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LUMINOSITY FUNCTIONS OF 12 OPEN CLUSTERS WITH WELL ESTABLISHED MEMBERSHIP*

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ABSTRACT

The luminosity functions of 12 open clusters are derived for which their membership and the colors of their individual stars have been established by detailed proper motion study and high quality photometric work. The resulting luminosity functions of these clusters are presented and discussed.

I. INTRODUCTION

The advance in observational technique has given us a possibility to explore how our Galaxy was born and evolved chemically and dynamically to reach the present stage. In studying the chemical evolution of our Galaxy the distribution of stellar masses at birth so-called "initial mass function" plays a critical role in chemically enriching the Galaxy. Numerous attempts have been made to derive the luminosity functions of field stars (in the solar neighborhood) and open clusters as well by a number of workers (e.g., Luyten 1938, 1968; van den Bergh 1957, 1961; van den Bergh and Sher 1960; Wanner 1972; Wielen 1974; Taff 1974; Yu 1976).

There seems to be a lack of concensus on the luminosity functions derived by various workers. Van den Bergh (1961), for example mentioned that the luminosity functions of open clusters contain more brighter and fewer fainter stars than the general stellar population in the vicinity of the Sun. Luyten (1968) noted from his luminosity function for field stars a marked deficiency in fainter field stars with $M_B \simeq 16$. The apparent diversity of the derived luminosity functions of open clusters from various workers could be due to the incompleteness of observations resulting from practical inability of including all the faintest stars at plate limits and some contaminations by field stars in their clusters under investigations. However, we are not sure at present whether the diversity of the observed luminosity functions is of intrinsic origin. If that is the case, we may expect some significant variations in the stellar mass spectrum and star formation processes.

Open clusters have a distinct advantage over the field stars for determination of stellar mass spectrum because all the members are considered to be born at about the same time, so the mass spectrum below the main sequence turn-off, in principle, provides us with the initial mass function. Accordingly, an extensive literature search has been carried out to select the open clusters whose membership and member's color had been well established by detailed proper motion study and high quality photometric work.

The purpose of the present work is to derive the luminosity functions of carefully selected 12 open clusters which meet the imposed requirements. In section II we present the observational data of the selected clusters and the reduction procedures to obtain the luminosity functions.

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The resulting luminosity functions are presented in section III. Finally, a brief summary and conclusions are given in section IV.

II. OBSERVATIONAL DATA AND REDUCTION PROCEDURES

The major properties of our selected 12 clusters are listed in Table 1, where N in the fifth column refers to the number of member stars whose membership probability exceeds 50% and 'sp' in the ninth column means the earliest spectral type of stars in a given cluster. The calculations of the membership probability made by the various workers (see the 11th column of the table) were based on the method of Vasilevskis (1962). The source references of the observational data used in the present study are listed in the last three columns of the table. These data are considered to be of high quality and best available at the present time. In Table 2, we also listed the suggested ages of these clusters determined by the theoretical evolutionary tracks by Iben (1965) and the observational limiting (due to proper motion study) apparent visual, absolute visual and bolometric magnitudes for these clusters.

In the present analysis the total to selective extinction ratio R has been taken to be 3.2 as an average (Turner 1976; Moffat *et al.* 1976) for all the clusters. In evaluating the bolometric magnitude we have used the bolometric corrections given by Flower (1977) for hot main sequence stars (O8~F4; $-0.33<(B-V)_0<0.43$), giant stars (O6~K8; $-0.33<(B-V)_0<1.61$) and supergiant stars (O5.5~M4; $-0.03<(B-V)_0<1.8$) and by Johnson (1966) for cool main sequence stars (F5~M5; $0.37<(B-V)_0<1.62$). A proper adjustment has been made to relate Flower's bolometric corrections to Johnson's by reducing the Johnson's values by $0^m.07$ Because of strong dependence of the

