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PHOTOMETRIC EVOLUTION OF OPEN CLUSTERS AND ASSOCIATIONS*

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ABSTRACT

The photometric evolution of cluster stars are examined for six synthetic clusters in the age range from 2.4×10^6 yr to 7.6×10^8yr by using the detailed evolutionary model calculation, and their results are compared with the observed integrated absolute magnitude and colors of 47 clusters. The reasonable agreements of the observed photometric parameters with the synthetic evolutionary sequences imply that there is a general form of time-dependent IMF including the noncoeval formation of stars and its detailed function is changed slightly with various environmental conditions of each primordial cloud.

Key Words: open clusters, associations.

I. INTRODUCTION

The C-M diagrams of open clusters and associations have been used for the derivation of cluster age and for the examination of evolutionary status. Also the initial mass function(IMF) can be derived from the luminosity function of stars in a cluster(Salpeter 1955, Miller and Scalo 1979). In this case, the mean slope of mass function of bright stars is very sensitive to the completeness in each cluster and to the brightening effect due to evolution, particularly for very young clusters and associations(Lee and Kim 1983). Accordingly some authors(Taff 1974, Claudius and Grosbøl 1980) claim the universality of IMF of clusters but the others(Burki 1977, Cohen and Kuhi 1979, Tarrab 1982) do not.

To avoid these uncertain effects, integrated absolute visual magnitudes and colors of clusters(Gray 1965, Spassova and Baev 1985) are used comparing those derived from synthetic clusters. These integrated photometric parameters are determined mainly by bright stars in each cluster and not sensitive to the completeness of stars within a limiting magnitude. The integrated photometric parameters have been derived theoretically from synthetic clusters, taking a simple IMF (Dixon *et al.* 1972, Searle *et al.* 1973, Barbaro and Bertelli 1977, Chiosi *et al.* 1986) or age-dependent IMF(Pandey *et al.* 1989) evolutionary model calculations. Usually the constant star formation rate(SFR) has been assumed for the synthetic clusters.

So far no detailed constraints have been used in the modelling of synthetic cluster except for common IMF and evolutionary grid of stars, and so the photometric evolutionary history of each cluster could not be estimated. Hence in this study, in order to examine the photometric evolutionary history of each cluster, we use the present day mass function(PDMF) of main sequence(MS) stars in the cluster and the time-dependent IMF and SFR(Lee and Kim 1983), adopting the recent evolution model calculations for metal abundance, $Z = 0.02$. In section 2, the stellar evolutionary grids used for the present study are summarized, and the PDMFs and theoretical C-M diagrams are discussed in section 3. The photometric evolutions of clusters and the comparison with observed integral photometric paramters are presented in section 4, following the final discussion in the last section.

II. EVOLUTIONARY GRIDS

The recent stellar evolutionary models of Maeder and Meynet(1988) in which the overshooting and mass loss are included, extend from $120m_\odot$ to $0.85m_\odot$ for $Z = 0.02$ and $X = 0.70$. Their evolutionary stages with mass are shown in Table 1.

The stars of mass in the range of $1.0m_\odot \leq m < 1.7m_\odot$ are evolved up to the end of asymptotic giant branch(AGB),

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Table 1. Evolutionary Stage

Mass Range	Evolutionary Stage	Reference
$m \geq 40m_{\odot}$	ZAMS $\rightarrow$ end of He-burning	Maeder & Meynet(1988)
$2 \leq m < 40m_{\odot}$	ZAMS $\rightarrow$ beginning of C-burning	Maeder & Meynet(1988)
$1.0 \leq m < 1.7m_{\odot}$	ZAMS $\rightarrow$ RGB	Maeder & Meynet(1988)
	ZAMS $\rightarrow$ AGB	Boothroyd & Sackmann(1988)
$0.7 \leq m < 1.0m_{\odot}$	ZAMS $\rightarrow$ RGB	Mengel *et al.*(1979)
		Sweigart & Gross(1978)
$0.3 \leq m < 0.6m_{\odot}$	ZAMS $\rightarrow$ MS turnoff point	VandenBerg *et al.*(1983)
$0.08 \leq m < 0.3m_{\odot}$	ZAMS	VandenBerg *et al.*(1983)

adopting the Boothroyd and Sackmann's (1988) models for AGB stars. In the process of the combination of red giant branch(RGB) and AGB, some adjustments were made because of two different evolutionary models. The low mass stars of $0.7m_{\odot} \leq m < 1.0m_{\odot}$ are evolved up to the RGB tip (Sweigart and Gross 1978, Mengel *et al.* 1979), and the faint stars of $m < 0.7m_{\odot}$ are at the H-buring phase on the ZAMS(VandenBerg *et al.* 1983). In the mass range from $120m_{\odot}$ to $0.08m_{\odot}$, the total 87 mass points are selected.

To convert luminosity and effective temperature to photometric parameters such as absolute visual magnitude and colors various stellar atmosphere models are adopted as listed in Table 2. Here the different models were adjusted to yield consistent values for bolometric correction and colors among the different models. For the low mass stars of low effective temperature(log $T_e < 3.74$) and high surface gravity(log $g > 3.75$), the atmosphere model of VandenBerg and Bell(1985) was adopted. Using the converted photometric parameters, the evolutionary tracks and isochrones of stars are transformed to the C-M diagram. The position on ZAMS in the C-M and C-C diagrams were adjusted for low mass stars of $m < 1.7m_{\odot}$, considering the observed position of Pop I stars (Schmidt-Kaler 1982).

III. PDMF AND C-M DIAGRAM

(a) Basic Equations

Lee and Kim(1983) have proposed a time-dependent IMF, $\xi(\log m, t)$, considering fragmentation(Reddish 1975, Silk and Takahashi 1979), accretion through fragment interaction(Bastien 1981) and noncoeval formation of stars(Iben and Talbot 1966, Cohen and Kuhi 1979, Kwon and Lee 1983);

$$\xi(\log m, t) = \xi_o(t) exp\left[-A(\log m - B)^2\right]\left(\frac{m}{C}\right)^{\left(\frac{CD}{m}\right)\left\{1-exp\left[1-(t-H)^2/G^2\right]\right\}} \quad (1)$$

Where A, B, C, D, H, and G are constants and $\xi_o(t)$ is a time-dependent normalization constant which is determined by the following condition,

$$1 = \int_{m_l}^{m_u} \xi(\log m, t)\, m\, d(\log m) \quad (2)$$

where m_u and m_l are the upper and lower mass limits. In the above equations, time t is in the units of free fall time of a primordial molecular cloud.

In Equation (1), the Gaussian function is equivalent to the Larson's(1973) simple probability fragmentation model which controls mainly the formation of massive stars. The constant H is related to the lower limit of mass in IMF, and the constant C to the fragmentation interaction at the late stage of evolution. The constant G controls the relative speed of process of fragmentation and fragment interaction. All the constants in Equation (1) can be determined by fitting the computed PDMF of MS stars in a cluster to the observed PDMF. For this, we need a SFR.

