THE ASTROPHYSICAL JOURNAL, 299:211–218, 1985 December 1

AGE CALIBRATION AND AGE DISTRIBUTION FOR RICH STAR CLUSTERS IN THE LARGE MAGELLANIC CLOUD

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Received 1985 March 1; accepted 1985 June 4

ABSTRACT

We present an empirical relation for estimating the ages of rich star clusters in the Large Magellanic Cloud (LMC), to within a factor of about 2, from their integrated *UBV* colors. The calibration is based on published ages for 58 LMC clusters derived from main-sequence photometry, integrated spectra, or the extent of the asymptotic giant branches. Using stellar population models, we isolate a sample of LMC clusters more massive than about 10^4 $M_\odot$, which we correct for incompleteness as a function of magnitude. We then determine an unbiased age distribution for these clusters. The number of clusters decreases with increasing age in a manner that is qualitatively similar to the age distribution for the open clusters in our Galaxy. The LMC age distribution is, however, flatter, and the median age of the clusters is greater. If the formation rate has been approximately constant over the history of the two galaxies, then our age distribution implies that clusters are disrupted more slowly in the LMC. Our results contain no evidence for bursts in the formation of clusters, although fluctuations on small time scales and slow variations over the lifetime of the LMC cannot be ruled out.

Subject headings: clusters: globular — clusters: open — galaxies: Magellanic Clouds — stars: evolution — stars: formation

I. INTRODUCTION

The rich star clusters in the Magellanic Clouds have long been useful in studies of stellar evolution, but their role in galactic evolution has remained elusive. They are sometimes referred to as "globular clusters" on the basis of their large masses and general appearance. In other respects, however, the clusters in the Magellanic Clouds resemble the open clusters in our Galaxy. Their ages range from 10^6–10^{10} yr and, at least in the LMC, most of them are members of a disk population (Freeman, Illingworth, and Oemler 1983). Moreover, the luminosity function for the clusters in the LMC rises monotonically toward faint magnitudes (Elson and Fall 1985). Such properties suggest the following questions: What is the history of formation and disruption of star clusters in the Magellanic Clouds? Is there a distinct subset of clusters that corresponds to the globular clusters in our Galaxy? We address these questions by deriving an age distribution for rich star clusters in the LMC.

In § II we present an empirical relation between the integrated *UBV* colors of the LMC clusters and their ages, derived from main-sequence turnoffs and other methods of dating. This relation allows us to estimate the ages of a large number of clusters from data available in the literature. In § III we use stellar population models to isolate an approximately mass limited sample of LMC clusters. This is corrected for incompleteness at faint magnitudes, using the luminosity function for a representative sample of clusters. The age distribution is presented in § IV. Our results differ from those of Mould and Aaronson (1982), who analyzed a smaller sample with different selection criteria and age estimates. We also compare the age distribution for the LMC clusters with that derived by Wielen (1971) for open clusters in our Galaxy and examine the dependence on richness using more recent compilations of data on open clusters. In § V we discuss the implications of our results for the history of the formation and disruption of clusters in the LMC.

II. AGE CALIBRATION

Searle, Wilkinson, and Bagnuolo (1980, hereafter SWB) have classified the rich clusters in the Magellanic Clouds into seven types, on the basis of two reddening-free parameters derived from integrated *ugvr* photometry. The SWB types form a one-dimensional sequence, which Searle *et al.* interpret in terms of increasing age and decreasing metal abundance. An essentially equivalent sequence appears in a plot of $U-B$ against $B-V$ (Frenk and Fall 1982; Freeman, Illingworth, and Oemler 1983). The availability of published *UBV* photometry more than triples the number of clusters that can be assigned SWB types, although not in a manner that is manifestly reddening-free. However, reddening in the Clouds is small; a typical value for the clusters is $E_{B-V} \approx 0.1$, and much of this is the result of absorption within our Galaxy (Sandage and Tammann 1974; Burstein and Heiles 1982). Apart from the clusters younger than a few times 10^7 yr, the deviations from the mean E_{B-V} seldom exceed 0.1 (van den Bergh and Hagen 1968). For many purposes, the advantages of a larger sample outweigh the small uncertainties caused by reddening.

There have been several attempts to assign ages to the SWB classes but often with poor agreement among the results (Cohen 1982; Frenk and Fall 1982; Mould and Aaronson 1982; Rabin 1982; Hodge 1983). For example, Hodge finds a spread in the ages derived from main-sequence turnoffs of about an order of magnitude at each SWB type, and that most of these ages are much smaller than the upper limits derived by Mould and Aaronson from carbon stars on the asymptotic giant branches. Our calibration is based on a more finely partitioned version of the SWB sequence, a larger sample of clusters, and several new age determinations.

