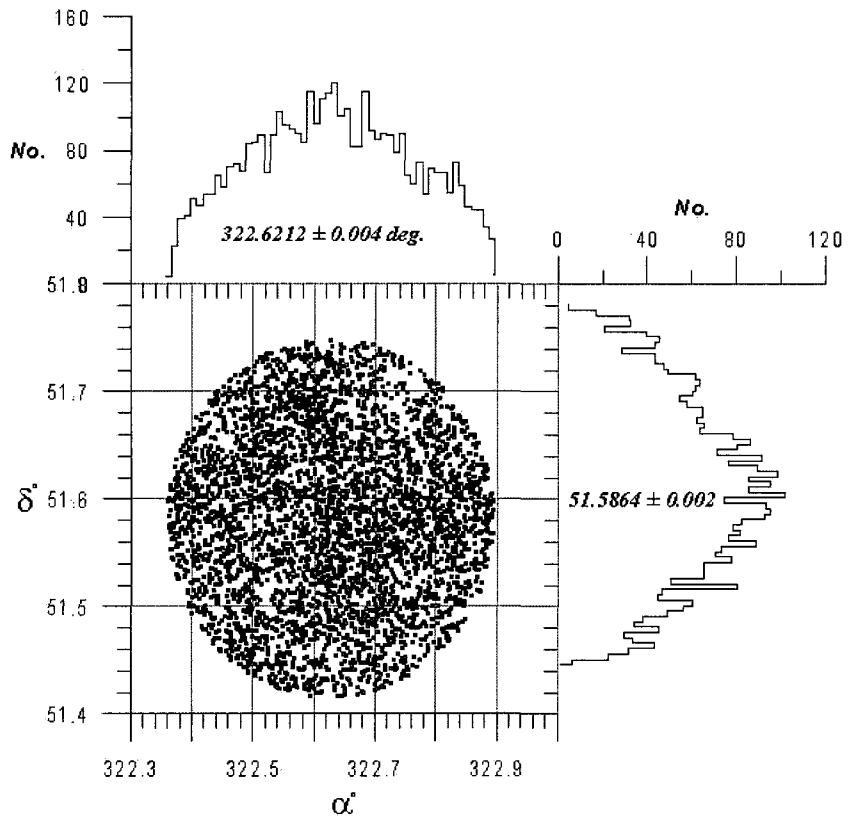

Fig. 3.— Profiles of stellar counts across NGC 7086. The Gaussian fits have been applied on the two profiles. The center of symmetry about the peaks of α and δ is taken to be the position of the cluster center.

data incompleteness is evaluated and removed using the seconde magnitudes of USNO-B1 catalog (*R2* & *B2*). The completeness limit are found to be 17.7 and 18.7 mag for R and B bands respectively. They are estimated from the luminosity function of each, where the sample considered to be completed up to the maximum bin. On this consideration, a *CMD*, (*B-R vs B*) has been constructed for the stars of zero proper motions, which lie inside the area of $r = 3'$, and verifying the completeness limit of B, as shown in the right panel of Figure 6. From the *CMD* we can conclude that the stars restricted between -1 $\leq B - R \leq$ 0.5 mag have been selected to be cluster probable members (159 stars).

On the other hand, the stellar density distribution has been performed for the inner stars of NGC 7086. Again, from the damping profile of the distribution and its tail, the radius can be taken at $r = 4'$, as shown in the left panel of Figure 7. The *CMD* (*B-R vs B*) of the inner stars within the defined radius is constructed as shown in the right panel of Figure 7. About 92 of 190 stars are considered as probable members in NGC 7086, which verifying the completeness limit of B, and having color indices between -1 and +0.5 mag.

In the light of the above analysis, the CMD of the cluster probable members based on the proper motions has been compared with that of the field stars of the whole area, as shown in Figue 8. The stars of ambiguous positions have been removed. So we can conclude that $\sim$ 210 stars can be considered as the cluster members based on the proper motions and their good positions on the CMDs.