According to the disk-halo model of Lee and Ann(1981), a time-dependent SFR, $S(t)$ is taken by

$$S(t) = S_o t\left\{1 - 0.6\left[exp\left(-\frac{(t-1)^2}{G^2}\right)\right]\right\} \cdot exp\left[-4|t-1|^{0.41}\right] \quad (3)$$

Table 2. Bolometric Correction and Colors

Photometric parameter	Luminosity class	Atmosphere model
	V, III	Buser & Kurucz(1978) (log $T_e \geq 3.74$)
B.C.		VandenBerg & Bell(1985) (log $T_e < 3.74$, log $g \geq 3.75$)
	III	Bell & Gustafsson(1978) (log $T_e < 3.74$)
	I	Lee(1985) (Pop I - relation)
	V, III	Buser & Kurucz(1978) (log $T_e \geq 3.74$)
B−V		VandenBerg & Bell(1985) (log $T_e < 3.74$, log $g \geq 3.75$)
	III	Bell & Gustafsson(1978) (log $T_e < 3.74$)
	I	Lee(1985) (Pop I - relation)
	V, III	Buser & Kurucz(1978) (log $T_e \geq 3.74$)
U−B		VandenBerg & Bell(1985) (log $T_e < 3.74$, log $g \geq 3.75$)
	III	Bell & Gustafsson(1978) (log $T_e < 3.74$)
	I	Lee(1985) (Pop I - relation)

where the normalization constant, S_o is determined by the following condition;

$$1 = \int_0^\infty S(t)\,dt \tag{4}$$

Then the total number $\Phi_{ms}(\log m, t)$ of MS stars with mass m at time t is given by

$$\begin{aligned}\Phi_{ms}(\log m, t) &= \int_0^{t-\tau_{pms}} \xi(\log m, t')S(t')\,dt' \qquad : \tau_{ms} \geq (t - \tau_{pms}) \\ &= \int_{t-\tau_{pms}-\tau_{ms}}^{t-\tau_{pms}} \xi(\log m, t')S(t')\,dt' \qquad : \tau_{ms} < (t - \tau_{pms})\end{aligned} \tag{5}$$

where MS lifetime τ_{ms} and pre-MS lifetime τ_{pms} are also in units of free-fall time of a cloud. The data of τ_{pms} were taken from the model results of Iben(1965).

The total number $\Phi(\log m, t)$ of all stars with mass m at time t is obtained from the first equation of Equation (5), putting $\tau_{pms} = 0$. And the total number $\Phi_l(\log m, t)$ of luminous stars with mass m at time t is given by

$$\begin{aligned}\Phi_l(\log m, t) &= \int_0^{t} \xi(\log m, t')S(t')\,dt' \qquad : \tau_m \geq t \\ &= \int_{t-\tau_m}^{t} \xi(\log m, t')S(t')\,dt' \qquad : \tau_m < t\end{aligned} \tag{6}$$

where τ_m is the lifetime of stars with mass m, and is in units of free-fall time of a cloud.

(b) Computed PDMF and Synthetic C-M diagram

The PDMF of MS stars in a cluster can be computed simply by using Equation (5) if the age of the cluster is known. Here the MS stars are defined as the stars at the phase of central hydrogen burning. The PDMF of MS stars can also be derived directly from the theoretical evolution of cluster. If the age of cluster is correct, the above two kinds of PDMFs will coincide with each other. These PDMFs must be controlled to agree to the observed PDMF of MS stars in a given cluster.

For two associations and four young open clusters which are well observed, their observed PDMFs for MS stars are compared with the computed PDMF and some cases are shown in Figure 1 where open and crossed histograms denote

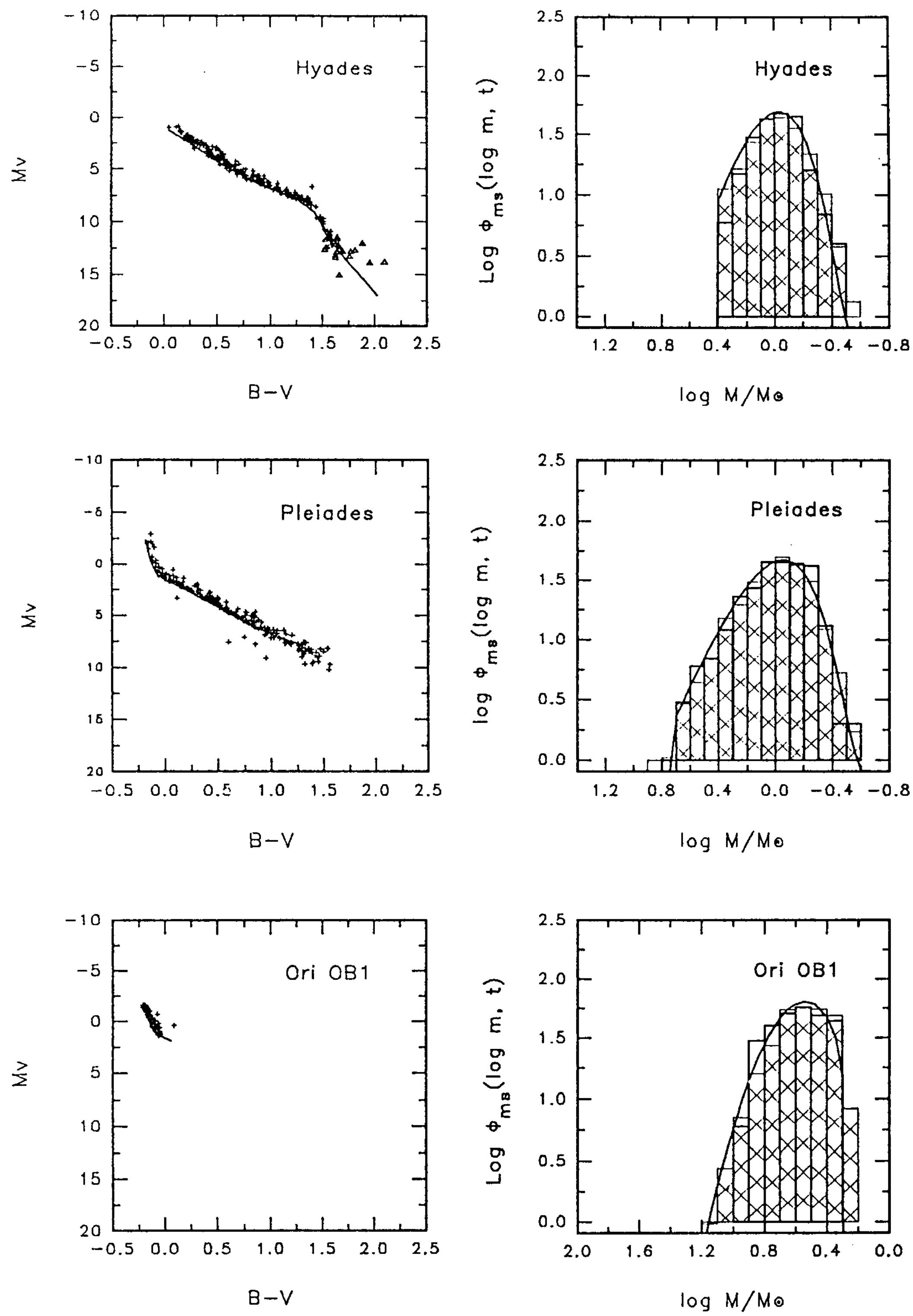

Fig. 1. PDMF and C-M diagram for MS stars. The cross and solid line in the C-M diagram represent the observed MS stars and the computed MS sequence of synthetic clusters, respectively. The triangles in the C-M diagram of Hyades denote some uncertain data of faint stars given by Altena(1969). The open and crossed histograms denote respectively the observed and computed PDMFs. The solid curve in PDMF represent the computed one by using Equation (5).