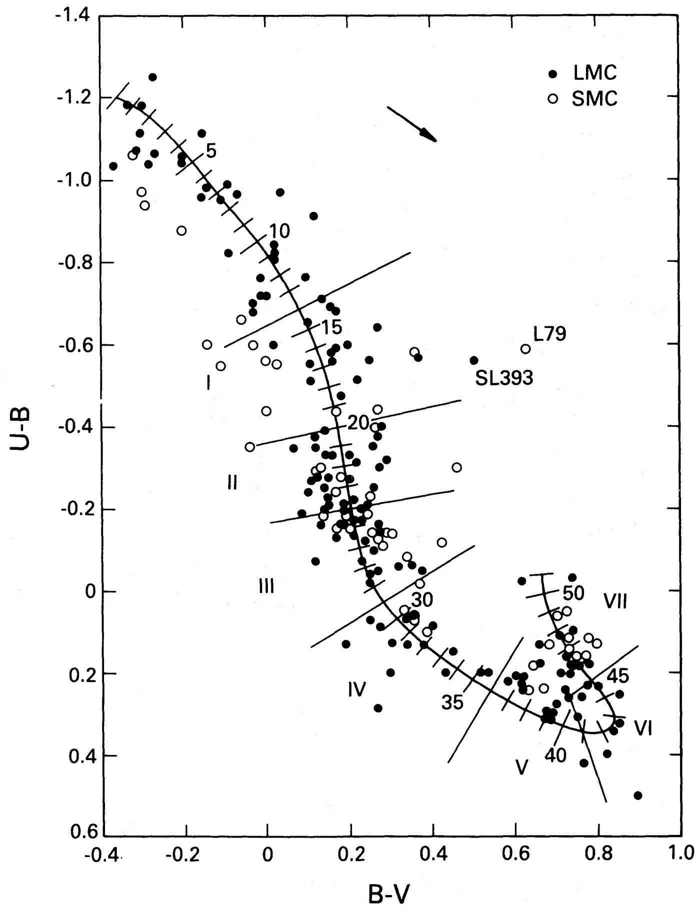

FIG. 1.—Two-color diagram for clusters in the LMC (*filled circles*) and SMC (*open circles*). The values of $U-B$ and $B-V$ are from van den Bergh's (1981) compilation of photoelectric data, except for NGC 2257 (Elson and Freeman 1985). The solid curve with tick marks defines the age parameter s, and the large bars indicate the approximate boundaries of SWB types I–VII. The two labeled points are considered outliers, and these clusters are not assigned s values. The vector indicates a normal reddening law with $E_{B-V} = 0.1$.

In Figure 1, we have plotted $U-B$ against $B-V$ for all the clusters with complete *UBV* data in van den Bergh's (1981) compilation of photoelectric data. Additional photometry for the very old cluster NGC 2257 was taken from Elson and Freeman (1985). We have drawn the smooth curve in Figure 1 along the sequence of LMC clusters to define a parameter s, analogous to the SWB types. The scatter about this curve (about ± 0.1 mag) is only slightly larger than would be expected from the photometric errors alone. We have divided the sequence into 51 intervals of equal length and have assigned a value of s to each cluster by projecting it normally onto the curve. These are listed in Tables 1 and 2 except for the two outlying clusters labeled in Figure 1. From a comparison with the SWB types assigned by Searle, Wilkinson, and Bagnuolo (1980), we find that 90% of the LMC clusters and 70% of the SMC clusters are classified correctly when plotted in the ($U-B$, $B-V$)-plane. This is true even in the crucial "hook" region with $s > 35$.

Figure 2 shows the logarithm of the age τ plotted against s for the clusters in Tables 1 and 2 that have been dated by the following methods: (*a*) Main-sequence turnoffs (33 clusters in the LMC and 14 in the SMC). Hodge (1983) compiled all the color-magnitude diagrams available at the time and compared them with isochrones from Schlesinger (1969), Stothers (1972), and Brunish (1981). We have adopted his age estimates, excluding upper and lower limits, unless they have been superseded by more recent work. The ages of NGC 1831, 1856, 2134, and 2162 and L8 (= K3) and L113 have been taken respectively from Hodge (1984), Hodge and Lee (1984), Hodge and Schommer (1984), Schommer, Olszewski, and Aaronson (1984), Rich, Da Costa, and Mould (1984), and Mould, Da Costa, and Crawford (1984). (*b*) Integrated spectra (16 clusters in the LMC and none in the SMC). Searle (1984) has assigned characteristic ages to SWB types V, VI, and VII, from the average equivalent widths of the Balmer and metallic lines of clusters of each type. The calibration of this method relies on synthetic spectra from model stellar populations and comparison with the observed spectra of clusters in our Galaxy with known ages and metallicities. (*c*) Carbon stars (nine clusters in the LMC and two in the SMC). Mould and Aaronson (1982) have estimated the ages of clusters from the infrared colors of stars near the tips of the asymptotic giant branches. We have used only their assigned ages "t_f," and not their upper limits. Unfortunately, none of the clusters has been dated by more than one of these methods. Figure 2 suggests, however, that the relation between $\log \tau$ and s is approximately linear, and that there are no major discrepancies between the methods.