Table 1 BASIC DATA FOR 12 OPEN CLUSTERS

Clusters	α (1950)	δ (1950)	Diameter (pc)	N (Member ship)	Distance (pc)	(m-M)	E(B-V)	sp
NGC 6611	$18^h16^m.0$	−13°38′	3.9	43	1571	13.35	0.74	o
IC 1805	$02^h28^m.9$	61°14′	14.0	141	2218	14.35	0.82	o
NGC 6530	$18^h01^m.7$	−24°20′	6.4	91	1780	12.37	0.35	o
NGC 6823	$19^h41^m.0$	23°11′	4.9	40	2228	14.46	0.85	o
NGC 2264	$06^h38^m.3$	9°56′	6.2	140	709	9.48	0.07	
NGC 654	$01^h40^m.6$	61°38′	14.5	60	2400	14.62	0.85	b0-b1
NGC 2168	$06^h05^m.8$	24°21′	7.3	562	870	10.43	0.23	b5
NGC 6705	$18^h48^m.4$	− 6°20′	5.9	513	1700	12.37	0.38	b8
NGC 6633	$18^h25^m.3$	6°32′	2.4	79	360	8.13	0.11	a0
Hyades	$04^h17^m.5$	15°31′	4.7	229	43	3.17	0.00	a2
NGC 2420	$07^h35^m.5$	21°41′	5.0	197	2885	12.30	0.00	f
NGC 188	$00^h39^m.4$	85°04′	6.3	150	1480	11.14	0.09	f

Clusters	Sources of References		
	Distance & E(B-V)	Proper motions	UBV Photometry
NGC 6611	Becker *et al.* (1971)	Kamp (1974)	Kamp (1974); Pg, Pe
IC 1805	Becker *et al.* (1971)	Sanders (1972)	Vasilevskis *et al.*; Pg (1965b)
NGC 6530	Altena (1972)	Altena (1972)	Sager *et al.* (1978); Pe
NGC 6823	Becker *et al.* (1971)	Erikson (1971)	Erickson (1971); Pg, Pe
NGC 2264	Becker *et al.* (1971)	Vasilevskis *et al.* (1965a)	Vasilevskis *et al.* (1965a); Pe
NGC 654	Stone (1977)	Stone (1977)	Stone (1980); Pg
NGC 2168	Cudworth (1971)		Cudworth (1971); Pg, Pe
NGC 6705	Becker *et al.* (1971)	McNamara *et al.* (1977)	Solomon *et al.* (1980); Pg
NGC 6933	Mermilliod (1980)	Sanders (1973)	Cudworth (1976); Pg
Hyades	Mermilliod (1980)	Pel *et al.* (1975)	Upgren *et al.* (1977); Pe
		Bueren (1952)	Pel et al. (1975) Pg, Pe
NGC 2420	Becker *et al.* (1971)	Cannon *et al.* (1970)	Cannon *et al.* (1970); Pg
NGC 188	Eggen *et al.* (1969)	Upgren *et al.* (1972)	Upgren *et al.* (1972); Pe

