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THE AGE CALIBRATION OF INTEGRATED ULTRAVIOLET COLORS AND YOUNG STELLAR CLUSTERS IN THE LARGE MAGELLANIC CLOUD[1]

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ABSTRACT

Integrated colors in selected far-UV bands are presented for a large sample of Large Magellanic Cloud (LMC) clusters. Theoretical calculations of these integrated colors are derived and discussed. We show that the location in the two-color diagram $C(18-28)$, $C(15-31)$ is expected to be a sensitive but smooth function of cluster age for ages in the range 5×10^6 to 8×10^8 yr. Theoretical results appear in very good agreement with the observed colors of LMC clusters. From this comparison, we suggest that the gap in the observed colors is caused by the lack of LMC clusters in the range of ages between 2×10^8 to 10^9 yr. The two-color location of old globulars is finally discussed, also in connection with available data for the M31 clusters.

Subject headings: clusters: globular — galaxies: individual (M31) — galaxies: Magellanic Clouds — stars: evolution

I. INTRODUCTION

The problem of interpreting integrated colors of stellar clusters in terms of the evolutionary parameters of evolving stars is receiving an increasing amount of attention in recent literature. As a matter of fact, stars which are members of a cluster can often be regarded as sharing a common age and chemical composition. It follows that star clusters represent ideal targets for testing theoretical calculations of integrated colors as a function of star evolutionary parameters, a test which represents an obvious but fundamental step toward a realistic interpretation of more complex aggregates of stars, such as galaxies. This paper will approach this problem, with particular reference to the Magellanic Clouds, which offer the rare advantage of including populous clusters where massive or intermediate mass stars are still alive, providing us with valuable samples of homogeneous, young stellar populations.

Synthetic integrated colors of stellar clusters in the optical range have recently been discussed, e.g., by Wyse (1985) for *U*, *B*, *V* colors, or by Brocato (1986) for redder bands. A known drawback related to the use of optical colors is that such colors are deeply affected by evolved red giants, a circumstance not simply related to the cluster age. Moreover, we know that theoretical colors for these giants depend on details of theoretical computations not yet well understood, such as the treatment of subatmospheric convection. As a consequence, the relation between optical colors and cluster ages appears largely open to question. In this context, one may recall, for example, the debate about the origin of the dichotomy observed in $B-V$ colors of the clusters in the Large Magellanic Cloud (see Renzini and Buzzoni 1986; Capuzzo-Dolcetta 1986; Chiosi, Bertelli, and Bressan 1986; Elson and Fall 1988).

Four-color *uvgr* photometry of integrated light has been used by Searle, Wilkinson, and Bagnuolo (1980) to derive for the first time a semiempirical age relation for star clusters in the Magellanic Clouds. A similar procedure, but one that is based on integrated *UBV* colors, has been adopted by Elson and Fall (1985, 1988) to derive their age indicator "*S*."

However, the correlation of colors with cluster age should be strengthened considerably in the far-ultraviolet, where the flux is dominated by stars near the top of the "blue sequence" (BS; see Brocato and Castellani 1987*a*, *b*), while the contribution of evolved red giants becomes rather negligible. Since the BS is the natural indicator of cluster age, one expects that far-UV colors should be straightforwardly related to that parameter, a relation which should remain valid up to cluster ages of some billions of years, when the appearance of hot horizontal branch (HB) stars can further affect the cluster UV colors (see, e.g., Caloi *et al.* 1985).

Unfortunately, theoretical evaluations for integrated UV colors are far from being settled. Cohen, Rich, and Persson (1984) produced a calibration of the UV color $C(1345-3150)$ aimed at the interpretation of old clusters in the Large Magellanic Cloud, where the present inability to make predictions about the temperatures of HB stars can play a relevant role. More recently, Barbaro and Olivi (1986) provided a calibration of the two UV colors $C(1345-3150)$, $C(1750-2670)$ for clusters in the range 1×10^6 up to 8×10^8 yr, but with a mixing of canonical and core-overshooting evolutionary tracks which may affect the reported result.

In this paper, we will approach this problem on the basis of new theoretical calculations of integrated UV colors for clusters in the range of ages 5×10^6–8×10^8 yr, a range which we consider safe from blue HB contamination. New observational UV colors of star clusters in the Large Magellanic Cloud (LMC) will be presented in § II. The results of the related theoretical calculations will be reported in § III, while the comparison of the theoretical UV colors with the observed ones will be performed and discussed in § IV.