Table 3. Some Characteristics of Clusters*

Parameter	IC 1805	Sco OB1	Ori OB1	NGC 654	Pleiades	Hyades
Age(yr)	2.4×10^6 (4×10^6)[1]	3×10^6 (4.3×10^6)[2]	8×10^6 ($0.3 \sim 28 \times 10^6$)[3]	3×10^7 (3.1×10^7)[4]	7.3×10^7 (7×10^7)[5]	7.6×10^8 (7×10^8)[6]
N_t	655 (354)[8]	149	412	82	328	263
M_t	3365	3100	1644	1117	557 (~ 550)[7]	355
N_{ms}	134	145	290	47	273	239
M_{ms}	2419	3009	1075	297	358	237 (300)[6]
N_g	0	0	31	5	0	6(4)[9]
M_g	0	0	308	51	0	15
N_{pms}	521	6	88	0	42	0
M_{pms}	946	40	126	0	16	0
N_{WD}	0	0	0	0	0	9(7)[6]
M_{WD}	0	0	0	0	0	31
N_d	0	0	3	30	13	18
M_d	0	0	135	769	183	103
$M_{max,f}$	120	100	45	79	25	12
$M_{max,l}$	100	100	22	12	6	2.5
M_{min}	0.13	4	0.4	1.6	0.13	0.13
M_{turn}	3.5	14	2.2	11	0.6	0.9

* mass : in unit of solar mass

1. Joshi & Sagar(1983) 2. Maeder(1972) 3. Warren & Hesser(1978)
4. Joshi & Sagar(1983) 5. Stauffer *et al.*(1984) 6. Weidemann *et al.*(1992)
7. Hambly & Jamerson(1991) 8. Vasilevskis *et al.*(1965) 9. Johnson & Knukles(1955)

respectively the observed and computed PDMFs. The latter ones for synthetic clusters are obtained on the basis of stellar evolution of stars with different masses. The solid curves in PDMFs represent the computed PDMFs simply by using Equation (5). If the adopted IMF and SFR are reasonable, they must yield the correct synthetic C-M and C-C diagram as well as the synthetic PDMF. The reasonable agreements between the observed and model computed C-M diagrams can be seen for typical three clusters in Figure 1 where the computed values are denoted as solid curve and the observed stars as cross. The data(open triangle) for the faint red MS stars of $(B-V) \geq 1.5$ in Hyades are chosen from the Altena's(1969) paper to show the faint part of the MS in Figure 1 although they are very uncertain. In the process of PDMF computation, the bright MS stars in very young clusters are not large enough in number, and so the synthetic C-M diagram and PDMF are very sensitive particularly to the adopted IMF.

The relatively correct age of a cluster can be determined by the above method in which two theoretical PDMFs and C-M diagrams are compared with observed ones. The derived ages for six clusters are listed in Table 3. These ages are similar to the conventionally estimated ones. In the present study, the age of Pleiades is estimated as 7.3×10^7yr, which is nearly the same as the turnoff age but smaller than the turnon age($1 \sim 2 \times 10^8$yr, Stauffer 1984) of pre-MS stars in the cluster. The age spread in very young clusters is also shown in IC 1805. Using the isochrones in the C-M diagram, Guetter and Vrba(1989) estimated the ages of $3 \sim 4 \times 10^6$yr and $12 \sim 20 \times 10^6$yr for O stars and B stars in IC 1805, respectively. In the IMF given in Equation (1), the noncoeval formation of stars in the cluster has been assumed, following the early observational results of Herbig(1962) and Iben and Talbot (1966). Recently Mazzei and Pigatto(1989) claimed the longer age of 1.5×10^8yr for Pleiades, applying the correction for rotational effect of bright stars, and they insist the coeval formation of stars as suggested by Stahler(1985). However, at present it is not clear whether the above argument for the coeval formation of stars can be applied to all other very young clusters because there are no enough data for rotation of bright stars in the clusters. Hence in the present study, we simply use the observed photometric data without taking into account the rotation effect of bright stars in the C-M diagram.

(c) Number Distribution

For given IMF and age for each cluster, the total number N_t of stars born up to now and total numbers of MS stars(N_{ms}), giant stars(N_g), pre-MS stars(N_{pms}), white dwarfs(N_{WD}) and dead stars(N_d) at the present time can be determined. These values are listed in Table 3 together with their masses, and some results for Hyades, Pleiades and Orion OB1 association are shown in Figure 2 where dead stars, luminous stars(MS and giants) and pre-MS stars are denoted respectively, as dark, open, and hatched histograms.

In the last four rows in Table 3, $M_{max,f}$, $M_{max,l}$ M_{min}, and M_{turn} represent respectively, the maximum mass formed effectively at the initial stage of evolution, the maximum and minimum masses seen at the present time and the turnover mass at which the mass frequency has a peak in the mass function of all stars born up to now. The progenitor of white dwarfs is set as the mass less than $5m_\odot$.

In Hyades of age, 7.6×10^8 yr, the computed total mass is $355m_\odot$ in Table 3, and the total number of luminous stars are 254, which is about 64% of the estimated value by the observed space density(Pels *et al.* 1975, Oort 1979). But the total mass is $283m_\odot$ of luminous stars is very close to the estimated value, $\sim 300m_\odot$(Weidemann *et al.* 1992). The computed number 6 of giant stars whose progenitor mass is $\sim 2.5m_\odot$, are close to four giants observed in Hyades. From the proper-motion survey, Altena(1969) estimated eleven white dwarfs in Hyades. Among these, seven white dwarfs whose progenitor mass is $\sim 3m_\odot$, were confirmed in Hyades(Weidemann *et al.* 1992), and this number is very close to to estimated number 9 from the present IMF whose progenitor mass is $\sim 3.4m_\odot$. According to the adopted IMF and age of Hyades, 18 stars whose mass is smaller than $\sim 12m_\odot$ and greater than $2.5m_\odot$ in Hyades, have finished their evolution and remain as invisible remnant whose total mass is about 30% of the total mass of Hyades. This computation is based on the present PDMF of MS stars in Hyades, and so the evaporation and escape of stars during the dynamical evolution of Hyades are not taken into account in the present study. (see Weidemann *et al.* 1992 for probable original mass of Hyades.)

Recently Hambly and Jamerson(1991) estimated the total mass $\sim 550m_\odot$ of Pleiades from their detailed observed luminosity function, and this value is consistent with the computed mass, $557m_\odot$ but greater than the luminous star mass $374m_\odot$. In this cluster of age 7.3×10^7yr, no giant stars have been observed and the adopted IMF (see Figure 5) predicts 42 pre-MS stars whose progenitor mass is $0.38m_\odot$. Until now no pre-MS stars are firmly confirmed in Pleiades although the existences of many pre-MS stars are clearly exhibited in the C-M diagram. About 20 faint red stars ($V > 15^m$) which lie above the MS by $\Delta V \simeq 0.^m7$ are known to be mostly binary stars (Stauffer 1980, 1982). No white dwarfs have been reported as indicated in Table 3. The total remnant isvisible mass after the completion of evolution of stars($6m_\odot < m < 25m_\odot$) is about one third of the total cluster mass. The maximum mass of luminous stars is $6m_\odot$, and the effective maximum mass at the initial stage of evolution is about $25m_\odot$, which is about twice the maximum initial mass of Hyades.

In NGC 654(Stone 1980, Joshi and Sagar 1983) of age 3×10^7yr, seven giant and supergiant stars are observed, which are comparable to estimated five giants in Table 3 whose average mass is $\sim 10m_\odot$. The total mass of MS stars in this cluster is estimated to be about $300m_\odot$, which is less than one half of the remnant of total mass of cluster. This large remnant mass after the completion of evolution of stars with mass greater than $12m_\odot$ and a young age, 3×10^7yr suggest that in NGC 654, the mostly massive stars might have formed as expected in IMF and mass function which has very large turnover mass($11m_\odot$) (see Figure 5) and also a large minimum mass($1.6m_\odot$).

The most of luminous O, B type young stars in Orion OB1(Warren and Hesser 1978) of age 8×10^6yr are at the MS phase and their total mass is 65% of the total mass of the association in Table 3, and about 30 bright giant stars exist above the MS. About 90 of pre-MS stars are expected, where pregenitor mass is about $1.4m_\odot$. So far three massive stars whose average mass is about $45m_\odot$, are expected to have finished their evolution. The maximum mass of the present luminous stars is about $22m_\odot$ in Orion OB1 whereas the effective maximum mass is $45m_\odot$. Hence in the Orion OB1 association, no very massive stars whose mass is greater than $\sim 50m_\odot$, seem to have formed.