(b) Luminosity Function *(LF)*

Depending on the estimated sample of the cluster members, which have been selected in the previous section, the apparent magnitude B was converted into absolute magnitude using the intrinsic distance modulus of the cluster. A step-plot has been constructed for the cluster stars showing the number of stars at 0.5 intervals between B = – 1.2 and 8.0 mag, as shown in Figure 9. This size interval was selected so as to include a reasonable number of stars in each bin and for the best possible statistics of the luminosity and mass functions. The cluster members have been shown in

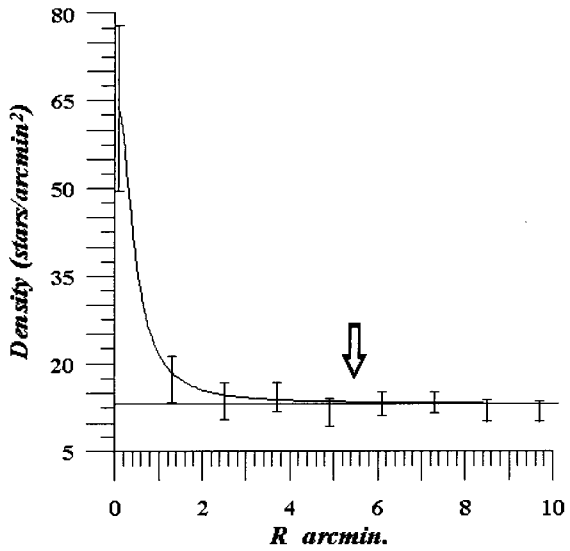

Fig. 4.— True radius estimation of NGC 7086 using the projected density distribution. The length of the error-bars denote errors resulting from sampling statistics, in accordance with Poisson distribution ($= 1/\sqrt{N}$, where N is the number of stars used in the density estimation at that point). The arrow marks the radius of the cluster, which obtained at 5.5 arcmin.

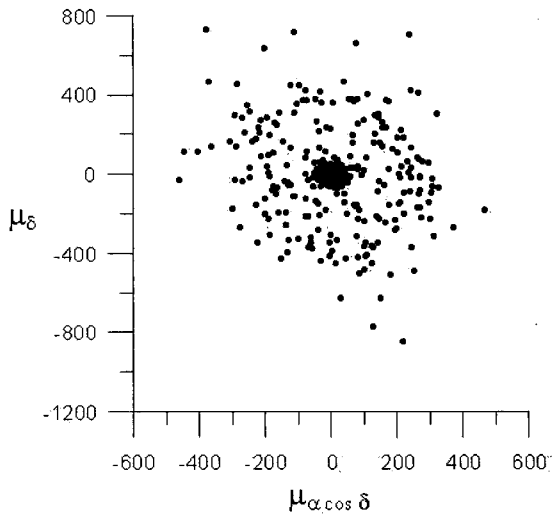

Fig. 5.— Proper motion measurements taken from USNO-B1 catalog for the whole stars lie in the region of NGC 7086.

the figure with a peak lies at $M_B = 5.75$ mag. On the other hand, the background field stars which removed from the cluster's area have been shown in the figure with a peak of $M_B = 7.40$ mag.

(c) Mass Function *(MF)*

The stellar initial mass function *IMF* is defined as the density of stars per unit mass bin, and represented as:

$$\Psi(M) = \frac{dN}{dM}$$

The *IMF* for high-mass stars ($> 1\,M_\odot$) has been established and well studied by Salpeter (1955). He derived the *IMF* from the luminosity function of the present day field stars assuming a constant rate of star formation and correcting for the stellar evolution. In linear units the Salpeter mass function is given by:

$$\Psi(M) \propto M^{-\alpha}$$

where $\alpha = 2.35$ for stars in the mass range 1–10 $M_\odot$. The steep slope of the *IMF* indicates that the low-mass stars is greater than the high-mass ones. Miller & Scalo (1979) and Scalo (1986) re-derived the stellar *IMF* by extending the study to the subsolar domain. Their derived values of α are 1.4, 2.5 and 3.3 for the mass ranges 0.1–1 $M_\odot$, 1–10 $M_\odot$ and $\geq 10\,M_\odot$ respectively.