II. OBSERVATIONS

An extensive compilation of ultraviolet observations of the star clusters in the Large Magellanic Cloud, based on a selection of the best quality data obtained by the *International*

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[1] Based on observations by the *International Ultraviolet Explorer* collected at the Villafranca Satellite Tracking Station of the European Space Agency, and on Archive *IUE* data.

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Ultraviolet Explorer until 1985 (31 clusters in total), has recently been published by Cassatella, Barbero, and Geyer (1987). We will adopt this data base with only a few modifications intended to extend the data set to clusters observed more recently or to improve the quality of the measurements.

In order to upgrade the accuracy of the observed fluxes, all *IUE* spectra obtained with the LWP camera were reprocessed with the new intensity transfer functions, ITF2, and were calibrated using the appropriate calibration as given by Cassatella, Lloyd, and González Riestra (1988). In addition, fluxes obtained with the SWP and LWR cameras were corrected for the sensitivity degradation of the cameras following the algorithms by Bohlin and Grillmar (1988) and Clavel, Gilmozzi, and Prieto (1988), respectively. In this way, corrections amounting to about 10% were introduced.

The observed fluxes have been corrected for both Galactic and LMC internal interstellar extinction. For the Galactic foreground extinction, we used the mean extinction curve given by Savage and Mathis (1979), together with a Galactic foreground reddening $E(B-V) = 0.04$ (Nandy, Morgan, and Carnochan 1979). For the LMC internal extinction, we used the average LMC extinction law given by Fitzpatrick (1986). The LMC internal color excesses of the individual clusters, $E(B-V)$, were taken from Cassatella, Barbero, and Geyer (1987).

From the reddening corrected fluxes, we have finally computed two color indices based on the mean fluxes in the four wavelength bands, 200 Å wide, centered at 1500, 1800, 2800, and 3100 Å:

$$C(1500-3100) = m(1500) - m(3100) ,$$

$$C(1800-2800) = m(1800) - m(2800) .$$

The choice of these photometric bands was suggested mainly by their similarity to the bands explored early by the *ANS* satellite and used widely in the literature. However, instead of the *ANS* band centered at $\lambda = 2500$ Å, we preferred a band at $\lambda = 2800$ Å in order to avoid the Fe II absorption lines expected in the former range, and thus in the hope of minimizing the composition effect on the color indices. As a matter of fact, one finds that substituting $C(1800-2500)$ with $C(1800-2800)$ allows the clusters in the LMC to locate in a much better defined sequence in the two UV color diagram than $C(1800-2500)$ did. The data base adopted in this work is reported in Table 1.

III. THEORETICAL COLORS OF STAR CLUSTERS

Integrated colors of star clusters have been computed following the population synthesis technique described in the pioneering work by Becker and Mathews (1983). For this purpose, we selected a number of evolutionary tracks covering the range of masses from 0.7 $M_\odot$ up to 30 $M_\odot$. Evolutionary tracks have been taken from van den Bergh (1983) and Sweigart and Gross (1978) for the mass range 0.7 to 2.2 $M_\odot$, from Becker (1981) for the range 3 to 9 $M_\odot$, and from Brunish and Truran (1978) in the range 15 up to 30 $M_\odot$, the last two sets covering both the H and the He burning evolutionary phases.

For each given slope of the initial mass function (we will assume the Salpeter value $\alpha = 2.35$ for the IMF unless otherwise specified) and for each assumed cluster age, theoretical isochrones have been populated with a suitable number of stars, the number chosen large enough to avoid statistical fluctuations producing sizable differences in the integrated colors.

TABLE 1

OBSERVATIONAL, UV, AND $B-V$ COLORS FROM *IUE* LMC CLUSTER DATA

NGC Number	$C(15-31)$	$C(18-25)$	$C(18-28)$	$B-V$
1711.........	−1.78	−0.81	−1.11	0.12
1755.........	−1.52	−0.65	−0.93	0.15
1774.........	−1.75	−0.86	−1.11	0.20
1805.........	−1.82	−0.84	−1.17	0.11
1818.........	−1.62	−0.81	−1.04	0.18
1850.........	−1.31	−0.66	−0.86	0.12
1854.........	−1.43	−0.81	−1.03	0.21
1856.........	−0.88	−0.64	−0.76	0.34
1866.........	−1.09	−0.58	−0.75	0.25
1951.........	−1.75	−0.82	−1.17	0.09
1967.........	−2.07	−0.86	−1.31	−0.01
1968.........	−2.14	−1.02	−1.33	...
1974.........	−2.11	−0.94	−1.29	...
1983.........	−1.62	−0.74	−1.06	0.10
1984.........	−1.67	−0.72	−1.03	0.02
1994.........	−1.94	−0.75	−1.20	0.16
2004.........	−1.64	−0.64	−0.99	0.17
2018.........	−1.89	−0.92	−1.30	0.02
2041.........	−1.33	−0.66	−0.86	0.22
2100.........	−1.39	−0.59	−0.86	0.16
2134.........	−1.15	−0.54	−0.76	0.25
2157.........	−1.21	−0.65	−0.85	0.19
2164.........	−1.34	−0.57	−0.85	0.10
2214.........	−1.25	−0.60	−0.87	0.11
1806.........	1.63	−0.03	0.10	0.73
1835.........	1.10	0.43	0.57	0.73
1978.........	2.08	0.26	0.60	0.78
1987.........	0.83	−0.06	−0.13	0.52
2019.........	0.94	0.42	0.63	0.75
2210.........	1.33	0.55	0.80	0.71

