INTERMEDIATE MASS STELLAR MODELS: AGES OF MAGELLANIC CLOUD STAR CLUSTERS

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Ages of six intermediate-age Large Magellanic Cloud star clusters have been estimated using the time dependent behavior of the luminosity of stellar interior models of red giants. All clusters studied, NGC 1783, NGC 1868, NGC 1978, NGC 2121, NGC 2209, and NGC 2231, were found to have ages $< 10^9$ yr. It is concluded that there is currently no substantial evidence for a major cluster population of large, populous clusters $> 10^9$ yr in the Large Magellanic Cloud.

The distributions of red giants on the six cluster color-magnitude diagrams were compared to a grid of 33 stellar evolutionary tracks, evolved from the main sequence through core-helium-exhaustion and up the asymptotic giant branch, spanning the expected mass range (2-3 solar masses) and metallicity range ($-0.2 \leq$ [Fe/H] ≤ -1.2) for intermediate-age Large Magellanic Cloud clusters. The faintest model core-helium-burners decreased in luminosity with decreasing mass; thus, model red giant luminosities decreased with age.

Although Cannon (1970) indicates that the mean M_V of the red "clump" giants reaches a limiting magnitude of +1, many galactic intermediate-age clusters exhibit red clump giants much fainter; e.g., the faintest red giants in NGC 559 reach $M_V = +2.5$, in NGC 1245, NGC 2477, and NGC 3496 they reach $M_V \simeq +2$.

Since the current main sequence photometry is generally still too inaccurate to obtain reliable Magellanic Cloud cluster ages with main sequence turnoffs, the red giant models have been used to estimate cluster ages (the red giant photometry is more accurate than the necessarily fainter main sequence photometry). These red giant ages are compared in Table 1 to the main sequence termination ages of Hodge (1982), Olszewski (1983), and Flower et al. (1983), the AGB ages of Mould and Aaronson (1982), and the integrated spectra ages of Rabin (1982). The red giant ages agreed with the main sequence termination ages; both techniques are based on cluster color-magnitude diagrams (CMD).

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TABLE 1 LMC CLUSTER AGE ESTIMATES (10^9 yr)

Cluster	Red Giants	MS Termination	Mould and Aaronson	Rabin	[Fe/H] Estimate	SWB Type
NGC 2209	0.8	0.7	3	1.5-2.5	-1.1	III-IV
NGC 1868	0.75	0.3	-	-	-1.2	-
NGC 2231	0.55	1.2	-	-	-1.3	V
NGC 1783	0.46	>0.2	3	4	-0.5	V
NGC 1978	0.45	0.7	2	>6	-0.5	VI
NGC 2121	0.39	0.4	4	5	-1.0	VI

In every instance of an age estimate for a cluster by both CMD and AGB dating techniques, the CMD ages are always significantly (factor of 3 or more) lower. The AGB ages are, however, very sensitive to the choice of the mass loss parameter used in the AGB evolutionary models (Renzini 1982). Increasing it from 0.45 (Mould and Aaronson 1982) to 1.0 will reduce all AGB age estimates to less than 10^9 yr. The AGB ages are also susceptible to statistical fluctuations in the luminosity function (in many clusters only one star defines the age).

Because the integrated spectra ages (Rabin 1982) are based on integrated light models that ignore the contribution of red clump giants, the extremely large ages (based on the strengths of the Balmer lines) are probably entirely unreliable. The working assumption of Rabin (1982) is that the blue part of the spectrum is dominated by the contribution of the brightest main sequence stars, those at the cluster turnoff. However, color-magnitude diagrams of populous LMC intermediate-age star clusters show a large number of bright, core-helium-burning red giants. In clusters like NGC 1978 (Olszewski 1983) and NGC 2121 (Flower et al. 1983), the red clump giants are at least a magnitude brighter than the brightest cluster main sequence stars. At colors near (B-V) $\sim$ 1, these giants are as bright in the blue as the main sequence stars.

The integrated light models used by Rabin (1982) were constructed from grids of stellar evolutionary models that did not include core-helium-burning giants; thus the important contribution of these giants to the cluster integrated light was ignored. Although such models may be applicable for sparce galactic clusters, they are inappropriate for populous galactic clusters like NGC 2158 and NGC 7789 and for the populous LMC clusters.

The strength of the red giant contribution to the integrated light from a cluster is a function of the number of cluster red giants, a stochastic effect, the magnitude of which is unknown to the observer and of the cluster metallicity (Flower and Jones 1983); the lower the metallicity, the brighter the core-helium-burning giants relative to the brightest main sequence stars.

Although it is clear that deep (CCD) cluster color-magnitude diagrams are needed to confirm the relatively low ages obtained for the LMC clusters listed in Table 1, it is equally clear that integrated photometric/spectroscopic dating techniques have serious flaws.

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DISCUSSION

McCarthy: Can you tell us more about how you determine the faintest giant star in a globular cluster?

Flower: For all the LMC clusters that I have dated there is a clear gap between the core-helium-burners or clump giants and the cluster main sequence. The distinctive red giant clump is the result of the clusters being too young ($\lesssim 3 \times 10^9$ yr) to exhibit subgiant branches and being very populated with red giants. Furthermore, most published data of LMC clusters also provide data of nearby star fields; thus the field contribution to the cluster CMD's can be accurately evaluated. This greatly improves the distinctiveness of the red giant clump.