THE STELLAR CLUSTERS OF M33

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ABSTRACT. Star clusters are a useful tool in the analysis of the stellar populations of galaxies, as they represent single age and abundance points which can be used to trace star formation activity. From HST WFPC2 multiband images of M33, we discovered a significant population of young, blue clusters, and compiled the first unbiased, representative sample of star clusters for this galaxy. Most of our 60 clusters are centrally concentrated and thus were confused with stellar objects in previous surveys. Our study extends the parameter space of known M33 clusters in two ways: (*i*) thanks to the HST spatial resolution, we could detect more peaked and intrinsically small objects (observable radii $\sim 1''$), which are not distinguishable from stellar objects in ground based studies; (*ii*) the far-UV and U,B,V images allowed us to reveal the youngest clusters and measure their ages, while studies of globular clusters usually employ V and I photometry, which is sensitive to a different parameter range.

By comparing the integrated photometry with evolutionary models, we find that the clusters formed continuously in M33 from $\sim 10^{10} - 10^{6}$ years ago. Combining the measured photometry and derived ages with theoretical M/L_V ratios we find cluster masses between $\sim 4 \times 10^{2} M_{\odot} - 3 \times 10^{5} M_{\odot}$. There is a correlation between the ages and masses of our clusters, the oldest objects being the most massive. The global properties of the M33 clusters are compared to other Local Group galaxy cluster systems. Clusters at all ages are found to have well relaxed density profiles which are reasonably well fit by King profiles. Core radii are found to be smaller on average than those of Galactic globular clusters and LMC populous clusters at similar magnitudes. Fifteen of the clusters are also bright in the far-UV.

1. Introduction.

A powerful way to learn about a galaxy's stellar content, and star formation history, is the study of its stellar clusters. Star clusters encapsulate a history of galaxy evolution. In individual packets, they represent single age and single abundance points which can be used to test stellar evolutionary models. Magnitudes and colors of Galactic cluster stars continue to provide fundamental data with which to compare (and improve) stellar evolution models. Determination of element abundances in cluster stars aids our understanding of the chemical evolution histories of the Galaxy. Positional information of clusters helps delineate Galactic structure, while velocities of clusters yield information on the kinematics of stellar populations and on the mass of the Galaxy. It is not yet known what physical factors favor the formation of star clusters and the cluster variations from galaxy to galaxy. The Magellanic Clouds (MC) are rich in star clusters, whereas the dwarf irregular galaxy IC1613 contains stellar associations, but almost no clusters (van den Bergh 1979). The widely varying specific frequency of globular clusters in galaxies indicates that cluster formation is almost certainly affected by the local environment within the galaxy.

Relationships between age, abundance, and kinematics can be probed using observations of star clusters in nearby, external galaxies where the distance is known for all members. The best studied external systems are M31 and the MC. M31 has a cluster population similar to that seen in the Milky Way. In our Galaxy, there is a large population of massive ($10^4 - 10^6 M_\odot$) globular clusters (GCs) with ages $> 10^{10}$ years, distributed in three kinematic components: a centrally concentrated, older halo, an extended, younger halo subsystem and a thick disk system (Zinn 1993). Much less massive ($10^2 - 10^3 M_\odot$) open clusters form a second distinct population of clusters in the Galaxy, with a wide range of ages ($10^6 - 10^{10}$ years), but for the overwhelming majority younger than GCs (e.g. Friel 1995). M31 exhibits a similar dichotomy of ages and masses between its open cluster and GC populations.