On this basis, the contribution of each single star to the theoretical energy distribution has been evaluated adopting Kurucz's (1979) LTE atmospheric models, and the model cluster's UV colors have been finally computed (Fig. 1).

As an example, Figure 2 shows the behavior of the color index $C(1500-3100)$ as a function of cluster age, computed for a chemical composition $Y = 0.28$ and $Z = 0.01$. As an expected feature, one finds that increasing the age causes the temperature of the luminous BS stars to decrease, driving an increase in the UV color. One important aspect shown by such a color-age calibration is the sensitive and regular variation of $C(1500-3100)_0$ with time, confirming the role of age indicator played by this parameter in the quoted range of ages. Comparing this behavior with the corresponding relation for $B-V$ colors, as reported, e.g., by Brocato (1986) or Chiosi, Bertelli, and Bressan (1988), one should appreciate not only the monotonic dependence of the UV color on the cluster age, but also the much greater sensitivity. As an example, one finds that passing from 50 to 150 million years $\Delta C(1500-3100) \simeq 0.4$ mag, about 2 times larger than the corresponding $\Delta(B-V)$.

It is interesting to evaluate how much the UV color-age calibration in Figure 2 is affected by the contribution of evolved He-burning giants. For this purpose, we show in Figure 3 the integrated colors as derived by accounting only for stars in the central hydrogen-burning phases. It appears that the contribution of evolved giants plays a significant role in an intermediate range of ages, progressively decreasing for very young or sufficiently old clusters. Such behavior can be understood by considering that the contribution of evolved giants to the UV fluxes typically comes from hot giants at the blue end of the He-burning loop at temperatures smaller than

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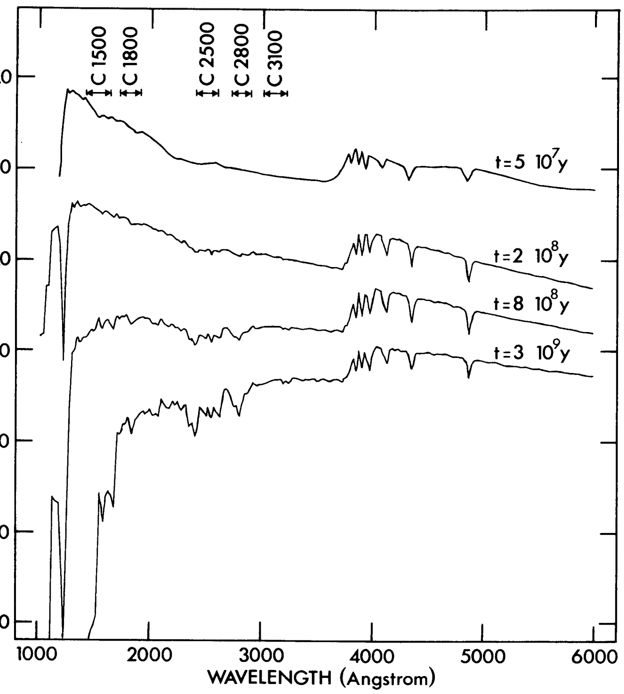

FIG. 1.—Theoretical age calibrations of the ultraviolet fluxes

those of BS stars. However, very massive stars (in very young clusters) burn He near the main sequence, thus with similar radiative properties. On the other hand, increasing the cluster age causes the He-burning loop to be progressively reduced (see Alcock and Paczyński 1978), so that stars in sufficiently old clusters burn He in a red giant clump with negligible contribution to the UV light.