An unweighted least squares fit for the LMC clusters gives

$$\log (\tau/\text{yr}) \approx (0.087 \pm 0.004)s + 5.77 \pm 0.12 . \qquad (1)$$

This calibration is plotted as the solid line in Figure 2. The standard deviation of $\log \tau$ from the mean relation is 0.3, which

TABLE 1

s-PARAMETERS FOR LMC CLUSTERS

Cluster	*s*	Cluster	*s*	Cluster	*s*	Cluster	*s*	Cluster	*s*
N1466	48[a]	N1804	23	N1880	1	N2011	13	N2209	35
N1644	37	N1805	17	N1885	28	N2018	11	N2210	48
N1651	39	N1806	40	N1895	28	N2019	46	N2213	39
N1652	43	N1810	18	N1898	50	N2025	27	N2214	22
N1698	21	N1818	18	N1903	23	N2027	7	N2231	37
N1704	20	N1828	25	N1910	4	N2029	10	N2249	34
N1711	20	N1830	29	N1913	24	N2031	27	N2257	51[a,d]
N1714	3	N1831	31	N1916	46	N2041	25	I2114	3
N1718	45	N1833	7	N1917	39	N2056	31	I2127	4
N1727	4	N1834	22	N1918	5	N2058	26	I2128	1
N1732	24	N1835	47	N1928	22	N2065	26	I2146	37
N1735	22	N1841	42[a]	N1943	25	N2070	14	SL 56	24
N1743	2	N1844	25	N1951	24	N2098	16	SL 106	21
N1748	1	N1846	40	N1953	29	N2100	17	SL 114	13
N1751	42	N1847	21	N1956	8[b]	N2107	32	SL 360	10
N1754	46	N1849	32	N1967	12	N2108	36	SL 361	9
N1755	24	N1850	21	N1978	45	N2118	24	SL 362	7
N1756	32	N1852	45	N1983	13	N2121	44	SL 363	37
N1766	17	N1854	24	N1984	11	N2133	...[c]	SL 393	...[e]
N1767	16	N1855	22	N1986	24	N2134	28	SL 477	20
N1772	17	N1856	30	N1987	35	N2136	26	SL 506	46
N1774	23	N1858	5	N1994	15	N2154	39	SL 538	15
N1775	28	N1860	20	N2000	25	N2155	45	SL 539	25
N1782	23	N1863	21	N2001	6	N2156	26	SL 562	32
N1783	37	N1866	27	N2002	17	N2157	25	SL 885	...[c]
N1786	48	N1868	33	N2003	15	N2159	25	H11	51
N1787	16	N1869	21	N2004	15	N2162	39	HS 314	10
N1793	22	N1870	24	N2005	46	N2164	23		
N1795	41	N1872	30	N2006	13	N2172	25		
N1801	30	N1873	12	N2009	16	N2173	42		

[a] Disputed members of the LMC (Cowley and Hartwick 1981). NGC 1466 and 1841 are included in Fig. 3 but do not enter the age calibration. NGC 2257 is included in the age calibration and Fig. 3.

[b] Misidentified cluster in van den Bergh's 1981 compilation. NGC 1956 is listed as a galaxy in Sulentic and Tifft 1973.

[c] Incomplete *UBV* data.

[d] *UBV* data from Elson and Freeman 1985.

[e] Outlying point in Fig. 1.

TABLE 2

s-PARAMETER FOR SMC CLUSTERS

Cluster	*s*	Cluster	*s*	Cluster	*s*	Cluster	*s*
L1	46	L35	...[a]	L58	...[a]	N411	37
L8	48	N269	29	N339	49	N416	46
N121	47	L39	22	N346	8	L84	5
L11	47	L40	27	I1611	26	N419	38
N152	37	N290	16	I1612	22	N422	24
N176	20	L44	25	L63	25	I1660	25
N220	22	L45	17	L66	18	I1665	24
L23	...[a]	L47	30	N361	48	N456	...[a]
N222	22	L48	15	L68	47	N458	25
N231	24	N299	20	L70	13	N460	...[a]
L26	32	N306	...[a]	N376	20	N465	...[a]
L27	...[a]	L51	15	L74	14	N602	6
N242	24	L53	30	N395	...[a]	L107	3
N256	25	N330	19	I1624	23	L113	49
N265	26	L56	16	L79	...[b]	L114	28
						N796	...[a]

[a] Incomplete *UBV* data.

[b] Outlying point in Fig. 1.

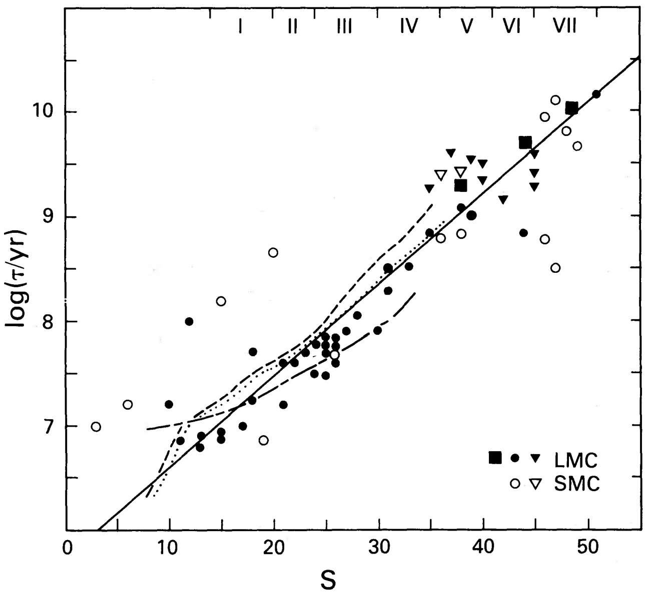

FIG. 2.—Calibration of the age parameter for clusters in the LMC (*filled symbols*) and SMC (*open symbols*). The values of *s* are derived from Fig. 1 and listed in Tables 1 and 2. The values of τ are derived as follows: main-sequence photometry (*circles*) from Hodge (1983) with exceptions noted in § II; integrated spectra (*squares*) from Searle (1984); asymptotic giant branch photometry (*triangles*) from Mould and Aaronson (1982). The solid line is the least-squares fit given by eq. (1) for the LMC clusters only. The smooth curves are derived from the stellar population models of Searle, Sargent, and Bagnuolo (1973) with IMF slopes $x = 1.1$ (*dashed line*) and $x = 2.2$ (*dotted line*) and the model of Dixon, Ford, and Robertson (1972) with a solar neighborhood IMF (*dot-dashed line*). The approximate boundaries of the SWB classes are the same as in Fig. 1.