Scorpio OB1 associaton(Genderen *et al.* 1984) includes NGC 6231 and situates in the Sagittarius-Carinar Spiral arm($\sim$

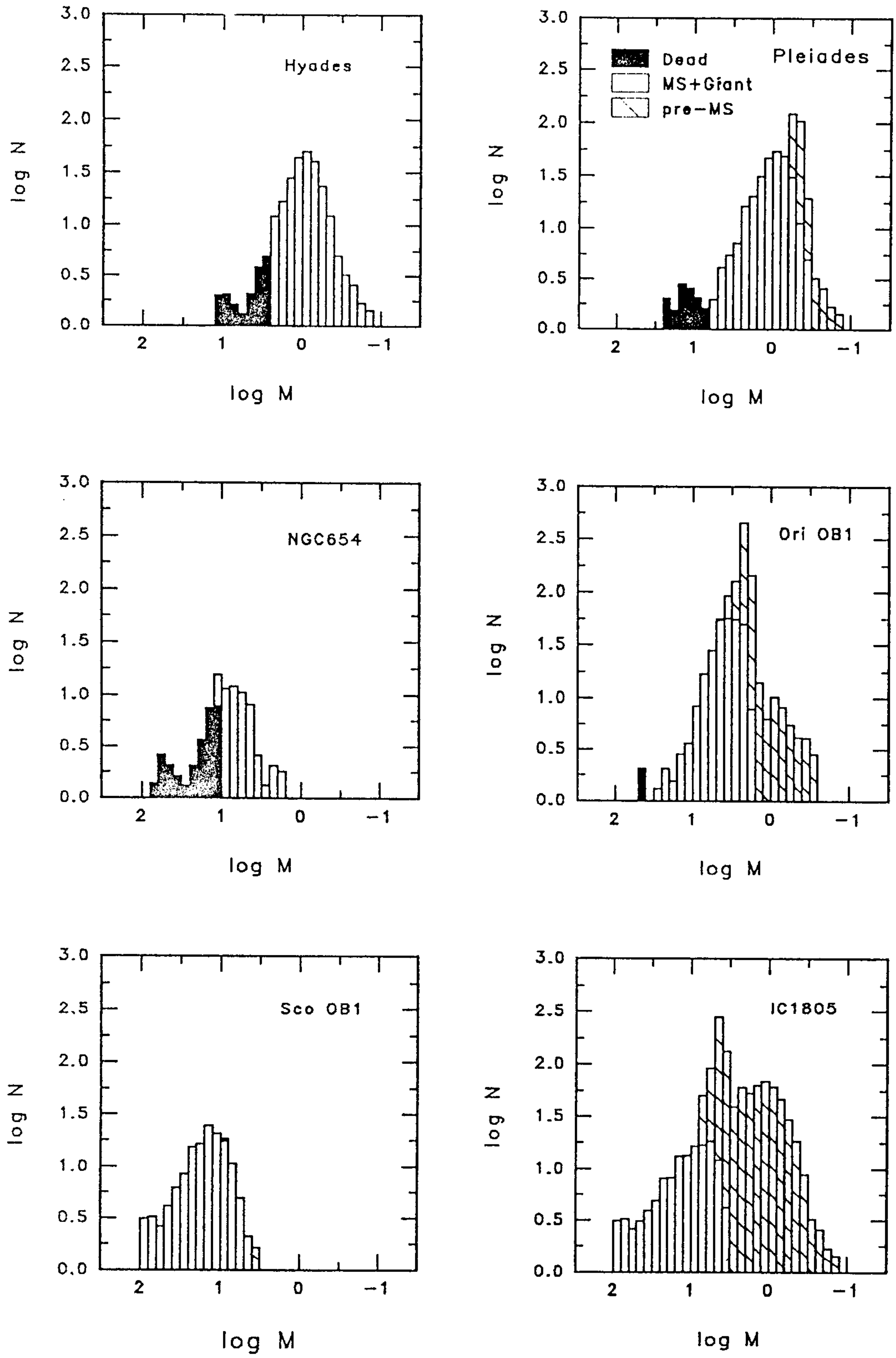

Fig. 2. Mass Function of all stars born up to now. The invisible dead stars are denoted as dark histogram, and visible stars(MS stars + giant stars) and pre-MS stars are denoted as open and hatched histograms, respectively.

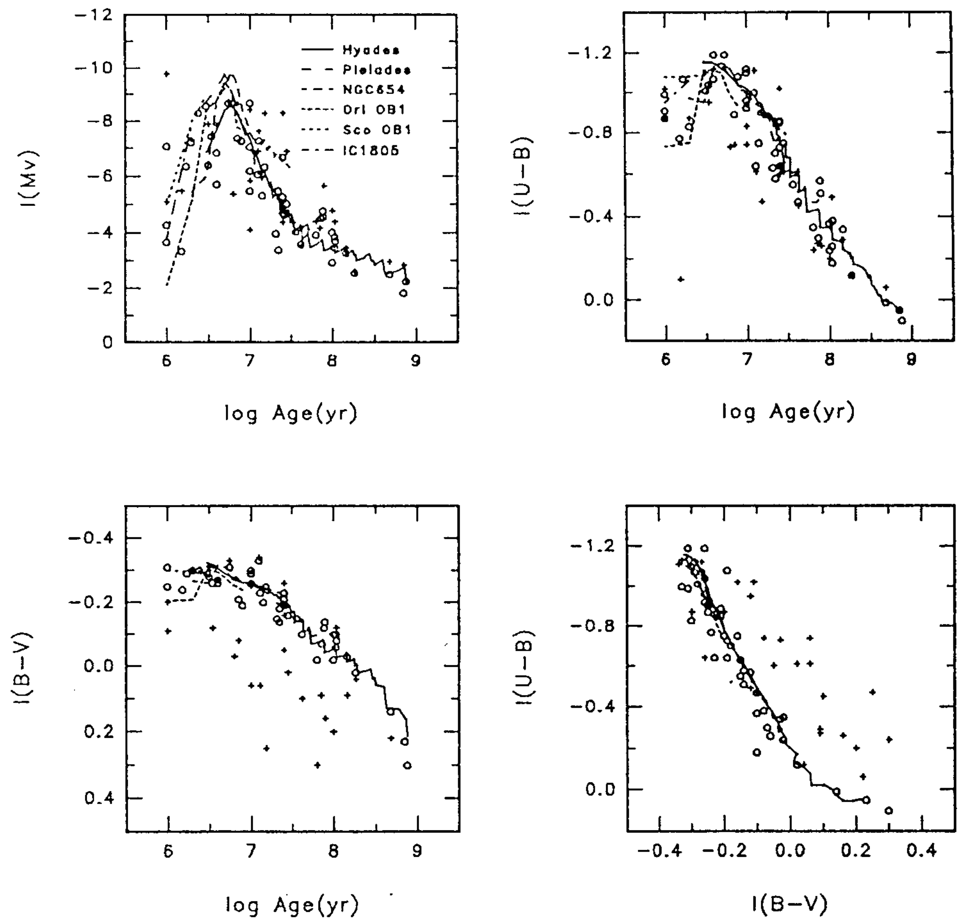

Fig. 3. Integrated photometric parameters. The observed integrated photometric parameters of clusters in Table 4 are compared with the theoretical photometric sequences of six synthetic clusters. Each sequence is evolved up to the age of a given cluster. The curves represent for only MS stars in each cluster. The open circle and cross denote the observed data for only MS stars and all stars in each cluster, respectively.