Numerical simulations show that the age calibration of the UV colors in Figure 2 is only slightly dependent on the assumed IMF. This is shown in Figure 4, where the previous results are compared with similar results obtained by keeping constant the cluster age and chemical composition but lowering the exponent of the IMF down to $\alpha = 1.5$. The fact that this dependence is slight is important because of our poor knowledge of the IMF slope. The result in Figure 4 can be understood by observing that decreasing α from 2.35 to 1.5 has the effect of increasing the relative population of He-burning giants, with the consequence already discussed in Figure 3. As for the index $C(1800-2800)$, we found a behavior largely reproducing the already discussed properties of $C(1500-3100)$.

The colors $C(1500-3100)$ and $C(1800-2800)$ have been

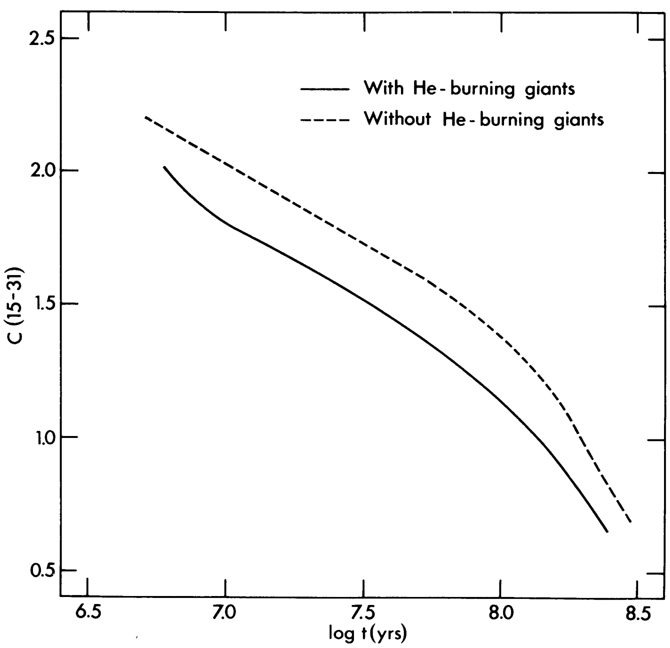

FIG. 3.—Influence of the He-burning giants on the calibration of Fig. 2

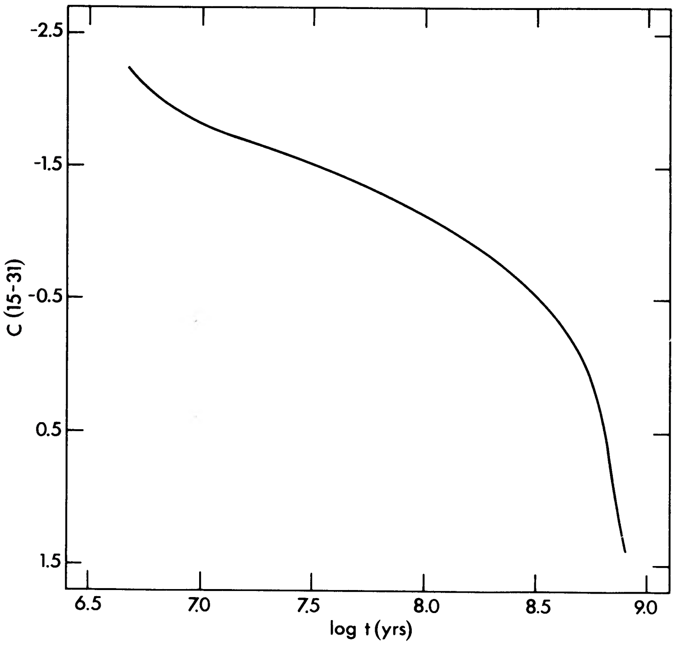

FIG. 2.—Theoretical dependence of $C(15-31)$ on the cluster age

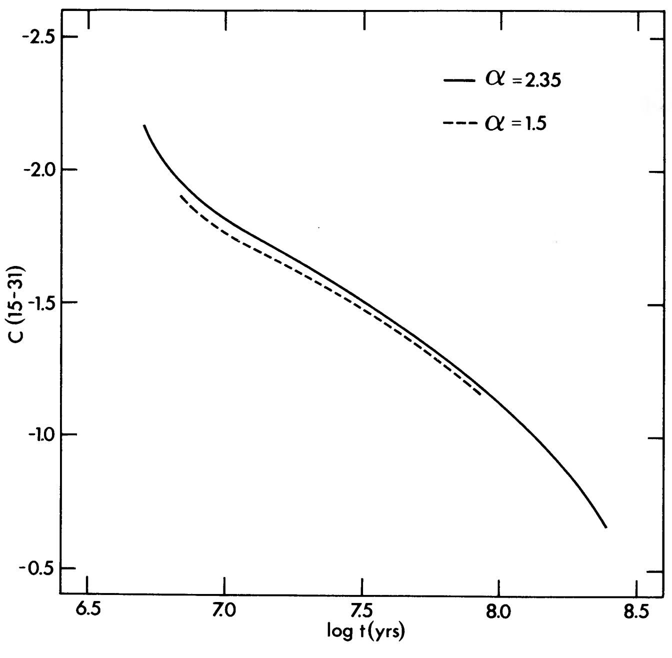

FIG. 4.—Influence of the assumed IMF on the calibration of Fig. 2

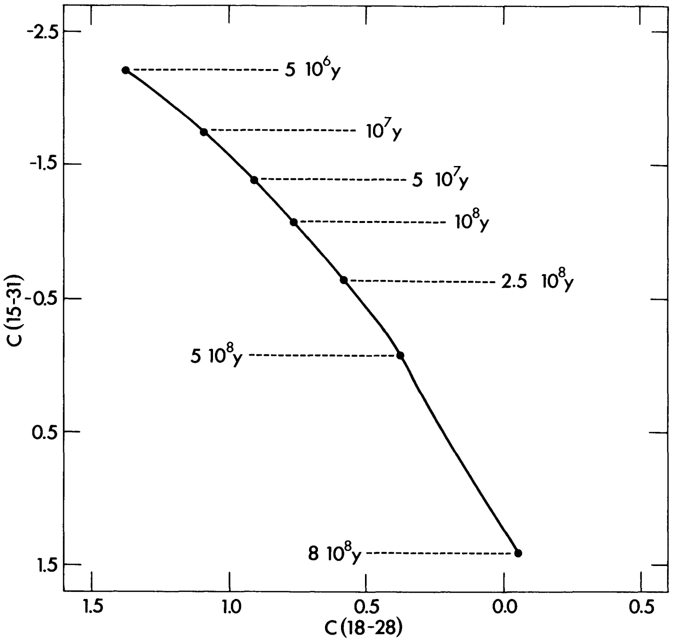

FIG. 5.—Theoretical ultraviolet two-color diagram $C(1500-3100)$ vs. $C(1800-2800)$ for $Y = 0.28$, $Z = 0.01$, $\alpha = 2.35$.

finally used to construct the theoretical ultraviolet two-color diagram shown in Figure 5. As expected, within the explored range of ages (5×10^6–8×10^8 yr), the model clusters arrange themselves along a smooth sequence in the UV two-color diagram, their location being a continuous function of age. We must now discuss the problem of how much the distribution reported in Figure 5 and the corresponding age calibration depend on the assumptions made about the chemical composition and/or the evolutionary treatment of the models. On the basis of evolutionary models available in the literature, we performed a series of numerical tests for different values