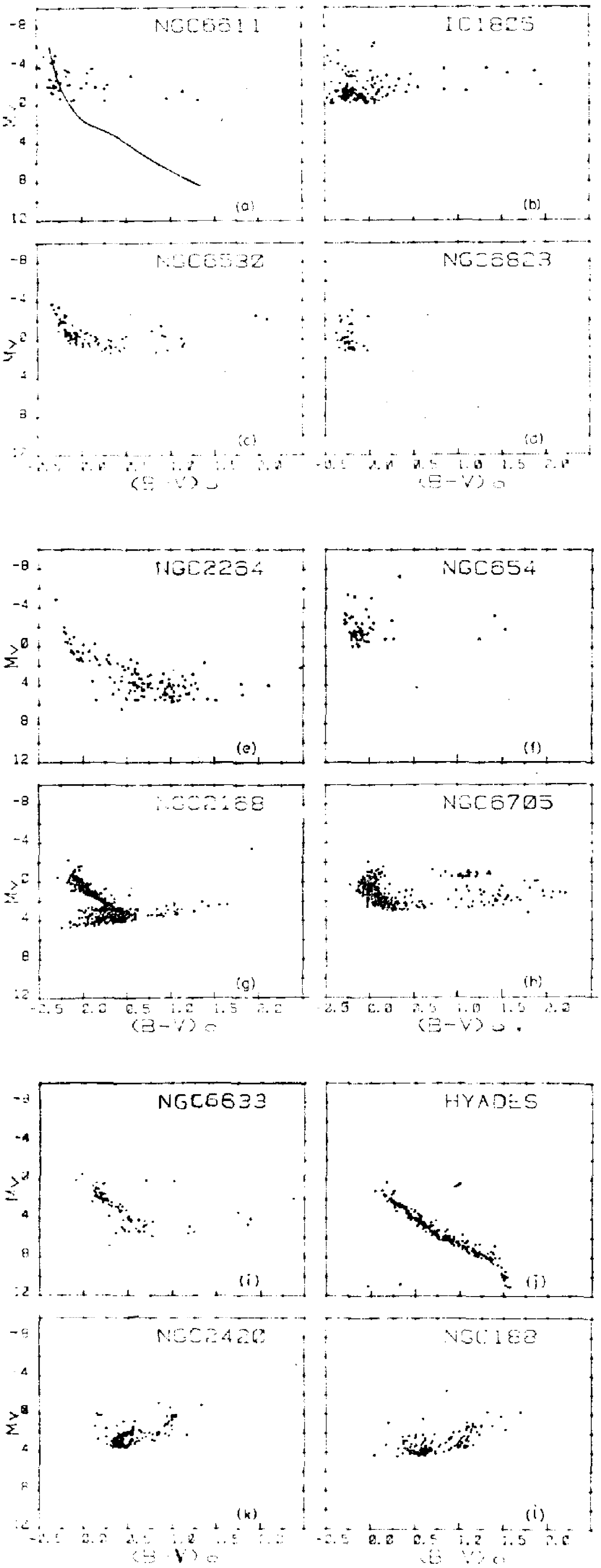

Fig. 1.-Herzsprung-Russell diagram of open clusters.

bolometric corrections on the intrinsic color in the region of $(B-V)_0<0.0$ and $(B-V)_0>1.5$, a small error in the observed intrinsic color $(B-V)_0$ may cause a considerable uncertainty (e.g., $\Delta(BC)\simeq 0^m.15$ for $\Delta(B-V)_0=0^m.01$) in the estimated bolometric corrections, particularly for the very hot and very cool stars.

In correcting the interstellar reddening we have simply used to suggested $E(B-V)$ values by the workers listed in the 10th column of Table 1, although our adopted values may differ somewhat from others. In order to differentiate the main sequence stars from the member stars, their absolute visual magnitude has been plotted against the $(B-V)_0$ color as shown in Figure 1, where the solid line in NGC 6611 is the ZAMS line given by Blaauw (1963). In the present study we have treated as main sequence stars, those member stars which fall within a span of $0^m.55$ in $(B-V)_0$ from the mean of the observed main sequence band at a given M_v. In addition, those stars which reside in the region of the bluer side of the main sequence near the observational limit are also treated as main sequence stars, because we interpreted that their shift towards the bluer side of the main sequence is due to the photographic effects near the plate limit.

The first six clusters in the table, NGC 6611, IC 1805, NGC 6530, NGC 6823, NGC 2264 and NGC 654, are very young clusters whose ages are less than 10^7 years. A large fraction of their members are likely to be in the contracting pre-main sequence stage. In particular, NGC 6611 the youngest of all seems to be made of mostly the pre-main sequence stars. In deriving the luminosity functions of these young clusters we face a serious problem in making bolometric corrections and using constant color excess because a proper bolometric corrections for the pre-main sequence stars are not available and their color excess seems to vary within the cluster. In the present investigation we have simply used the main sequence's bolometric corrections for them.

The next four clusters, NGC 2168, NGC 6705, NGC 6633 and Hyades, are our middle aged group whose ages are less than 10^9 years. In the present study 81 newly determined fainter member stars of Hyades (Pels *et al.* 1975) have been included in the analysis. We also noted that fainter parts of the main sequence of these clusters except Hyades are not detected due to observational limit (proper motion study).

Table 2 CLUSTER'S AGES AND THEIR OBSERVATIONAL LIMITING MAGNITUDES

Clusters	Age(yrs)	Magnitudes at Observational Limit			References for Cluster's Age
		V	M_v	M_{bol}	
NGC 6611	2×10^6	13.3	−0.5	−0.2	Walker (1961)
IC 1805	2×10^6	14.3	−0.1	−0.2	Vasilevskis (1965)
NGC 6530	2×10^6	13.8	1.4	1.4	Altena (1972)
NGC 6823	3×10^6	13.2	1.2	0.9	Johnson *et al.* (1956)
NGC 2264	6×10^6	15.3	5.8	5.3	Allen (1976)
NGC 654	$<10^7$	14.1	−0.5	−0.7	Wielen (1971)
NGC 2168	1×10^8	14.8	4.5	4.4	Mermilliod (1981)
NGC 6705	2×10^8	15.4	3.0	3.0	Mermilliod (1981)
NGC 6633	6.6×10^8	13.7	5.8	5.7	Mermilliod (1981)
Hyades	6.6×10^8	14.2	1.1	10.8	Mermilliod (1981)
NGC 2420	4×10^9	15.8	3.5	3.5	Patenaude (1978)
NGC 188	8×10^9	15.6	4.4	4.4	Patenaude (1978)