To date, the system of clusters in M33 has not been well studied. This small Scd Local Group galaxy, $\sim$ 15 times farther from us than the LMC (distance modulus = 24.64, Freedman et al. 1991) is interesting because it represents a morphological type intermediate between the largest spiral galaxies (Milky Way, M31) and the dwarf irregulars in the Local Group. Ground based works yielded a preliminary database of star clusters for M33 (Hiltner 1960; Kron & Mayall 1960; Christian & Schommer 1982, 1988). Christian & Schommer (hereafter CS) catalogued 250 nonstellar objects by visually examining $\sim 6.7''$ mm^{-1} direct plates of M33, and obtained ground based B, V and R photometry of 60 of these objects, which they believe to be star clusters, in an area $10' - 18'$ from the center of the galaxy (CS 1982). With $\sim 10\mathring{A}$ resolution spectrophotometry ($\lambda\lambda 3700-5500\mathring{A}$) of 20 of these objects, CS found these M33 clusters to have a range of ages of $\sim 10^7 - 10^{10}$ years and metallicities of $-2.0 < [Fe/H] < 0.0$ (CS 1983). Prior to our study, the total "true" globular cluster population of M33 was estimated to be only $\sim$ 20 (CS 1991). The initial evidence for a halo GC system (Schommer et al. 1991) in M33 is a surprising result given the extremely small bulge. The number and characteristics of the bluer cluster population remained uninvestigated to date, mainly because these clusters are predominantly located in the crowded spiral arm regions, and have centrally peaked profiles of $\sim 1-2''$ diameter. At the M33 distance of 840 kpc, $1''$ corresponds to a linear distance of 4.12 pc.

2. The Star Cluster system in M33

In five HST WFPC2 fields in M33 from our program GO6038 (Bianchi), with U, B, V, and far UV filters (F170W), and fifteen other fields from our previous programs and archive programs, we discovered 60 stellar clusters. Only 11 of them were previously catalogued as extended objects, and only four were previously confirmed as clusters. The characteristics in our sample range from UV-bright young clusters to red globular clusters. Most of our objects, however, have morphologies consistent with the "populous clusters" abundant in the Magellanic Clouds, and absent in the Milky Way and M31. Examples are shown in Figure 1. The cluster morphology and statistics are discussed in Chandar, Bianchi and Ford (1998a).

The M33 clusters follow single mass King profiles reasonably well. Core radii of the M33 clusters vary from less than 0.20 parsec to $\sim$ 2 parsecs, only a portion of the M_V vs. r_c parameter space observed in Galactic GCs. This may partially be due to