of Y and Z and/or for different assumptions on the efficiency of central mixing by overshooting. As a result, one finds that the theoretical distribution in the two-color diagram is practically unaffected by the quoted variations, whereas the calibration in terms of cluster ages does depend, sometimes sensitively, on the adopted evolutionary scenario. This rather unexpected occurrence can be understood as evidence that the UV energy distribution of the cluster approaches in any case the distribution of a typical hot star, whereas the temperature of such a "mean star" depends on the adopted modeling. The effects of the various assumptions on the age calibration are exemplified in Table 2, where we report the different ages evaluated under the labeled assumptions for the given value $C(1500-3100) = -1.2$. Results in Table 2 can be easily interpreted in terms of the evolutionary characteristics of the models. Let us recall, e.g., that decreasing the metal content causes the temperatures of the "hot" He-burning giants to increase (see again, e.g., Alcock and Paczyński 1978). As a result, one finds that decreasing the metal content for a given age causes both UV colors to decrease, simulating lower ages; or, in turn, that for a given UV color, the smaller the metallicity, the larger is the age. From the data in Table 2, one can also recognize the "aging" effect induced by overshooting already discussed in a previous paper (see Brocato and Castellani 1988).

TABLE 2

VARIATION OF THEORETICAL CLUSTER AGE[a]

Y	Z	Convection	Age (10^6 yr)	Source of Evolution
0.28.........	0.01	Canonical	85	Becker 1981
0.28.........	0.001	Canonical	137	Becker 1981
0.28.........	0.02	Overshooting	131	Bertelli *et al.* 1986
0.30.........	0.01	Overshooting	290	Bertelli *et al.* 1986

[a] Corresponding to $C(1500-3100) = -1.2$ for different assumptions on the cluster chemical composition and for the labeled assumptions on the treatment of convection. The IMF exponent is $\alpha = 2.35$ in all cases.