corresponds to an uncertainty of a factor of only 2 in the ages of individual clusters. This is comparable with the external errors claimed for each method of age determination and is only twice the internal uncertainties claimed for the different methods. Equation (1) is consistent with the calibration

$$\log(\tau/\mathrm{yr}) = 0.5(\mathrm{SWB\ class}) + 6.6 \quad (2)$$

adopted by Fall and Frenk (1983). Our relation between the *s*-parameter and age is tighter than previous calibrations of the SWB classes because the partitioning of the sequence is finer, and because only the LMC clusters are included. The SMC clusters obey a slightly flatter relation with about twice as much scatter.

To check for consistency between the empirical results and theoretical models, we have plotted the values of $U-B$ and $B-V$ for stellar populations of various ages on a two-color diagram and have assigned values of *s* to the models in the same way as for the clusters. The dotted and dashed curves in Figure 2 show the relations between $\log \tau$ and *s* from Searle, Sargent, and Bagnuolo's (1973) models, with solar composition and slopes $x = 1.1$ and $x = 2.2$ for the initial mass function (IMF) (where $x = 1.35$ for the Salpeter IMF). We have reddened the models by $E_{B-V} = 0.1$ at each age. The similarity between these theoretical relations, resulting from the weak dependence of the colors on the IMF slope, undoubtedly helps to account for the small scatter in the empirical relation. We have plotted as the dot-dashed curve in Figure 2 results from the models of Dixon, Ford, and Robertson (1972); these have solar composition and a solar neighborhood IMF and have also been reddened by $E_{B-V} = 0.1$. The main cause of the difference between the Searle *et al.* models and the Dixon *et al.* models is in the treatment of stellar interiors. Given this difference, the agreement between the theoretical and empirical results in Figure 2 is entirely satisfactory. From Larson and Tinsley's (1978) discussion of the evolution of stellar populations with different chemical compositions, we suggest that the flatter relation for the SMC clusters is consistent with their lower metallicities. A smaller reddening for young clusters in the SMC would change the relation between *s* and $\log \tau$ in the same sense.

III. MASS LIMITS

At this stage we could use the relation between color and age from the previous section to derive an age distribution for the 144 LMC clusters with photoelectric *UBV* data. The results would, however, have little meaning, because the clusters were selected by different observers for a variety of purposes. To estimate an age distribution that can be interpreted in terms of the physical processes governing the formation and disruption of clusters, we would like to isolate a mass-limited sample. This can be done approximately by limiting the sample at an age-dependent luminosity that reflects the fading of the clusters. In Figure 3 we have plotted the *V* magnitudes from van den Bergh's (1981) compilation of photoelectric data against the *s* parameters given in Tables 1 and 2. The SMC clusters are included in the figure only for comparison; there are too few of them to estimate an age distribution reliably. Since the clusters lie along an essentially one-dimensional sequence in the two-color diagram, all the independent information available from integrated *UBV* data is in principle displayed in the $V-s$ plane. In practice, the magnitudes were measured with diaphragms that did not admit all the light from the clusters; we refer to these as "aperture magnitudes" and identify them with the subscript *a*.

The solid and dashed lines in Figure 3 show the evolution of the Searle, Sargent, and Bagnuolo (1973) models with IMF slopes $x = 1.1$ and $x = 2.2$. For a given value of *x*, the fading of the Dixon, Ford, and Robertson (1972) and Larson and Tinsley (1978) models is virtually identical to that of the Searle *et al.* models. Unlike the relation between color and age discussed in the previous section, the relation between luminosity and age depends strongly on the IMF slope. Star counts in six LMC clusters indicate a large range, $0.2 \leq x \leq 2.5$, with a median value closer to the lower end (Freeman 1977). Given this range, we should ideally estimate age distributions for samples with several different assumed IMF slopes. However, the fading line with $x = 1.1$ is too steep to isolate a sample with enough clusters at all ages for reliable analysis. We therefore present quantitative results only for $x = 2.2$. The qualitative dependence of the age distribution on the IMF slope can be judged from Figure 3; after correcting for incompleteness at faint magnitudes, more old clusters would be expected in mass-limited samples with smaller values of *x*.