In the present work, the mass function of NGC 7086 has been estimated using the fiducial isochrones of Girardi et al. (2000). The members' masses have been estimated from a polynomial equation that developed from the isochrones data at the same age and metal abundance of the cluster. A scatter-plot has been constructed for the cluster stellar masses showing the number of stars at 0.1 intervals between 0.75 – 3.5 $M_\odot$, as shown in Figure 10. Using a least-squares fit, the slope of the *IMF* is found to be – 2.67 ± 0.16. This value is different somewhat from the value given by Salpeter (1955), whereas the most stars of NGC 7086 concentrated in the mass bins of 0.75–1.30 $M_\odot$, i.e. it lies between the first and second categories of Miller & Scalo (1979) and Scalo (1986).

On this respect, the total mass of the cluster has been estimated by summing up the stars in each bin weighted by the mean mass of that bin. It yields a direct cluster mass of about $330\,M_\odot$. In the sake of comparison, the total mass of NGC 7086 has been estimated by Bruch & Sanders (1983) to be $166\,M_\odot$.

V. DISCUSSION AND CONCLUSIONS

Depending on the spatially unlimited USNO-B1 catalog of Monet et al. (2003), and the recent *CMD* of Balog and Kaszás (1997), the most photometric and astrometric parameters of NGC 7086 have been estimated, as the following:

(i) The cluster center is found to lie at α= 322.6212 and δ= 51.5864 degrees. This center is found to differ from WEBDA by 2 sec in right ascension and 50 arcsec in declination. On the other hand, the radial density

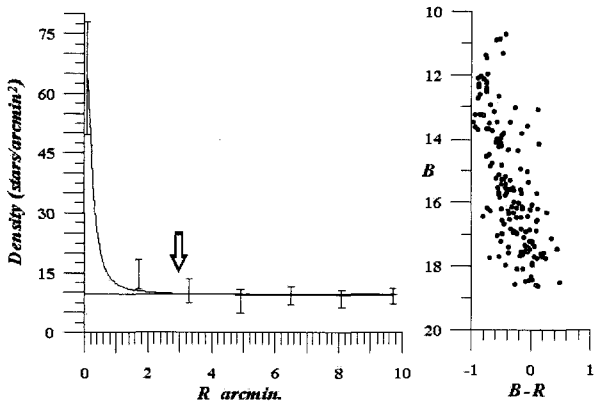

Fig. 6.— Left panel indicates the projected stellar density for the stars of zero proper motions. Error-bars as the same of Fig. 4. The arrow marks the taken radius of 3 arcmin. Right panel indicates the *CMD* for the stars inside the radius of the left panel, and verifying the completeness limit of $B = 18.7$ mag. The stars restricted between -1 $\leq B - R \leq$ 0.5 mag have been selected to be probable members (159 stars).

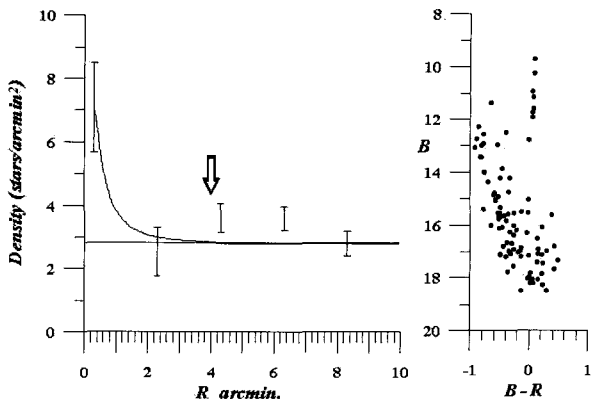

Fig. 7.— Left panel indicates the projected stellar density for for the inner stars. Error-bars as the same of Fig. 4. The arrow marks the taken radius of 4 arcmin. Right panel indicates the *CMD* for the stars inside the radius of the left panel, and verifying the completeness limit of $B = 18.7$ mag. The stars restricted between -1 $\leq B - R \leq 0.5$ mag have been selected to be cluster members (92 stars).

profile of NGC 7086 indicates that the extent of the cluster is 5.5 arcmin, which corresponding to 2.2 pc.