IV. COMPARISON WITH OBSERVATIONS

We have shown in the previous section that stellar clusters of different ages should arrange themselves along a well-defined sequence in the ultraviolet two-color diagram, their location along the sequence being a smooth function of age. The calibration of the sequence in terms of cluster age will depend on the adopted evolutionary scenario with a further but small dependence on the adopted IMF.

Let us now compare this theoretical UV two-color diagram with the reddening-corrected colors of the LMC clusters as observed with *IUE* and given in § II. The comparison, shown in Figure 6, indicates a rather good agreement between observations and theory. Only a few old clusters clearly deviate from the theoretical sequence, appearing shifted to the right of the sequence, i.e., toward larger values of the $C(1800-2800)$ color. We suggest that such deviations are evidence for the appearance of hot HB stars in very old clusters. This is probably the case for NGC 1835 and NGC 2210, which are known to contain RR Lyrae stars (Graham and Nemec 1984). This suggestion appears to be further supported by the location in our two-color diagram (Fig. 6) of typical representatives of galactic globular clusters; see Table 3. It turns out that the three LMC globular clusters falling to the right of the age sequence agree well with the two-color location of these old galactic clusters, arranging themselves in an intermediate region in between the extremely blue (EB) and blue (B) horizontal branch galactic clusters, as defined by van Albada, de Boer, and Dickens (1981). In this context, we note that the use of the $C(1800-2800)$ color index appears better able to discriminate

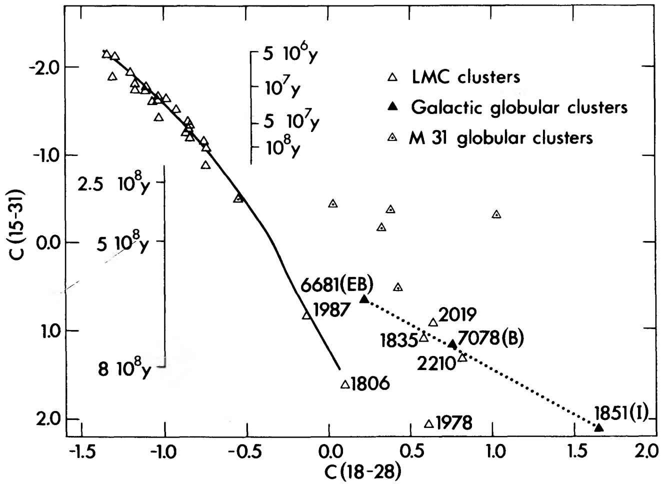

FIG. 6.—Comparison of the theoretical diagram from Fig. 5 with observational data for clusters in LMC, Galaxy and M31.

TABLE 3

OBSERVATIONAL UV COLOR FROM *IUE* DATA

Identification	$C(15-31)$	$C(18-25)$	$C(18-28)$
Galactic globulars[a]:			
NGC 6681−EB	0.65	0.38	0.21
NGC 7078−B	1.21	0.45	0.75
NGC 1851−I	2.12	1.01	1.62
M31 globulars[b]	−0.41	0.16	0.03
	−0.35	−0.07	0.38
	−0.29	0.40	1.03
	−0.51	0.13	−0.55
	0.53	0.42	0.42
	−0.16	0.32	0.32

[a] Selected on the basis of their HB morphology; Caloi, Castellani, and Galluccio 1984.

[b] From Cowley and Burstein 1988.

among the various sequences than $C(1500-2500)$ did. This is an advantage to be added to the already quoted influence on the two-color distribution of UV-bright clusters.

The location in a two UV color diagram of LMC UV-weak clusters has already been reported and discussed by Cowley and Burstein (1988) in discussing the globulars in M31. Following the new calibration given in Figure 6, we can now suggest that only two of these clusters (NGC 1987 and NGC 1806) should be bona fide intermediate-age clusters, with ages of the order of $7-8 \times 10^8$ yr. The three clusters NGC 2019, NGC 1835, and NGC 2210 appear, on the contrary, to be old globulars with well-developed horizontal branches, which implies ages of the order of 10^{10} yr. No firm statement can be made about NGC 1987: according to the classification given by Searle, Wilkinson, and Bagnuolo (1980) or Elson and Fall (1988), we are inclined to regard this cluster as much older than NGC 1987, perhaps with a population of red horizontal branch stars. As a whole, we feel that the age relation given in Figure 6 represents a precise mapping of the previous relation given by Searle, Wilkinson and Bagnuolo (1980) in their Figure 9 (see also their Fig. 7). In this sense, the present work confirms and extends the previous quoted works given over the past 15 years, confirming in particular the intermediate age of NGC 1987.