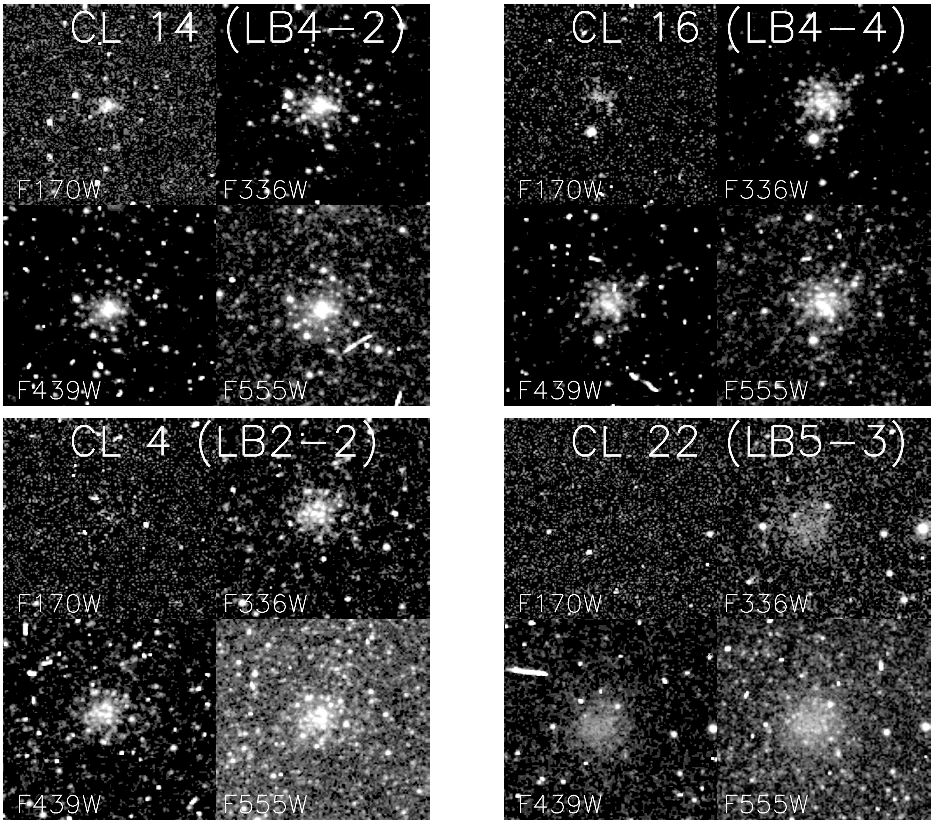

Fig. 1. Multiband images of 4 M33 clusters. The HST WFPC2 filters for each image, clockwise from upper left are: far-UV (1700$\AA$), U, V, and B. These clusters are chosen from the 60 objects of our sample to represent a morphology and evolution sequence: from youngest (centrally bright, compact, sharp peak in the UV) to oldest (close to globular cluster morphology, no UV emission). From Chandar, Bianchi & Ford (1998a).

observational bias in our sample. LMC clusters at similar magnitudes are more diffuse than M33 clusters (Chandar, Bianchi & Ford 1998b).

The integrated CMD and V luminosity functions of our sample indicate that clusters in M33 have a slightly broader distribution of colors than in the LMC. No young clusters brighter than $M_V < -9.0$ have formed in the twenty M33 fields studied; the most luminous young M33 clusters are ~ 1 magnitude fainter than their LMC counterparts. Luminous clusters between $0.3 < (\mathrm{B}-\mathrm{V})_0 < 0.6$ are not seen in our or CS's sample of M33 clusters (Chandar, Bianchi & Ford 1998b). This is also the case for the LMC. The so-called "gap" in LMC cluster formation appears to be a period of lower cluster formation efficiency, correlated with a drop in cluster magnitudes.

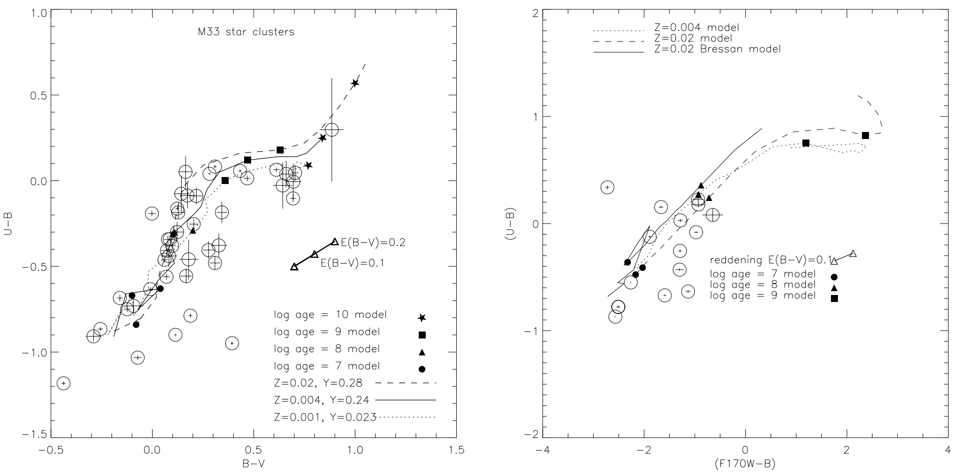

Fig. 2. Left: The WFPC2 photometry for M33 clusters is compared to stellar evolutionary models (Bertelli et al. 1994) for three metallicity values to derive cluster ages. The integrated (B−V) vs. (U−B) cluster colors are circled for clarity, and the photometric errors are represented by the error bars. The cluster colors have been dereddened by calculating E(B−V) from nearby stars. Figure from Chandar, Bianchi, & Ford (1998b). Right: The far-UV (1700Å) magnitude for the UV-bright clusters of our sample is used to derive ages for the youngest objects. The evolutionary models shown are from Chiosi et al (1997).