(ii) Based on the *CMD* of Balog and Kaszás (1997), the age and metal abundance are found to be 1.58 $\times 10^8$ yr, and 0.02 respectively. The reddening and the apparent distance modulus are found to be E(B-V) = 0.72 $\pm$0.07 and $V - M_v = 12.9 \pm 0.10$ mag. The true distance modulus is then $(V - M_v)_o = 10.74 \pm 0.10$ mag, corresponding to a distance of 1400 ± 65 pc. The distances of the cluster from the galactic plane, Z, and from the galactic center, R_g, are found to be 5.38 pc and 8.72 kpc respectively.

(iii) From the analysis of the membership, comparing with the field stars of the whole area, and removing the ambiguous stars, NGC 7086 is found to have $\sim$ 210 members. These members have been selected from the inner stars and the stars of zero proper motions; all of them have good positions on the CMDs.

(iv) The luminosity function of NGC 7086 is constructed with that of the field background stars. The high peaks of the cluster and the background field stars are found to lie at $M_B = 5.75$ and 7.40 mag respectively.

(v) The mass function of NGC 7086 has been constructed, and the slopes of *IMF* is found to be -2.67 $\pm$ 0.16. The total mass is found to be $\sim 330\,M_\odot$. Comparing with the previous studies, the total mass of NGC 7086 has been estimated by Bruch & Sanders (1983) to be $166\,M_\odot$. They estimated this value by converting the relative mass of Reddish (1978) to the absolute mass with error of about 25%.

ACKNOWLEDGEMENTS

I would like to express my appreciation to the teamwork of USNO-B catalog (Monet *et al.*, 2003) for providing their useful catalog that serves such kind of work.

REFERENCES

Balog Z. & Kaszás G., 1997, CCD Photometry of Five Poorly Studied Open Clusters in Cygnus, I.A.P.P. Comm. 67, 70

Bruch A. & Sanders W. L., 1983, The absolute masses of 72 galactic clusters and 12 OB associations, A&A, 121, 237

Garcia B., Clariá J. J., & Levato H., 1988, The ratio of total to selective absorption in the Carina OB2 association, Ap&SS, 143, 317

Gáspár L. et al., 2003, The first CCD photometric study of the open cluster NGC 2126, A&A, 410, 879

Girardi L. et al., 2000, Evolutionary tracks and isochrones for low- and intermediate-mass stars: From 0.15 to 7 Msun, and from Z=0.0004 to 0.03, A&AS., 141, 371

Hassan S. M., 1967, Three-Color Photometry of NGC 7086, Zeitschrift für Astrophysik, 66, 6

Hoag A. A., Johnson H. L., Iriarte B., Mitchell R. I., Hallam K. L., & Sharpless S., 1961, Photometry of stars in galactic cluster fields, Publ. US. Nav. Obs., 17, 347