In the same Figure 6, we finally reported the location of the globulars in M31, as derived (Table 3) from the data given by Cowley and Burstein (1988). Following our theoretical approach, we now suggest that only one cluster out of five may be suspected to be an intermediate-age cluster, with an age of the order of about 300 million yr. The remaining four clusters fall well outside the expected distribution of young and intermediate-age clusters and are probably mostly old globular clusters. By relying on the correlation between the HB morphology and the UV fluxes shown in the same Figure 6, one should suspect an exceptional content of hot HB stars or of UV-bright post–HB stars, producing the observed UV fluxes which appear much stronger than in any Galactic or LMC globular clusters. The occurrence of a non-negligible contribution by UV-bright objects could be related to the evidence that observational data for M31 refer to clusters $\sim 10^2$ times more luminous (and thus more populated) than typical Galactic globulars.

An important aspect shown by Figure 6 is the striking evidence for the lack of LMC clusters in the range $\sim 0.8 < C(1800-2800) < \sim 0.2$. If a metallicity close to the solar value is adequate for the clusters (see, e.g., Cohen, Rich, and Persson 1984; Russel, Bessell, and Dopita 1988), this would imply the lack of clusters in a range of ages from about 2×10^8–7×10^8 yr. To understand how far such a characteristic of our sample can be taken as a general property of the LMC clusters, we compare in Figure 7 the $B-V$ color distribution of our sample with the larger sample of LMC clusters given by van den Bergh (1981). The data in Figure 7 suggests that our subsample could be representative of the LMC cluster population. If this is the case, it appears difficult to escape the conclusion that the observed color gap reflects a real age gap. Note that a possible correlation between age or metallicity, in the sense of a decreasing metallicity in increasing the age, should act in the sense of filling rather than producing gaps. One could conclude that either the absent clusters have already been disrupted or that efficient cluster formation in the LMC stopped about 7×10^8 yr ago and started again about 2×10^8 yr ago.

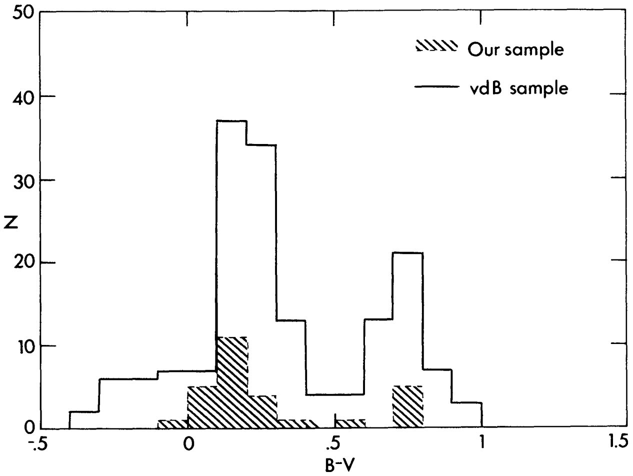

FIG. 7.—Histogram of the observed $B-V$ colors for the clusters in the LMC from van den Bergh (1981), showing (*hatched areas*) the subsample discussed in this paper.

A suggestion for the possible existence of two discrete epochs of star formation in the LMC, already mentioned by Cassatella, Barbero, and Geyer (1987), is one which would agree with the early results of Frogel and Blanco (1983), who interpreted the evidence for two asymptotic giant branches (AGBs) in the LMC as a result of an episode of active star formation which happened in the last 10^8 yr and which might still be in progress. However, such a difficult problem deserves much more statistically relevant data allowing a detailed treatment as the one given by Elson and Fall (1988) in their recent paper.

V. CONCLUSIONS

We found that the use of the $C(15-31)$ versus $C(18-28)$ two-color diagram allows young LMC clusters to arrange themselves in a well-defined sequence. The location of this sequence is reproduced nicely by theoretical computations, which show that the exact calibration in terms of age depends on the adopted chemical composition, and, of course, on the adopted stellar evolution models.

However, the gap found in the LMC colors has to be related to the lack of clusters in the corresponding range of age. If our sample is really representative of the LMC cluster, this would indicate the possible existence of two epochs of star formation.

We found that the use of the $C(15-31)$ versus $C(18-28)$ diagram allows a good discrimination of old Galactic globulars, which arrange themselves following the mean temperature of their HB stars. On this basis, we suggest that the three LMC clusters should be rich in hot HB stars, and that the four clusters in M31 should have peculiar UV contributors, likely to be identified as UV-bright post–HB stars.