$2^\circ \times 1^\circ$). Its rich association consists of mostly high luminosity O, B type stars. This is a very massive association of age 3×10^6yr with the total mass of $3100m_\odot$ according to the present model. Heske and Wendker(1985) estimated a large population of pre-MS stars in this association. However, in the present study, a few pre-MS stars are expected now and all other stars are evolving on the MS. Therefore, the present luminous maximum mass, $\sim 100m_\odot$, is the same as the effective initial maximum mass of the association. This association has the very large minimum mass($4m_\odot$) and large turnover mass($1.2m_\odot$). This effect may be related to the very active star formation in a large nebulocity distributed around this association.

The very young cluster, IC 1805(Joshi and Sagar 1983) as the central concentration of stars in Cas OB6, has many bright O, B stars and is only 2.4×10^6yr old. This age corresponds to the age of O stars($2 \sim 4 \times 10^6$yr, which is younger than the age of B stars($1.2 \sim 2 \times 10^7$yr) (Guetter and Vrba 1989 and de Andres *et al.* 1982). After all, this age difference indicates the noncoeval formation of stars in this cluster. The total number of stars born up to now in this cluster is expected about 480 in Table 3, whereas Vasilevskis *et al.*(1965) estimated 354 stars from proper-motion survey which is less than on half of the total number of luminous stars including pre-MS stars. The total mass of stars born up to now is very large as $\sim 2000m_\odot$ of which three of fourths are now MS stars and the rest mass consists of pre-MS stars whose large population is a characteristics among the young clusters in Table 3. Many pre-MS stars are clearly seen in IC 1805 with a large diameter of $\sim$ 20pc(Baade 1983). Because of the young age, the effective initial maximum mass of this cluster is the

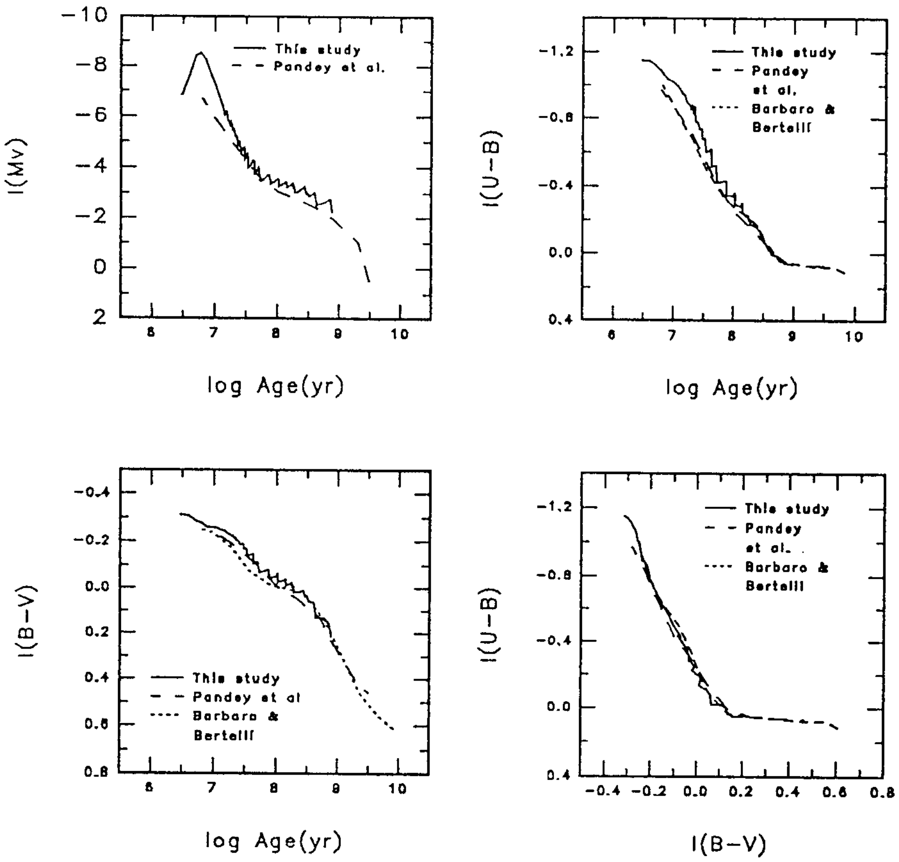

Fig. 4. Comparison of the present results with the others. The photometric evolutionary sequences obtained by Pandey *et al.*(1989) and Barbaro and Bertelli(1977) are denoted as dashed and dotted curves for MS stars, respectively. These results agrees quite well with the present sequences for MS stars.

same as the observed maximum mass now. According to the IUE survey of O stars in IC 1805, the mass of most massive O stars was estimated as $129m_{\odot}$ and the next one as $100m_{\odot}$ by Burki and Llorente de Andrés(1979). This large mass is also seen in the theoretical PDMF(see Figure 5).

IV. PHOTOMETRIC EVOLUTION OF CLUSTERS

Since the age and IMF of each cluster can be determined by comparing PDMFs discussed in the previous section, the photometric evolution can be carried out for each cluster. And also the photometric integrated parameters such as total absolute magnitude $I(M_v)$ and total colors I(B−V) and I(U−B) can be estimated for each synthetic cluster. Six synthetic clusters are evolved from the beginning to their present age, and their results are shown in Figure 3 where the curves represent the computed evolutionary sequence for only MS stars in each cluster. For a comparison, the observed integrated parameters of many clusters in Table 4 where the values in the first and second rows are respectively, for MS stars and all stars in each clusters, are also included in Figure 3 where the open circle and cross denote the data for only MS stars and all stars in each cluster. Here it can be seen that the observed parameters for MS stars follow relatively well the synthetic evolutionary sequences for MS stars.

The integrated parameter $I(M_v)$ is generally sensitive to bright giants and they are not contiuously distributed along