The use of the "fading lines" in Figure 3 to isolate mass-limited samples is only approximate for the following reasons. First, the difference between aperture and total magnitudes decreases from about 0.5 mag for clusters brighter than $V_a \approx 12$ to less than 0.2 mag for clusters fainter than $V_a \approx 13$ (Elson and Fall 1985). A correction for this effect would increase the number of clusters in the sample with $s \lesssim 30$. Second, the stellar population models have solar composition, whereas the metallicities of the LMC clusters decrease from [Fe/H] ≈ -0.3 for SWB types I–V to [Fe/H] ≈ -0.7 for type VI

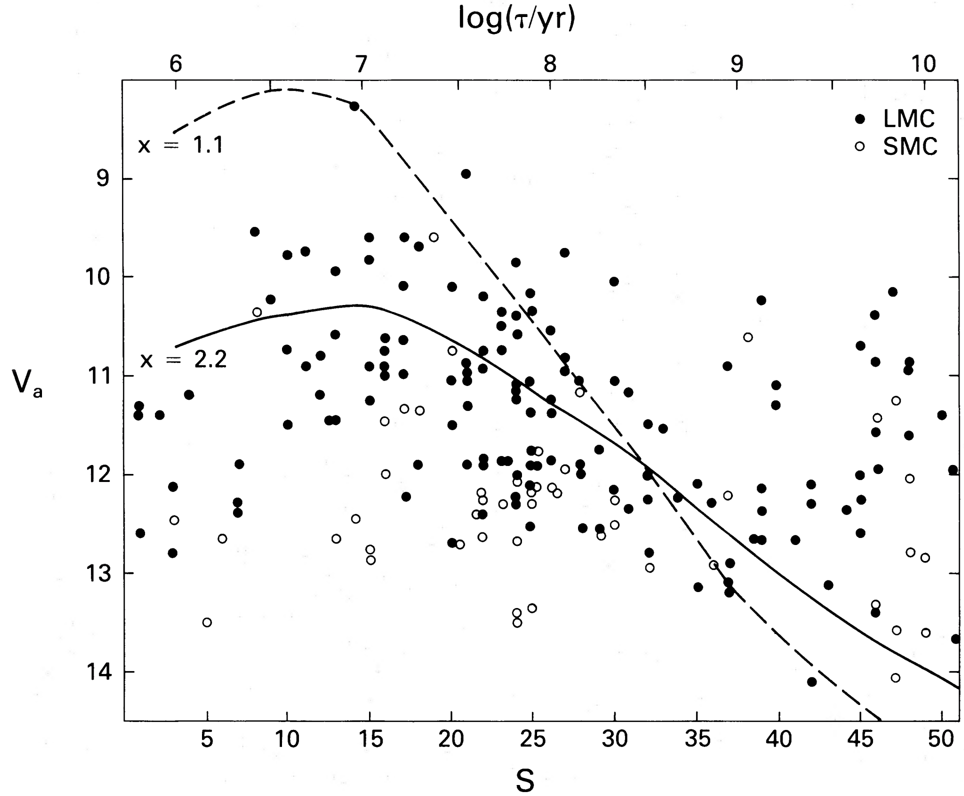

FIG. 3.—Aperture magnitude against age parameter for clusters in the LMC (*filled circles*) and SMC (*open circles*). The values of V_a are from van den Bergh's (1981) compilation of photoelectric data, except for NGC 2257 (Elson and Freeman 1985). The values of s are from Tables 1 and 2, and the age scale at the top is from eq. (1). The smooth curves show the evolution of the stellar population models of Searle, Sargent, and Bagnuolo (1973) with IMF slopes $x = 1.1$ (*dashed line*) and $x = 2.2$ (*solid line*). The vertical normalization of these lines is discussed in § III.

and [Fe/H] ≈ -1.3 for type VII (Cohen 1982; Searle 1984). A correction for this effect would exclude a few clusters with $s \gtrsim 40$ from the sample. Third, the ejecta from evolved stars will reduce the mass of a cluster and may also influence the rate at which it fades. For reasonable upper and lower cutoffs of the IMF, a cluster could lose between 10% and 50% of its total mass. Fourth, the escape of stars from a cluster in the process of disruption would cause it to fade even more rapidly than predicted by the models. Attempts to correct for these effects are hardly justified with our present level of understanding, but we have checked that they would not alter our main conclusions. As we have already emphasized, the largest uncertainty in the age distribution arises from the poorly known IMF slopes of the clusters. The samples defined by the fading lines are, nevertheless, more suitable for analysis than samples with magnitude limits or unknown selection criteria.

An estimate of the mass limits defined by the fading lines in Figure 3 requires some assumptions about the range of stellar masses within the clusters. With the cutoffs adopted by Searle, Sargent, and Bagnuolo (1973), $M_L = 0.25\ M_\odot$ and $M_U = 35\ M_\odot$, the inferred masses of the clusters near the fading lines are $5 \times 10^3\ M_\odot$ for $x = 1.1$ and $1 \times 10^4\ M_\odot$ for $x = 2.2$. However, reasonable variations in the cutoffs, especially M_L, would imply mass limits that are lower or higher by factors of a few. An independent check on these estimates is provided by a recent measurement of the velocity dispersion within the old LMC cluster NGC 1835 (Elson and Freeman 1985). The central mass-to-light ratio of this cluster is 0.4 in solar units, but the global value could be about twice as high with a modest degree of internal mass segregation. If so, and if NGC 1835 is typical of the other LMC clusters with $s \approx 47$, then the inferred mass limits are quite similar to those mentioned above. In contrast, the masses of the open clusters in our Galaxy seldom exceed a few times $10^3\ M_\odot$. This difference is also reflected in the luminosities of the clusters; only a few of the Galactic open clusters in the compilations by Gray (1965), Lyngå (1981, 1982), and Sagar, Joshi, and Sinvhal (1983) would appear in our mass-limited sample if viewed at the distance of the LMC. In particular, the familiar clusters M67 and NGC 188 would lie well below both the fading lines.