NGC 2168 and NGC 6705 are few of the richest open clusters with well populated main sequence. Furthermore, NGC ·2168 and Hyades have relatively smaller color excess. Therefore, they seem to be the best candidates for studying the initial mass spectrum of open clusters. The final two clusters, NGC 2420 and NGC 188, are extremely old and their main sequences are not also detected due to the observational limit (proper motion study).

III. DERIVED LUMINOSITY FUNCTIONS

The number of stars (including the non-main sequence stars) falling within a magnitude span of $M_{bol}\pm1/2$ for our selected 12 open clusters is tabulated in Table 3, and the resulting luminosity functions are plotted in Figure 2. The luminosity functions in the figure are normalized in such a way that the peak becomes unity, and we arranged them in the order of increasing age.

As seen from Figure 2, the overall characteristics of our derived luminosity functions are similar to each other in the sense that they increase with the value of M_{bol} until reaching a certain magnitude and then decline rapidly beyond the peak magnitude. According to our examinations the rapid decline seems to be mostly responsible for the observational limitations set by the proper motion study of the individual stars. Therefore, it is hard to say how the derived luminosity functions will behave beyond this point.

It is also interesting to note that there is a definite tendency that the magnitude at which

Table 3 FREQUENCY DISTRIBUTION OF LUMINOSITY FUNCTIONS OF 12 OPEN CLUSTERS

Clusters	Absolute Bolometric Magnitudes (M_{bol})																					
	−10	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9	10	11
NGC 6611			3	1	5	13	3	5	7	4	2											
IC 1805		1	0	6	6	13	25	33	27	25	5											
NGC 6530				4	5	1	9	3	12	23	19	15										
NGC 6823					1	4	2	10	11	9	2	1										
NGC 2264			1	0	1	1	2	1	5	4	9	13	12	20	43	27	1					
NGC 654			1	2	3	5	5	17	16	11												
NGC 2168				1	0	0	1	1	12	21	36	53										
NGC 6705		1	0	0	0	1	3	5	9	56	99	182	38									
NGC 6633										1	7	12	18	11	13	16	1					
Hyades											5	8	16	27	32	34	54	40	7	4		2
NGC 2420									1	2	15	12	71	95	1							
NGC 188								2	0	2	5	12	20	36	73							