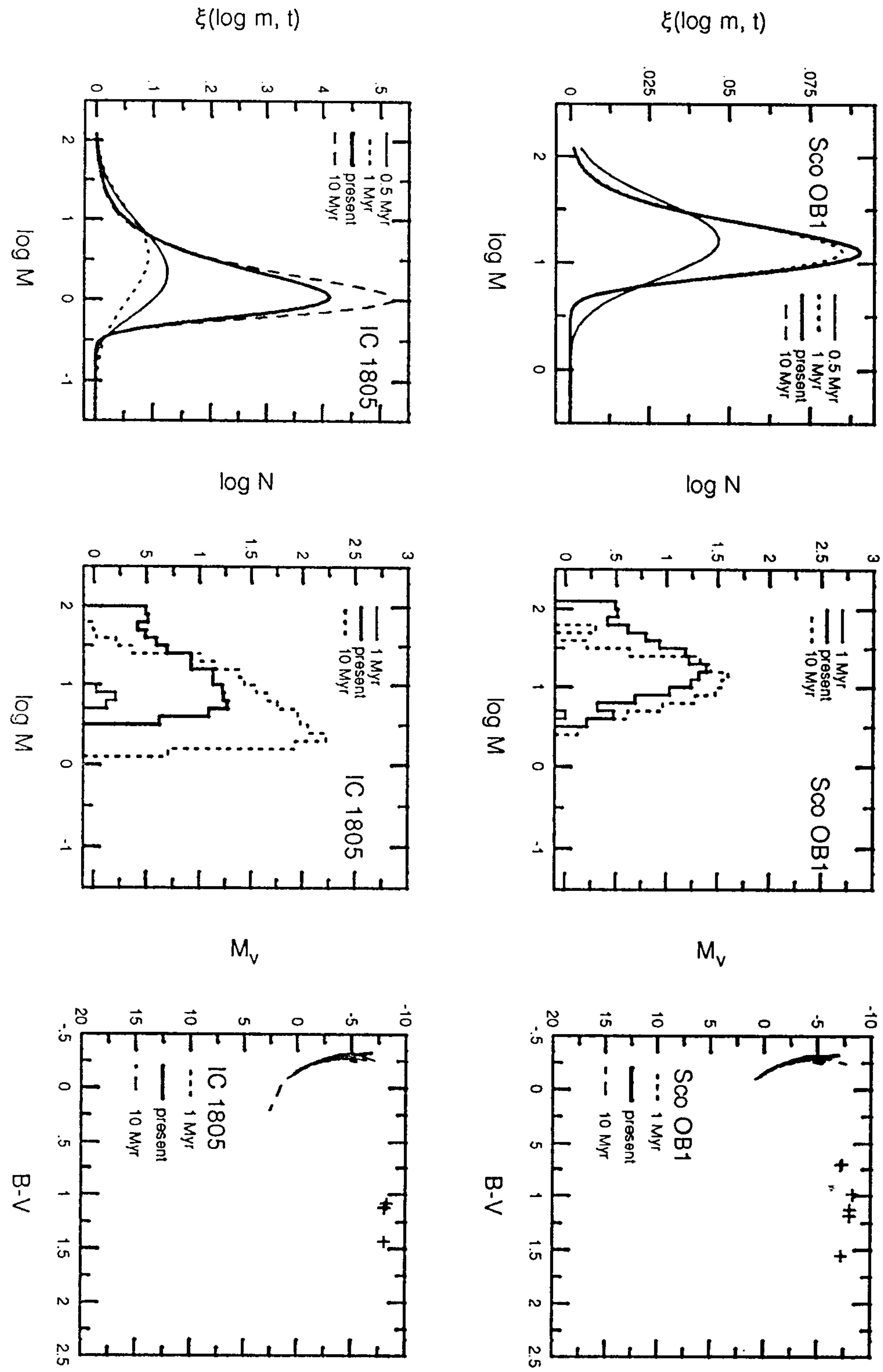

Fig. 5. Evolution of clusters. The C-M diagrams and mass functions are dependent of the time variation of IMF. The dependences of IMF, mass function and C-M diagrams are shown for different times.