The most serious bias in the sample of LMC clusters with photoelectric *UBV* data is decreasing completeness with increasing apparent magnitude. This affects the age distribution derived from the mass-limited samples because the number of missing clusters above the fading lines in Figure 3 is larger at the old end than at the young end. We have made statistical corrections for incompleteness by the following procedure. First, we identified all the clusters in two large regions of the LMC, referred to here as A and B, using the Hodge-Wright (1967) atlas. The magnitudes of the clusters were then estimated by eye from an unfiltered IIIaJ plate taken with an 8 inch f/1 Schmidt camera. As discussed in a separate paper, the magnitudes are accurate to better than 0.4 mag, and the sample is essentially complete to $B = 14.5$ (Elson and Fall 1985). Next, we computed the fraction of clusters in van den Bergh's (1981) compilation brighter than each magnitude B_a in regions A and B. This "completeness function" is shown in Figure 4. Combining the solid curve with the relation between $B-V$ and s shown in Figure 1, we derived the completeness as a function of V_a. The number of clusters above the fading line in Figure 3

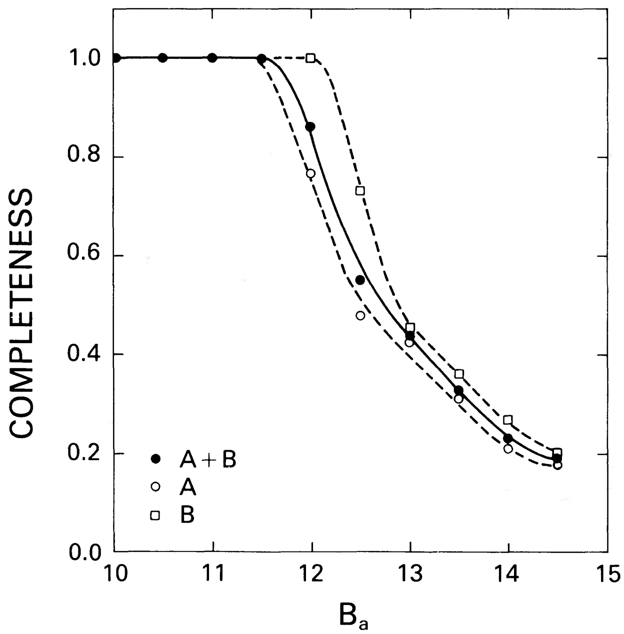

FIG. 4.—Completeness of van den Bergh's (1981) compilation of LMC clusters with photoelectric *UBV* data as a function of aperture magnitude. The open symbols are for regions A and B separately, and the filled circles are for the two regions combined. The procedure for estimating the magnitudes of the clusters in this representative sample is described in Elson and Fall (1985). The solid curve was used to correct the age distributions in Figs. 5 and 7.

was then weighted inversely by the completeness at each value of s. We restricted the sample to $s \geq 15$ because the corrections for very young clusters, which are often obscured by gas and dust, are uncertain.

IV. AGE DISTRIBUTION

The age distribution for the mass-limited sample of LMC clusters with an assumed IMF slope of $x = 2.2$ is shown in Figure 5. We have chosen the intervals Δs so that each bin contains at least five clusters before weighting and have plotted the points at the median ages τ_m within the bins. The age distribution was computed from the corrected number of clusters ΔN in each bin and the relation $dN/d\tau = (5.0/\tau_m)\Delta N/\Delta s$ implied by equation (1). We have checked that the age distribution is not sensitive to the binning of the clusters. The error bars reflect only counting statistics, which are likely to dominate any systematic uncertainties in the corrections for incompleteness. We find $dN/d\tau = 3 \pm 1 \times 10^{-7}$ clusters yr^{-1} at $\tau = 10^7$ yr, although the age distribution in the diagram is normalized to unity at the young end for later comparisons. Figure 5 also shows the results with equal weight given to all the clusters above the fading line in Figure 3; this illustrates the importance of correcting for incompleteness and sets an extreme lower bound on the age distribution. For the reasons mentioned in the previous section, we would expect the age distributions for the mass-limited samples to depend sensitively on the assumed IMF slope of the clusters. Freeman's (1977) results suggest that $x = 2.2$ is almost certainly too large for a typical IMF slope, and therefore that the true age distribution is even flatter than those shown in Figure 5. Irrespective of this uncertainty, the smooth decline with increasing age makes the existence of a large population of globular clusters of the kind found in our Galaxy seem unlikely.