The integrated (B−V) vs. (U−B) cluster colors have been compared with stellar evolution models to estimate cluster ages (Figure 2, left). We find the star clusters to have a range of ages from 4×10^6 to 15×10^9 yrs, and that formation of these clusters has been fairly continuous during this period. The comparison also gives an indication of metallicity in some cases. There is evidence for a population of clusters with solar metallicity around $1-3\times10^8$ years, and a distinct turnoff to lower metallicities (Z=0.001 and Z=0.0004) around 10^9 years (Chandar, Bianchi and Ford 1998b). Fifteen of these clusters have detectable far-UV (1700Å) flux. These are the youngest clusters ($\leq 10^8$, see Figure 2-right), thus more accurate ages can be estimated from the UV and blue colors. For instance, the F170W-B color spans a range of two magnitudes for clusters younger than 10^8 years, as compared with a range of 0.4 mag. for (B-V). Moreover, the V-band photometry for three of these clusters is contaminated by serendipitously sumperimposed red supergiants, making the (B-V) color useless. Red field stars do not affect the UV measurements. Analysis of the far-UV emitting clusters is in preparation, in collaboration with A.Bressan and B.Salasnich (Padova).

Chandar, Bianchi & Ford (1998b) find a peak in cluster formation in M33 between $\sim 10^7 - 10^8$ years ago. This epoch corresponds to an inflow of gas in the center of M33 which sparked the formation of a blue, metal rich bulge population. We postulate that the gaseous inflow is also responsible for the enhanced overall cluster formation during this period. A similar peak is found in the LMC cluster population.

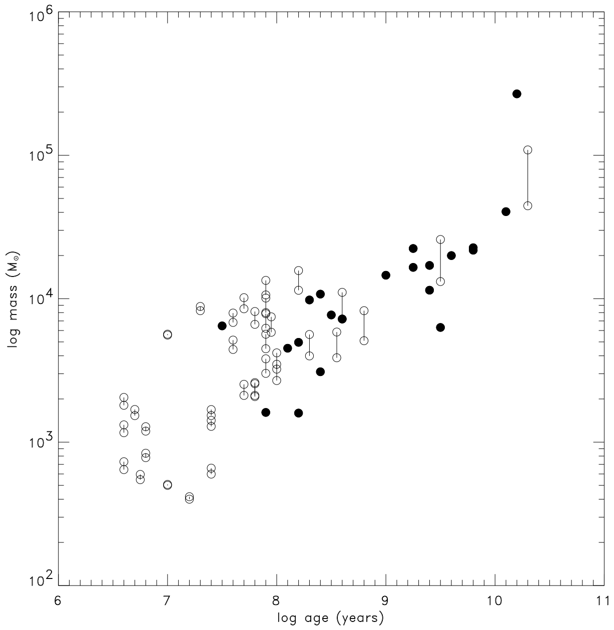

Fig. 3. Mass *vs.* age for the M33 clusters (from Chandar, Bianchi, & Ford 1998b). Filled circles represent masses for clusters where the metallicity could be constrained to either Z=0.02 or Z=0.001. The connected pairs of open circles represent the mass range from both the Z=0.02 and Z=0.001 models for clusters where the metallicity could not be constrained yet.

Luminosities and ages combined with theoretical mass-to-light ratios give mass estimates for M33 star clusters between $4 \times 10^2 M_\odot - 3 \times 10^5 M_\odot$. An important result is that M33 cluster masses have been systematically decreasing from the oldest to youngest (Figure 3), confirming again that young M33 clusters are numerous, but not as massive as the old clusters. In Figure 3, the lack of clusters with low masses at old ages could be due to fading of the small clusters below our detection limits (see Chandar, Bianchi and Ford 1998b for details), while the lack of massive clusters towards younger ages is real. In fact, if there were young massive clusters these would be certainly detected with our choice of filters. There is a small population of old, luminous M33 clusters which, in spite of fading, are more luminous than the young M33 cluster population. Chandar, Bianchi and Ford (1998b) also report the first collapsed core candidate cluster in M33.

Acknowledgements

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