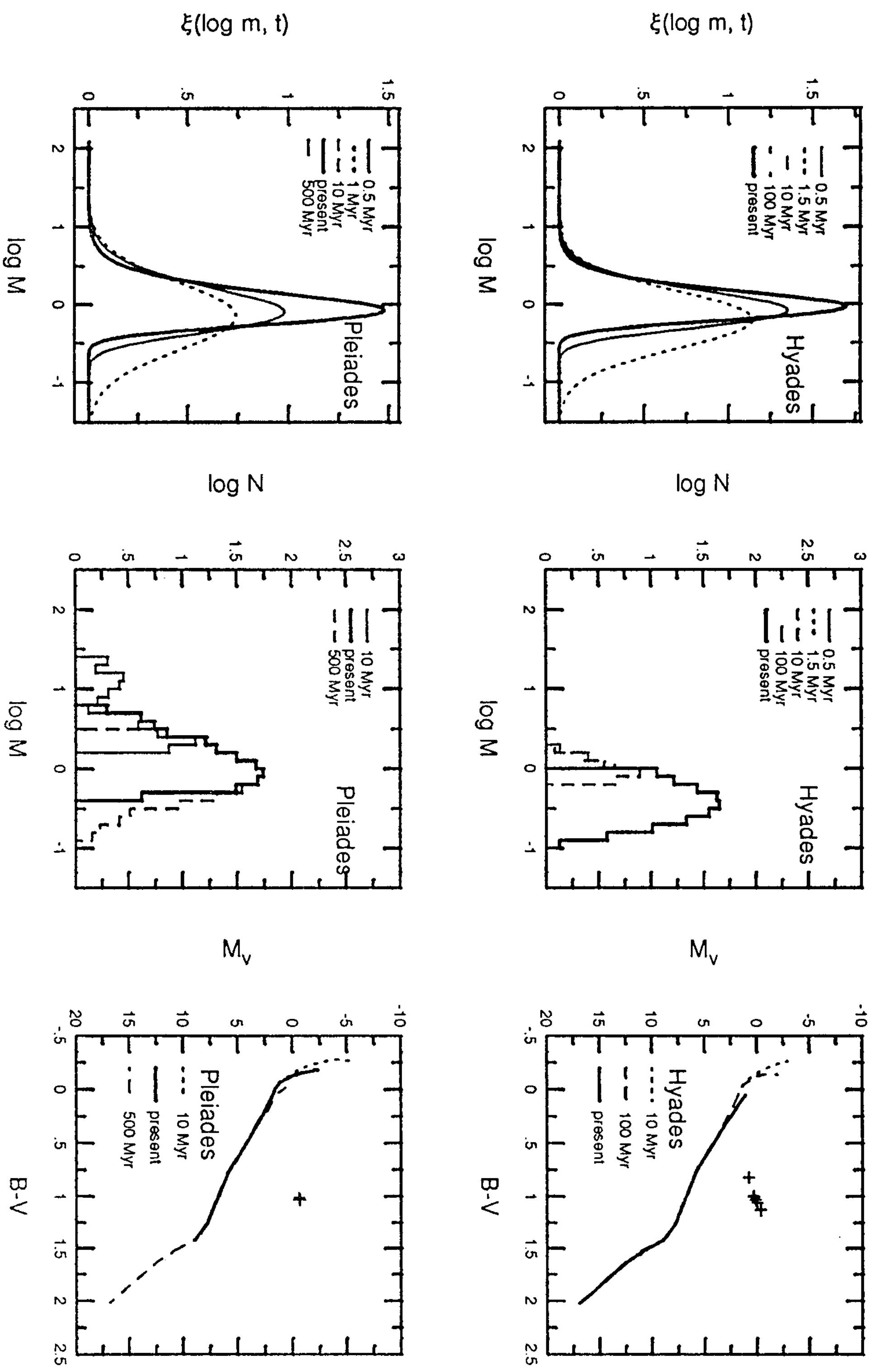

Fig. 5. Continued

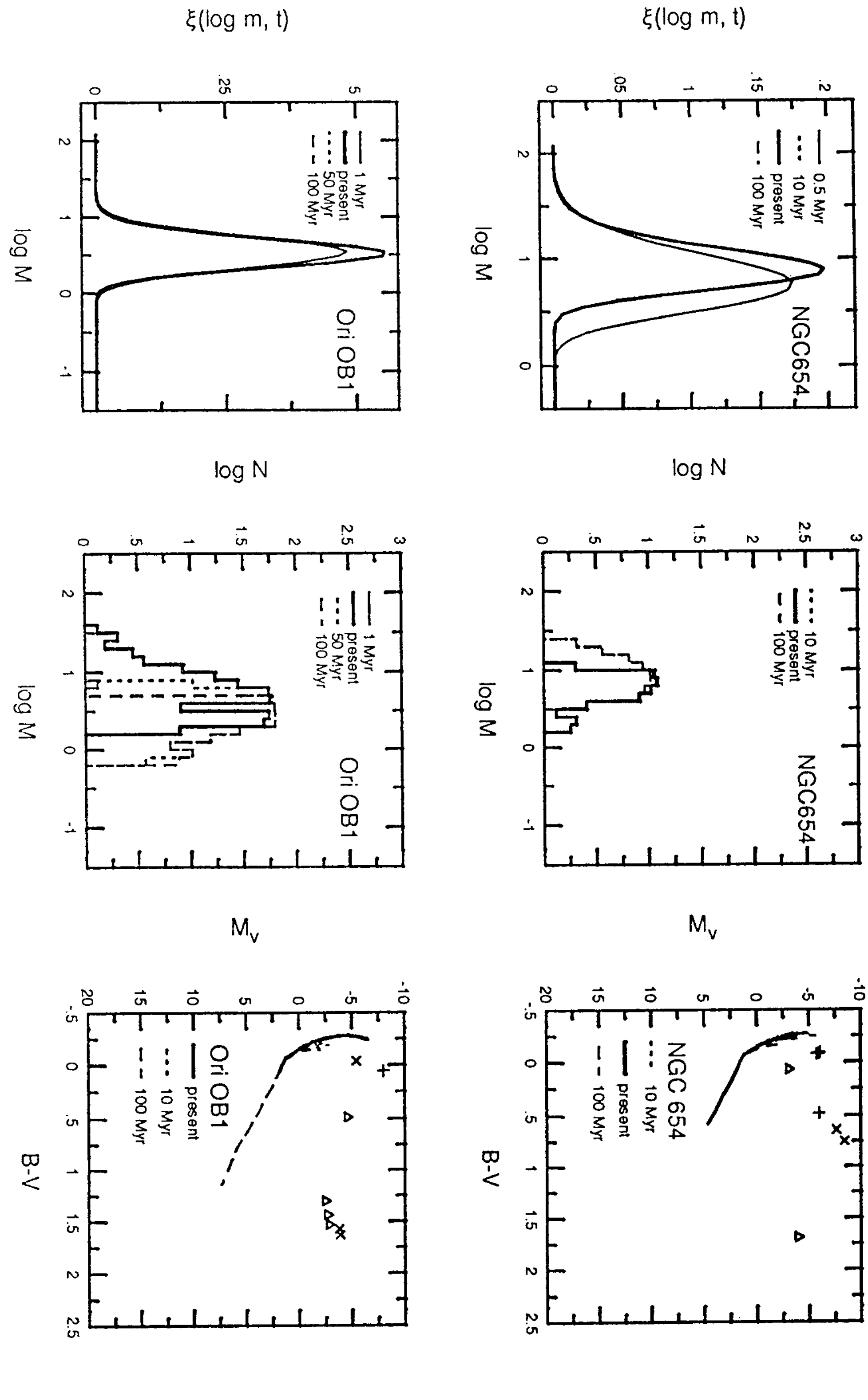

Fig. 5. Continued

Table 4. Open Clusters & Associations : Integrated Parameters

Cluster	(m−M)	E(B−V)	log t	I(M_v)	I(B−V)	I(U−B)	Reference
NGC 457	13.94	0.45	7.11	-7.28	-0.23	-0.64	24
				-7.61	0.06	-0.61	
NGC 581	13.91	0.39	7.45	-5.04	-0.16	-0.75	24
				-6.88	0.02	-0.61	
NGC 654	11.90	0.94	7.18	-6.33	-0.25	-0.90	33
				-8.28	0.25	-0.47	
NGC 1039	8.20	0.07	8.00	-2.94	-0.02	-0.24	1
NGC 2169	9.60	0.16	7.40	-4.71	-0.23	-0.86	31
NGC 2287	9.03	0.01	8.00	-4.01	-0.10	-0.37	9
				-4.78	0.20	-0.20	
NGC 2345	11.22	0.70	7.90	-4.55	-0.14	-0.51	25
				-5.65	0.16	-0.26	
NGC 2367	12.43	0.35	6.00	-4.28	-0.31	-0.99	39
NGC 2384	13.50	0.29	6.00	-3.67	-0.25	-0.91	39
				-5.11	-0.11	-1.02	
NGC 2421	12.85	0.47	7.40	-3.79	-0.28	-0.61	26
				-4.36	-0.26	-0.64	
NGC 2477	11.00	0.30	8.85	-1.82	0.23	0.05	15
				-2.84	0.62	0.33	
NGC 2571	10.49	0.10	7.35	-3.37	-0.14	-0.58	3
NGC 3293	12.94	0.32	7.40	-6.67	-0.21	-0.85	35
				-8.29	-0.16	-1.02	
NGC 3572	13.70	0.46	7.10	-6.06	-0.33	-1.00	27
				-6.89	-0.34	-1.11	
NGC 4103	12.00	0.30	7.35	-5.47	-0.18	-0.70	41
NGC 4609	10.60	0.36	7.56	-4.03	-0.15	-0.55	8
NGC 4755	12.62	0.38	6.85	-7.37	-0.12	-0.89	5
				-8.64	-0.08	-0.74	
NGC 5460	9.88	0.14	8.03	-3.86	-0.10	-0.18	2
NGC 5662	10.00	0.32	7.80	-3.93	-0.02	-0.35	16
				-4.38	0.30	-0.24	
NGC 6025	9.40	0.17	8.03	-3.46	-0.06	-0.26	7
				-4.38	-0.12	-0.49	
NGC 6231	11.60	0.44	6.50	-6.39	-0.28	-1.01	13
				-7.88	-0.31	-1.10	
NGC 6250	11.26	0.38	7.15	-5.32	-0.20	-0.75	28
NGC 6322	12.64	0.67	7.00	-6.19	-0.30	-0.53	28
NGC 6383	11.90	0.33	6.23	-6.35	-0.29	-1.07	11
NGC 6396	13.67	0.96	7.40	-4.89	-0.19	-0.64	28
				-5.08	-0.05	-0.60	
NGC 6475	7.08	0.06	8.16	-3.25	-0.03	-0.34	24
				-3.44	0.09	-0.29	
NGC 6604		0.97	6.60	-6.85	-0.37	-1.19	12
				-7.84	-0.27	-1.12	
NGC 6611	13.74	0.48	6.74	-8.68	-0.31	-1.19	32
				-8.73	-0.33	-1.13	
NGC 6633	7.50	0.17	8.68	-2.50	0.14	0.01	18
				-2.96	0.22	-0.06	
NGC 6823	11.81	0.78	6.54	-7.44	-0.26	-1.04	34
				-7.48	-0.12	-0.95	
NGC 6913	13.42	0.78	6.30	-7.21	-0.30	-0.83	21
				-7.30	-0.30	-0.87	

Table 4. Continued

Cluster	(m−M)	E(B−V)	log t	I(M_v)	I(B−V)	I(U−B)	Reference
NGC 7092	7.13	0.01	8.27	-2.56	0.02	-0.12	23
				-2.58	0.04	-0.12	
NGC 7790	14.36	0.52	7.46	-4.76	-0.12	-0.57	22
IC 1805	11.70	0.52-1.13	6.38	-8.29	-0.30	-1.09	20
				-8.51	-0.28	-1.09	
IC 4665	8.21	0.17	7.62	-3.58	-0.10	-0.47	24
				-3.51	0.10	-0.45	
Tr 1	11.64	0.52	7.42	-4.62	-0.19	-0.64	19
Tr 16	13.82	0.49	7.00	-8.67	-0.29	-1.12	10
Tr 22	12.85	0.56	8.04	-3.72	-0.08	-0.38	16
Tr 24	12.16	0.38	6.00	-7.07	-0.25	-0.71	17
				-9.78	-0.20	-0.87	
Tr 27	11.60	1.30	7.00	-7.06	-0.26	-0.96	29
				-8.42	0.06	-0.74	
Stock 16	12.90	0.49	6.60	-5.72	-0.27	-1.07	37
Mar 50	14.28	0.86	7.00	-5.48	-0.26	-0.92	36
				-5.84	-0.25	-0.94	
Pleiades	5.65	0.04	7.86	-4.52	-0.07	-0.30	24, 30
Hyades	3.30	0.00	8.88	-2.25	0.30	0.10	24, 38
Ori OB1	8.03	0.05	6.90	-7.28	-0.19	-1.08	40
Sco OB1	11.00	0.50	6.48	-8.56	-0.29	-	14
Col 121	9.00	0.03	6.18	-3.34	-0.24	-0.77	6
				-5.47	1.14	-0.10	

References of Table 4.

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the giant branch for young clusters($< 10^9$yr). Therefore, large scatters are produced in the relation including I(M_v) in the case of including giants as seen in Figure 3.