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REFERENCES

Alcock, C., and Paczyński, B. 1978, *Ap. J.*, **223**, 244.
Barbaro, G., and Olivi, F. M. 1986, in *Spectral Evolution of Galaxies*, ed. C. Chiosi and A. Renzini (Dordrecht: Reidel), p. 283.
Becker, S. A. 1981, *Ap. J. Suppl.*, **45**, 475.
Becker, S. A., and Mathews, G. S. 1983, *Ap. J.*, **270**, 155.
Bertelli, G., Bressan, A. G., Chiosi, C., and Angerer, K. 1986, *Ap. J. Suppl.*, **66**, 191.
Bohlin, R. C., and Grillmair, C. J. 1988, *Ap. J. Suppl.*, **66**, 209.
Brocato, E. 1986, *Mem. Soc. Astr. Italiana*, **57**, 479.
Brocato, E., and Castellani, V. 1987*a*, *Stellar Evolution and Dynamics in the Outer Halo of the Galaxy*, ed. M. Azzopardi and F. Matteucci (Garching: ESO), p. 461.
———. 1987*b*, *Astr. Ap.*, **182**, 36.
———. 1988, *Astr. Ap.*, **203**, 293.
Brunish, W. M., and Truran, J. W. 1982, *Ap. J. Suppl.*, **49**, 447.
Caloi, V., Castellani, V., and Galluccio, D. 1984, in *Proc. 4th European IUE Conference* (ESA SP-218), p. 15.
Caloi, V., Castellani, V., Nesci, R., and Rossi, C. 1985, *Ap. J. Suppl.*, **59**, 505.
Capuzzo-Dolcetta, R. 1986, *Mem. Soc. Astr. Italiana*, **57**, 469.
Cassatella, A., Barbero, J., and Geyer, E. H. 1987, *Ap. J. Suppl.*, **64**, 83.
Cassatella, A., Lloyd, C., and Gonzalez Riestra, R. 1988, ESA *IUE* Newsletter No. 31.
Chiosi, E., Bertelli, G., and Bressan, A. 1988, *Astr. Ap.*, **196**, 84.
Clavel, J., Gilmozzi, R., and Prieto, A. 1988, *Astr. Ap.*, **191**, 392.
Cohen, J. G., Rich, R. M., and Persson, S. E. 1984, *Ap. J.*, **285**, 595.
Cowley, A. P., and Burstein, D. 1988, *A.J.*, **95**, 1071.
Elson, R. A. W., and Fall, S. M. 1985, *Ap. J.*, **299**, 211.
———. 1988, *A.J.*, **96**, 1383.
Fitzpatrick, E. L. 1986, *A.J.*, **92**, 1068.
Frogel, J. A., and Blanco, V. M. 1983, *Ap. J.* (*Letters*), **274**, L57.
Graham, J. A., and Nemec, J. M. 1984, in *IAU Symposium 108, Structure and Evolution of the Magellanic Clouds*, ed. S. van den Bergh and K. S. de Boer (Dordrecht: Reidel), p. 37.
Kurucz, R. L. 1979, *Ap. J. Suppl.*, **40**, 1.
Nandy, K., Morgan, D. H., and Carnochan, D. J. 1979, *M.N.R.A.S.*, **186**, 431.
Renzini, A., and Buzzoni, A. 1986, in *Spectral Evolution of Galaxies*, ed. C. Chiosi and A. Renzini (Dordrecht: Reidel), p. 195.
Russel, S. C., Bessell, M. S., and Dopita, M. A. 1988, in *The Impact of Very High S/N Spectroscopy on Stellar Physics*, ed. Cayrel de Strobel and M. Spite (Dordrecht: Kluwer), p. 545.
Savage, B. D., and Mathis, J. S. 1979, *Ann. Rev. Astr. Ap.*, **17**, 73.
Searle, L., Wilkinson, A., and Bagnuolo, W. G. 1980, *Ap. J.*, **239**, 803.
Sweigart, A. V., and Gross, P. G. 1978, *Ap. J. Suppl.*, **36**, 405.
van Albada, T. S., de Boer, K. S., and Dickens, R. J. 1981, *M.N.R.A.S.*, **195**, 591.
VandenBergh, P. A. 1983, *Ap. J. Suppl.*, **51**, 29.
van den Bergh, S. 1981, *Astr. Ap.*, **46**, 79.
Wyse, R. F. G. 1985, *Ap. J.*, **299**, 593.

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