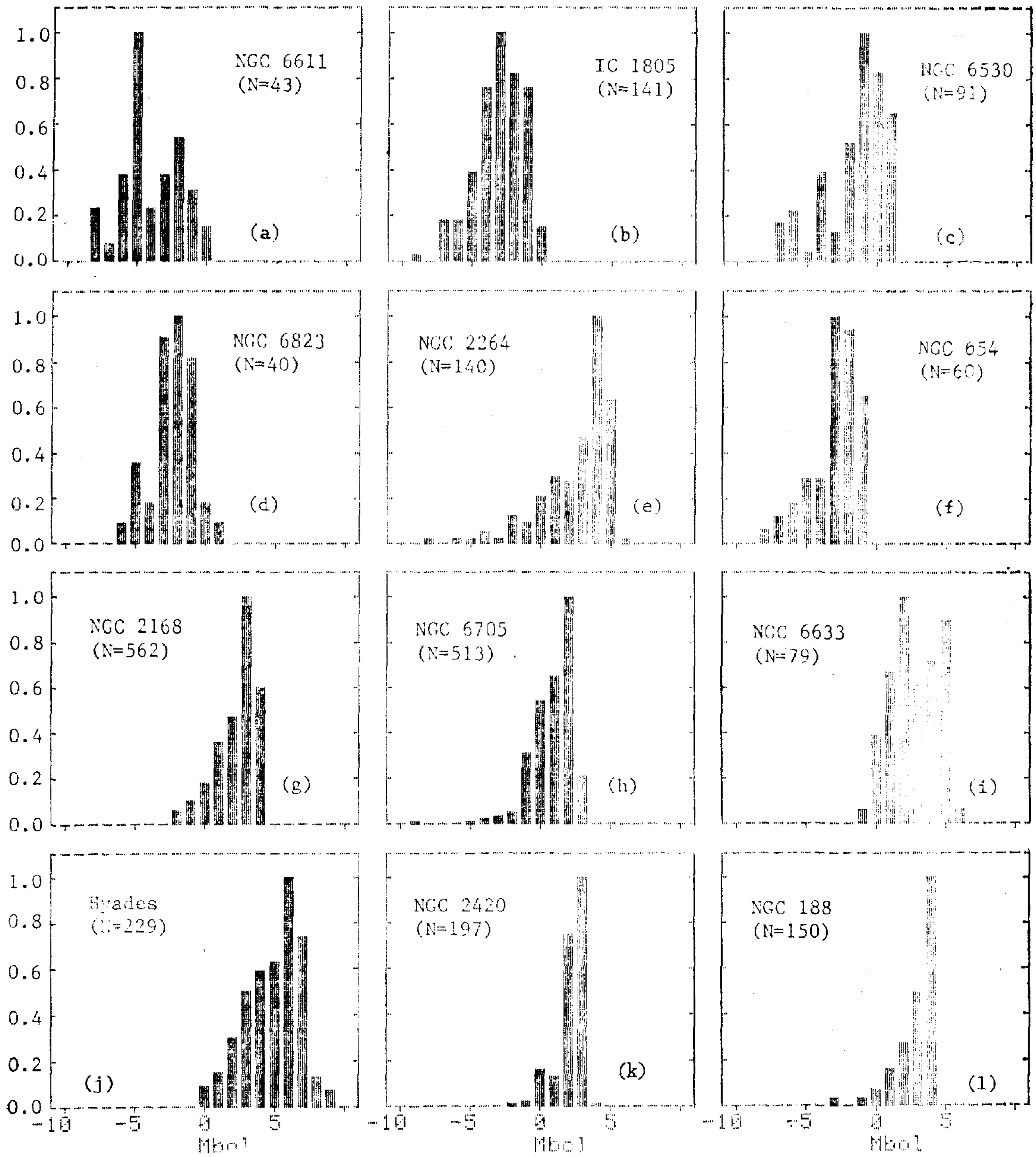

Fig. 2. -The derived luminosity functions of 12 open clusters.

the luminosity function becomes maximum increases with the cluster's age. This is consistent with the view point of dynamical evolution of clusters (c.f., King 1966). For the young clusters, the derived luminosity functions are somewhat irregular; particularly, it is true for NGC 6611 the youngest open cluster. The apparent irregulaity found in the derived luminosity functions of the young clusters appears to be due to the uncertainty in M_{bol} introduced by our use of constant color excess in the reddening corrections and the application of the values of the main sequence's bolometric corrections to the pre-main sequence stars.

It is of interst to look into the derived luminosity function of Hyades cluster, because

Hyades is by far the nearest galactic cluster with a considerable membership. Close examinations of the Hyades luminosity function tell us that it is distinctly different from the luminosity function of the field stars in the solar neighborhood. For example, the peak of the Hyades luminosity function occurs at $M_v \simeq 6^m$, while the peak of the derived luminosity functions of field stars determined by Luyten (1968), Wielen (1974) and Wanner (1972) for example, ranges from $M_v=12^m$ to $M_v=15^m$. It seems very unlikely that the original Hyades luminosity function can be modified by that much due to the escape of the least massive member stars from the cluster.

IV. A BRIEF SUMMARY AND CONCLUSIONS

We have derived the luminosity functions of 12 open clusters whose membership and member's color have been well established by detailed proper motion study and high quality photometric observations. The derived luminostiy functions are presented and discussed.

Close examinations of our derived luminosity function of Hyades show that some significant differences exist between the Hyades and field star's luminosity functions. One of the richest cluster NGC 2168 appears to be another good candidate for studying the initial mass function for open clusters, since it has a well populated main sequence.

It is found that the contaminations by non-main sequence stars would pose a serious problem in deriving cluster's initial mass spectrum and that the uncertainty in the bolometric corrections caused by the non-uniformity of the internal reddening within the cluster and by the application of the main sequence's bolometric corrections for the pre-main sequence stars is an acute problem, especially for the young clusters. More careful analyses are needed and a lot of work remains to be done before we come up with any meaningful results.

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