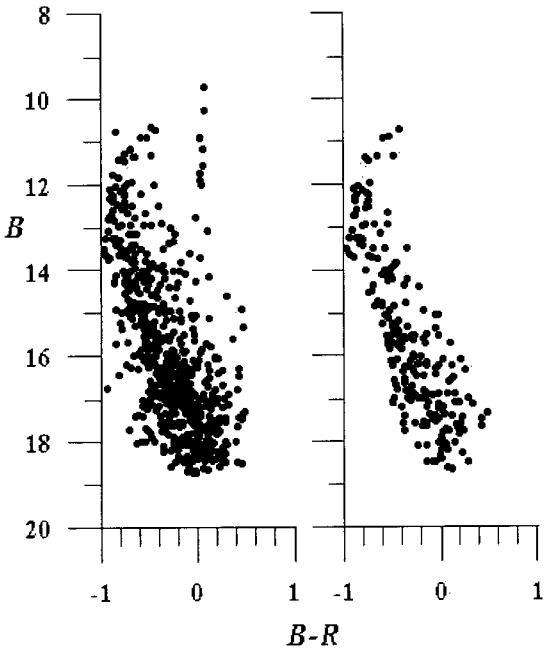

Fig. 8.— Comparing the CMDs of the cluster probable members based on the proper motions (right panel) and that of the field stars of the whole area (left panel).

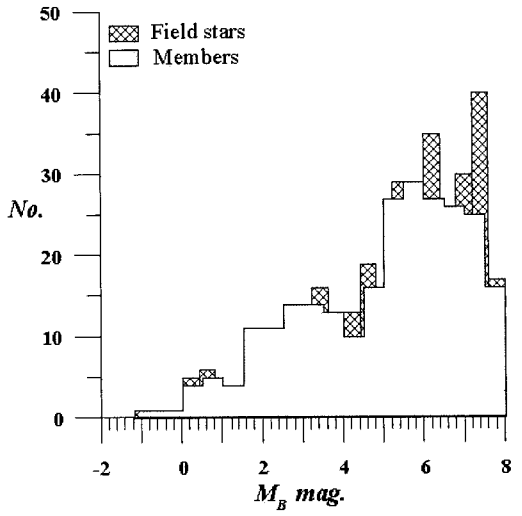

Fig. 9.— The luminosity functions of the cluster members and field ones. The peak of the *LFs* for the cluster and contaminated field are found to be lie at M_B= 5.75 and 7.40 mag respectively.

Miller G. E. & Scalo J. M., 1979, The initial mass function and stellar birthrate in the solar neighborhood, ApJS, 41, 513

Monet D., et al. (28 coauthors) 2003, The USNO-B Catalog, AJ, 125, 984

Reddish V. 1978, Stellar Formation, Pergamon Press, p. 69

Salpeter E., 1955, The Luminosity Function and Stellar Evolution, ApJ, 121, 161

Scalo J. M., 1986, The stellar initial mass function, Fundam. Cosmic Phys., 11, 1

Tadross A. L., 2005, Analytical studies of NGC 1193, AN, 326, 19

Trumpler R. J., 1930, Preliminary results on the distances, dimensions and space distribution of open star clusters, Lick Obs. Bull. No., 420, 154

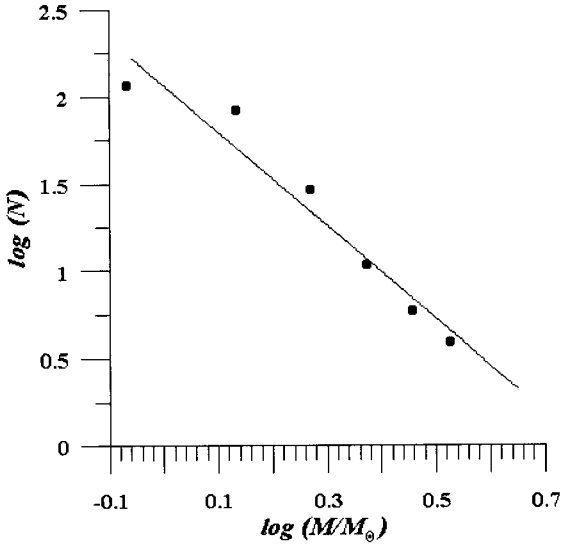

Fig. 10.— The mass function of the cluster NGC 7086. The solid inclined line represents the slope of *IMF*, which is – 2.67 ± 0.16.