Our results suggest that a comparison with the age distribution for the open clusters in the Galaxy would be interesting. The smooth curve in Figures 5–7 is Wielen's (1971) best fit for the clusters with distances less than 1 kpc in the compilations by Lindoff (1968) and Becker and Fenkart (1971). The ages of these clusters, which are based on turnoff colors and magnitudes, are probably accurate to within a factor of 2 on average. Wielen gives several arguments that his sample is not biased by selection effects and is representative of a complete sample. We have checked his results by analyzing the more recent and extensive compilations of data on open clusters by Lyngå (1981, 1982) and Janes and Adler (1982). Figure 6 shows the age distributions for this sample with distance limits of 0.5, 1.0, and 2.0 kpc. The similarity of the first two distributions sug-

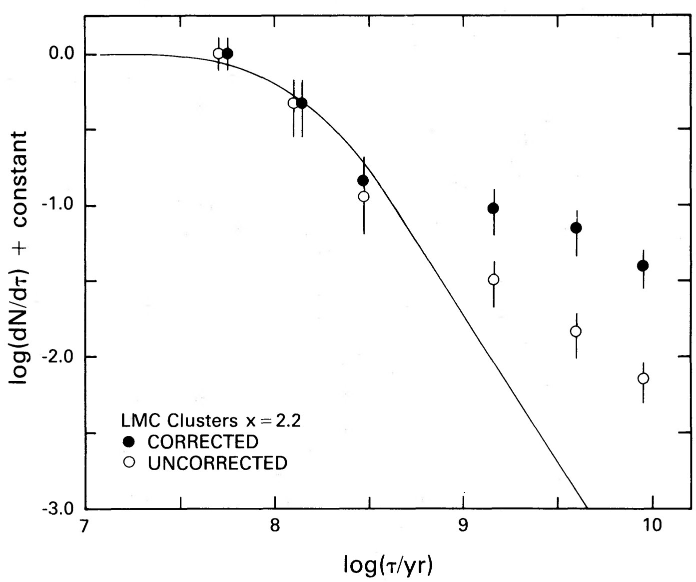

FIG. 5.—Age distributions for the mass-limited samples of LMC clusters with an assumed IMF slope of $x = 2.2$. This includes all clusters with $s \geq 15$ above the fading line in Fig. 3; with corrections for incompleteness (*filled circles*) and without corrections (*open circles*). The normalization is $dN/d\tau = 1$ at $\tau = 10^7$ yr, and the error bars represent $N^{1/2}$ uncertainties. The solid curve is Wielen's (1971) best fit for Galactic open clusters within 1 kpc.

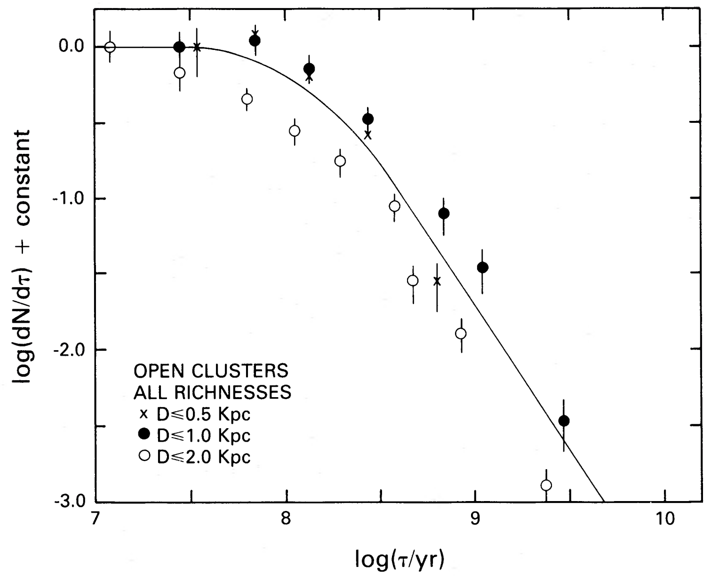

FIG. 6.—Age distributions for open clusters in our Galaxy with distance limits of 0.5 kpc (*crosses*), 1.0 kpc (*filled circles*), and 2.0 kpc (*open circles*). The ages and distances were taken from the compilations of Lyngå (1981, 1982) and Janes and Adler (1982). The normalization is $dN/d\tau = 1$ at $\tau = 10^7$ yr, and the error bars represent $N^{1/2}$ uncertainties. The solid curve is Wielen's (1971) best fit for Galactic open clusters within 1 kpc.

gests that the 1 kpc sample is indeed representative, while the deviation of the third distribution indicates that the 2 kpc sample may have a slight bias. In any case, the age distribution for the rich clusters in the LMC has the same general shape as that for the open clusters in our Galaxy, although the LMC distribution has a flatter tail. This important difference is also reflected in the median ages; the open clusters in the 1 kpc sample have $\tau_m = 2 \times 10^8$ yr, whereas the LMC clusters in the mass-limited sample with $x = 2.2$ have $\tau_m = 4 \times 10^9$ yr with corrections for incompleteness, and $\tau_m = 7 \times 10^8$ yr without corrections.