The present synthetic results for MS stars in Hyades and Pleiades are well consistent with those (dashed) derived by Pandey *et al.*(1989) who used the age-dependent IMF and with those (dotted) given by Barbaro and Bertelli(1977) who used a simple IMF($\propto m^{-2.35}$). Particularly in the latter case, the results derived by using two different evolutionary models (Tables 1 and 3 in Barbaro and Bertelli's paper) are combined in Figure 4. As shown by Pandey *et al.*(1989), the other results by Dixon *et al.*(1972) and Searle *et al.*(1973) are quite different from the present model. The above agreement of evolutionary sequences in spite of different IMFs and stellar evolutionary models implies for the clusters older than $\sim 10^7$yr that the evolution of total integrated photometric parameters are not much sensitive to an IMF because these parameters are mostly determined by massive bright stars in each cluster from which the usual power-law IMF is derived. However, for very young clusters($<\sim 10^7$yr), the early photometric sequence is very sensitive to an adopted IMF in which noncoeval formation of stars is assumed. As compared with previous results, the present results explain reasonably well the very early evolutionary sequences in Figure 3 for MS stars.

That is, the steep increasing of total integrated magnitude and colors with time for very young synthetic clusters is shown during the very early evolutionary period($< 7 \times 10^6$yr), and this trend fits fairly well the observed integrated parameters of the very young clusters in Table 4.

The importance of IMF particularly for very young clusters and of a large minimum mass and turnover mass can be seen in the time-dependent IMF in Figure 5 where IMF, mass function(MF) and C-M diagrams are compared. For instance, the time-dependent IMFs of IC 1805 and Sco OB1 show the quite different variation with time, yielding the different MFs. That is, in these two IMFs, much massive stars as well as low mass stars are formed at the early period of evolution, extending to more than $100m_\odot$. But the maximum mass formed at the early period is more massive in Sco OB1($\sim 16m_\odot$) than in IC 1805($\sim 1.5m_\odot$). These different IMFs cause for IC 1805 to have a wider mass spectrum($120m_\odot \sim 0.13m_\odot$) including many low mass pre-MS stars than for Sco OB1.

On the other hand, Hyades and Pleiades have very similar time-dependent IMF which shows a large time-variation in the formation of low mass stars, having the maximum mass frequency at $\sim 1m_\odot$ and the suppressed formation of massive stars.

The IMF of Orion OB1 is limited within a relatively narrow mass spectrum and so the mass function of total stars born up to now can have a nearly symmetric distribution, having many pre-MS stars as seen in Figure 2.

In NGC 654, the IMF becomes time-independent after 0.5×10^6yr and hence the formation of low mass stars is suppressed at the very early period of evolution. This result can be seen also in Figure 2 where there are no lower mass stars than $1.5m_\odot$. However, the many massive stars form at the early period and so about 70% of the total mass of the cluster remains now as invisible remnant after the completion of the evolution.

V. DISCUSSION AND SUMMARY

The general agreements between the computed and observed results seen in Figure 1 and 3 suggest that the clusters older than $\sim 10^7$yr have a general common IMF similar to that of Pleiades or Hyades although the detailed IMF is slightly

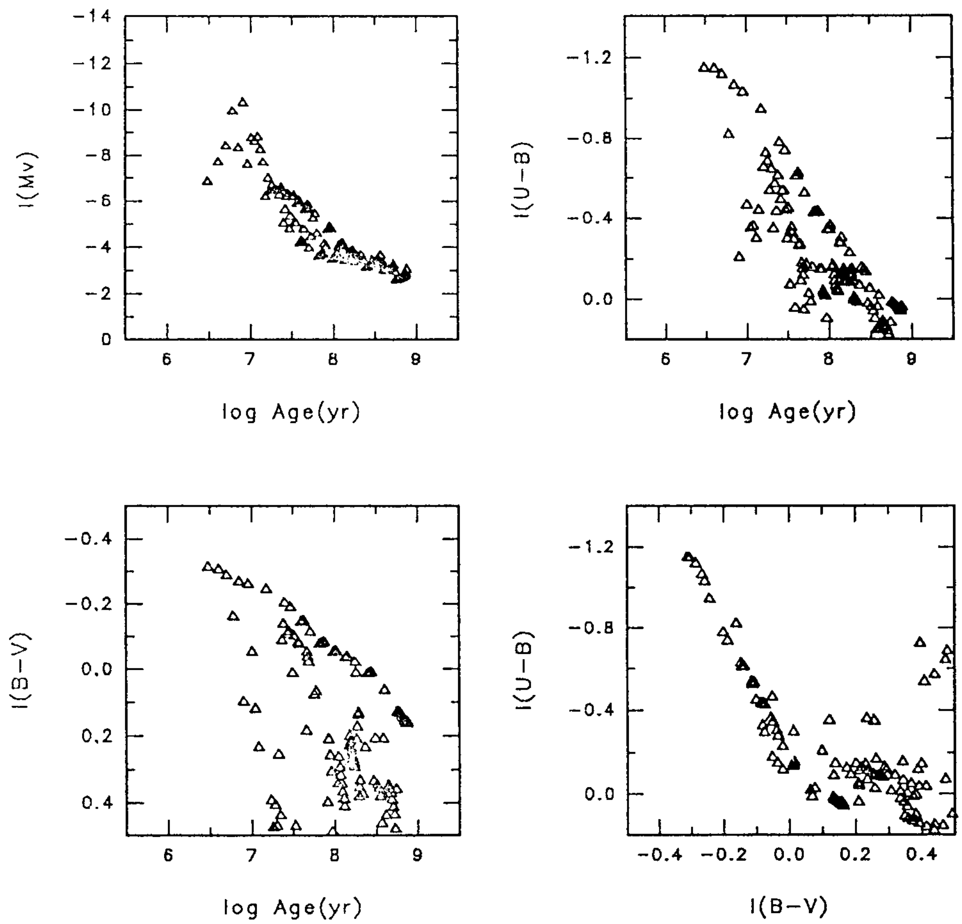

Fig. 6. The integrated photometric evolution of all stars in Hyades. The large scatters in each figure are due to some bright or red giant stars at the relevant evolutionary time.

different with clusters because of the differences in metallicity, temperature, turbulence and cloud mass, etc. (Flecker 1982, Silk 1979, Larson 1981, Zinnecker 1984, Yoshii and Saio 1985, Field and Janes 1993).

For very young clusters (age $<\sim 10^7$yr), the evolution of integrated parameters is very sensitive to an adopted IMF which controls the number of pre-MS stars, which in turn control the photometric evolution at the later stage of evolution. In the simple Salpeter(1955) IMF, only bright stars are taken into account and the faint stars less massive than the turnover mass in the mass function are not included . Therefore, their IMF cannot be applicable to the evolution of very young clusters when we consider the faint MS stars in the PDMF and the photometric evolution of the clusters.

When we consider the reasonable agreement of the observed photometric parameters with the evolutionary sequences of very young synthetic clusters in the present study, the time-dependent IMF(Lee and Chun 1986) and noncoeval formation of stars(Herbig 1966, Iben and Talbot 1966, Guetter and Vrba 1989) seem to be reasonable at least for the evolution of young clusters. For all open clusters and associations, it can be concluded that there is a general form of time-dependent IMF including the noncoeval formation and its detailed functional form is slightly changed with various environmental condition as indicated above.

To include giants in open clusters, the photometric evolutionary sequences for all stars in a cluster are determined by assuming a continous distribution of giant stars along each isochrone in the C-M and C-C diagrams. This assumption can be applicable for very old clusters with well defined giant branch. For instance, the photometric evolution of all stars in Hyades from the beginning to the age of 10^9 yr is shown in Figure 6, where large scatters of integrated parameters in each sequence are due to the appearance of a few bright or red giant stars at the relevant evolutionary phase. Therefore, it can be said that the photometric evolution of open clusters and associations is more meaningful for MS stars in the study of their IMF, SFR and integrated properties.

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