The fact that the rich star clusters in the LMC are on average more massive than the open clusters in our Galaxy may have a bearing on the differences between their age distributions. Janes and Adler (1982) have assigned a measure of richness R, which is roughly correlated with mass, to most of the open clusters in their compilation. They find that the age distributions become flatter with increasing richness in subsamples selected without regard to distance. We have repeated the analysis with a distance limit of 1 kpc to ensure that the results are representative of a complete sample and have combined the clusters into two richness groups to reduce the statistical uncertainties. From about 50 open clusters with masses reported by Lyngå (1981, 1982), we estimate mean masses of about 500 and 1000 $M_\odot$ respectively for the groups with $0 \leq R \leq 2$ and $3 \leq R \leq 5$. Figure 7 confirms the dependence of

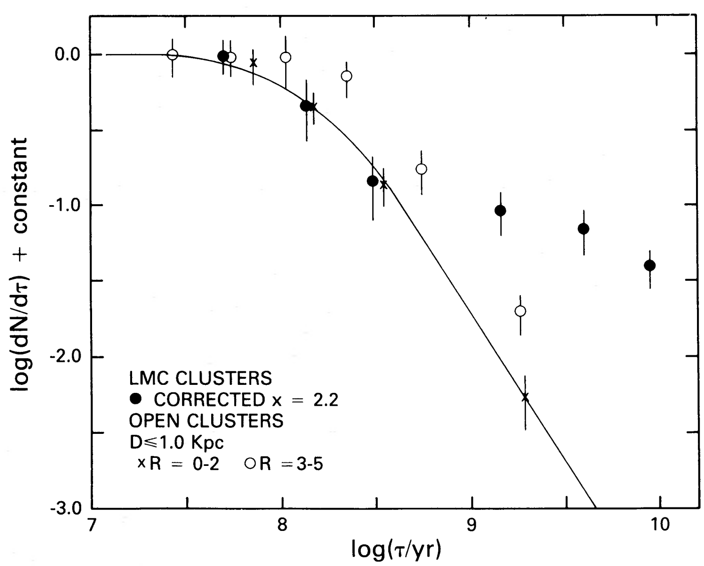

FIG. 7.—Age distributions for open clusters in our Galaxy with richness classes $0 \leq R \leq 2$ (*crosses*) and $3 \leq R \leq 5$ (*open circles*). The samples are distance-limited at 1 kpc, and all data are from the compilations of Lyngå (1981, 1982) and Janes and Adler (1982). The normalization is $dN/d\tau = 1$ at $\tau = 10^7$ yr, and the error bars represent $N^{1/2}$ uncertainties. The filled circles show the corrected age distribution for the mass-limited sample of LMC clusters with an assumed IMF slope of $x = 2.2$. The solid curve is Wielen's (1971) best fit for Galactic open clusters within 1 kpc.

the age distributions on richness found by Janes and Adler and also shows that the age distribution for the LMC clusters is flatter than that for the richest open clusters in our Galaxy. The appearance of Figure 3 strongly suggests that there may be a similar dependence on richness within the sample of LMC clusters. However, the number of clusters is not large enough to derive reliable age distributions with mass limits much different from the ones we have adopted.

V. DISCUSSION

To interpret the age distribution for the open clusters in our Galaxy, Wielen assumes that their rate of formation has been roughly constant over the past few times 10^9 yr. This is intended to apply in an average sense when allowance is made for passages through spiral arms and for other local episodes in the formation of clusters. The function $dN/d\tau$ is then proportional to the probability that a cluster will survive to an age τ. Wielen suggests that the scarcity of old open clusters is evidence for disruption by various dynamical processes, including evaporation by two-body diffusion and impulsive encounters with molecular clouds. A similar interpretation might apply to the rich star clusters in the LMC, since their age distribution is qualitatively similar to that for the open clusters in our Galaxy. The flatter tail would then reflect the larger relaxation times of the LMC clusters or a smaller rate of disruption by molecular clouds, or both. Cohen, Montani, and Rubio (1984, and private communication) report that the abundance of carbon monoxide is much lower in the LMC than in our Galaxy, which, for reasonable ratios of H_2 to CO, probably implies a lower abundance of molecular hydrogen. There may also be a connection between the age distribution and the suggestion by Freeman, Illingworth, and Oemler (1983) that the disk of old clusters in the LMC is inclined with respect to the disk of young clusters and gas. If true, the old clusters would spend less time in the layer containing any molecular clouds than would the young clusters, and their life expectancy would be enhanced.

The interpretation of the age distribution for the LMC clusters is complicated by the possibility that their rate of formation may not have been constant. Several authors have suggested that close encounters between the LMC and the SMC or between the Magellanic Clouds and our Galaxy could have induced bursts in the formation of stars and clusters (Gunn 1980; Murai and Fujimoto 1980; Mathewson and Ford 1984). There is some evidence for periods of enhanced star formation in small regions of the LMC, but whether these are representative of the whole stellar population or are stochastic fluctuations is not yet clear (Butcher 1977; Stryker and Butcher 1981; Stryker, Butcher, and Jewell 1981; Frogel and Blanco 1983). The age distribution for the LMC clusters presented by Mould and Aaronson (1982) has a large peak at $\tau \approx 4 \times 10^9$ yr, which they tentatively suggest is evidence for a burst in the formation of clusters. We find, however, that their results are sensitive to the binning of the clusters, and that the peak disappears entirely when the bins are shifted by 0.25 mag in $M_{\mathrm{bol},m}$. There is no evidence for a burst of any sort in the age distribution presented here. Unfortunately, both our sample and the one used by Mould and Aaronson are too small to test for fluctuations with durations much shorter than the times at which they occurred. The birth rate may have varied slowly over the lifetime of the LMC, but the large variation required to explain the age distribution without any disruption seems unlikely.

We are grateful to Drs. Kenneth Freeman and Leonard Searle for their valuable advice and encouragement. R. A. W. E. is supported by an Isaac Newton Studentship and an Overseas Research Student Award.

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