THE CLUSTERS OF M 33

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1. INTRODUCTION

Star Clusters are essential tools in studies of stellar and galactic evolution and in cosmology. In reference to investigations of stellar populations, star clusters are used to probe the chemical enrichment, kinematical and dynamical history of a galaxy. The relationship between the characteristics of a cluster population and the morphology of the parent galaxy is enigmatic, however.

In our Galaxy the two groups of clusters, the globulars and the open clusters, are quite distinct in spatial distribution, age, chemistry mass, etc. The sample of open clusters is fairly restricted due to severe selection effects inherent in studies of the Galactic disk (c.f. Janes and Adler 1982). In M31, it appears that globular clusters share some similarities with their galactic counterparts but there are important differences. Little is known about the M31 population equivalent to the galactic open clusters due to the difficulty in observing the highly inclined M31 disk. A first look at the global characteristics of cluster populations in galaxies comes from studies of the Magellanic Clouds (MC) where it was found that few globulars exist but that a large population of massive "globular like" young to intermediate aged clusters exists.

This information uncovers many puzzles concerning galactic structure and evolution as well as problems in stellar evolution. One is lead to speculate about the parameters that lead to cluster formation, for example for galactic globular clusters there appear to be relationships between metallicity, mass functions, tidal truncation and possibly orbital parameters (see Pryor, Smith, and McClure

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1986 and references therein) that are clues to cluster formation processes.

For the LMC it has been suggested that the populous star clusters are confined to disks possibly inclined as a function of age (Freeman, Illingworth and Oemler 1983; hereafter FIO). In M31 and the Galaxy it appears that except for globulars these clusters may be rare although selection effects may exacerbate the discovery of such objects. One naturally turns to the Sc galaxy M33 for clues to these riddles. The modest inclination of the galaxy (~60°) allows the global properties of a cluster population to be examined which is particularly of interest because it is the only Local Group spiral that can be studied so extensively.

2. PREVIOUS WORK ON M33 CLUSTERS

2.1 Catalogues and photometry

The first hint that M33 clusters were not completely analogous to M31 and galactic globulars came from the photoelectric photometry of Hiltner (1960) and Kron and Mayall (1960) who discovered that several of the brightest clusters are bluer than even the bluest globular clusters in the Galaxy. The cluster population was also surveyed extensively by A. Sandage and P. Osmer by examination of Palomar 5m plates taken in three colors (A. Sandage, unpublished). These plates were also used by Humphreys and Sandage (1980) for a study of bright blue and red stars in M33 and for the studies of M33 Cepheids (Sandage and Carlson 1983 and references therein) where printed reproductions of several of the fields can be seen. Over 500 clusters were found covering wide range of ages.

More recently, a catalog of clusters was compiled by R. Schommer and myself (Christian and Schommer 1982, hereafter CSI) that included over 250 nonstellar objects. The objects were selected from Kitt Peak National Observatory (KPNO) 4m Richey-Chrétien and 4m prime focus plates. We specifically looked for nonstellar objects with uniform symmetric profiles with the goal of finding MC type star clusters. BVR photometry was obtained for a sample of 60 of the objects, which when combined with the previous photometry suggested that the clusters are fairly uniformly distributed in (B-V) from 0.0 mag to 0.8 mag. The apparent magnitudes of the surveyed objects suggest that there is a substantial population of clusters brighter than $M_V = -5$ at <u>all ages</u>. Compared to the LMC it appears that the formation of these clusters is less episodic than in the LMC. The intermediate aged M33 clusters are much brighter (and hence more massive) than the most populous clusters known in the galaxy such as M67 and NGC2158. Therefore it appears that the M33 cluster population is quite distinctive compared with the other Local Group galaxies. We were therefore tempted to suggest that the distinctive characteristics of M33 cluster population are causally related to the galaxy's intermediate mass and morphology which must determine the star formation history in the galaxy.

2.2 Spectroscopy

While the photometric studies were indicative of the M33 cluster population further investigation as to the identities and the age-metallicity kinematic relationships is important. Intermediate resolution spectroscopy (~10Å) was obtained at KPNO with the Intensified Image Dissector Scanner (IIDS) on the 4m (Christian and Schommer 1983, hereafter CSII). Twenty M33 clusters were observed covering the range of (B-V) sampled in the photometric surveys. Spectrophotometric indices measuring Hβ, Mg b, the Ca H and K lines and the 4200Å CN features indicated that the photometric results were correct: the M33 massive clusters occur at the full range in ages with metallicities from [Fe/H] = -2.0 to nearly solar, with metallicity roughly correlated with age. These results agree with an independent studies by Cohen, Persson and Searle (1984) and Sharov and Lyutyj (1984).

The kinematics of the cluster system appears to be more typical of a spiral (disk) galaxy than in the LMC in that the oldest clusters appear to have "random" velocities when compared to the HI disk rotational velocities, but clusters with ages $<10^{10}$ years appear to follow the disk rotation. These results suggest that kinematically the clusters "know" they are in a spiral galaxy but that the environment for formation (and disruption) of clusters does not inhibit continuous production of massive systems.

3. RECENT INVESTIGATIONS

3.1 Catalog

The catalog of M33 clusters in CSI, while extensive, cannot be considered complete due to selection effects involving the plate material used and our cataloging procedure which avoided regions of dust and star formation. In fact as noted in CSII some of the brightest clusters were found close to the galaxy's nucleus by R. Racine on short 3.6m plates taken at the Canada-France-Hawaii Telescope (CFHT) in very good seeing.

Also, it was known that an extensive catalog of clusters had been compiled at Palomar. Dr. A. Sandage kindly lent the catalog material including prints and plates to me in order that a new catalog may be published. With the assistance of D. Ward (University of Hawaii) the two catalogs (Palomar and CSI) were cross referenced and all objects identified were reclassified into two bins solely on the basis of morphology. The first group represents clusters as specified in the CSI catalog; namely objects with non-stellar symmetric profiles. Nearly all of the CSI objects identified as "clusters" are in this group. In addition a large percentage of objects designated as "UFO" in CSI, a handful of objects identified as "H" in CSI (see CSII), and roughly 40% of the Palomar clusters are designated cluster candidates.

The second group which have asymmetric or extremely diffuse morphology or which are clearly imbedded in nebulosity were classified as "younger" objects. The majority of objects classified as "H" in CSI, a substantial number of "UFO" objects and the remainder of the Palomar clusters fall in the second group.

The spatial distributions of the two groups (Figure 1) are revealing. The younger objects do preferentially lie within regions that correspond to the most active star formation regions. The mamority of the objects appear to be truly imbedded in nebulosity although it is possible that some of the objects are "clusters" superimposed on star formation regions. The uniform morphology clusters are in clearer regions of the disk including the outlying regions. The catalog is relatively complete to V = 19.0 but there are significant numbers of objects that can be identified to V ~ 20.

The spatial distribution for the most part is fairly uniform except it can be seen in Figure 1 that there is a lack of clusters in the SE quadrant of M33. This is an area notably deficient in star formation regions and disk population possibly due to obscuration. There are a few outlier clusters, one notable example is C39 (Figure 1 in CSI) an intermediate aged cluster (CSII) situated in this region of M33 that appears devoid of a significant stellar population.

The new catalog is being prepared for publication and will include cross references to the previous catalogs.

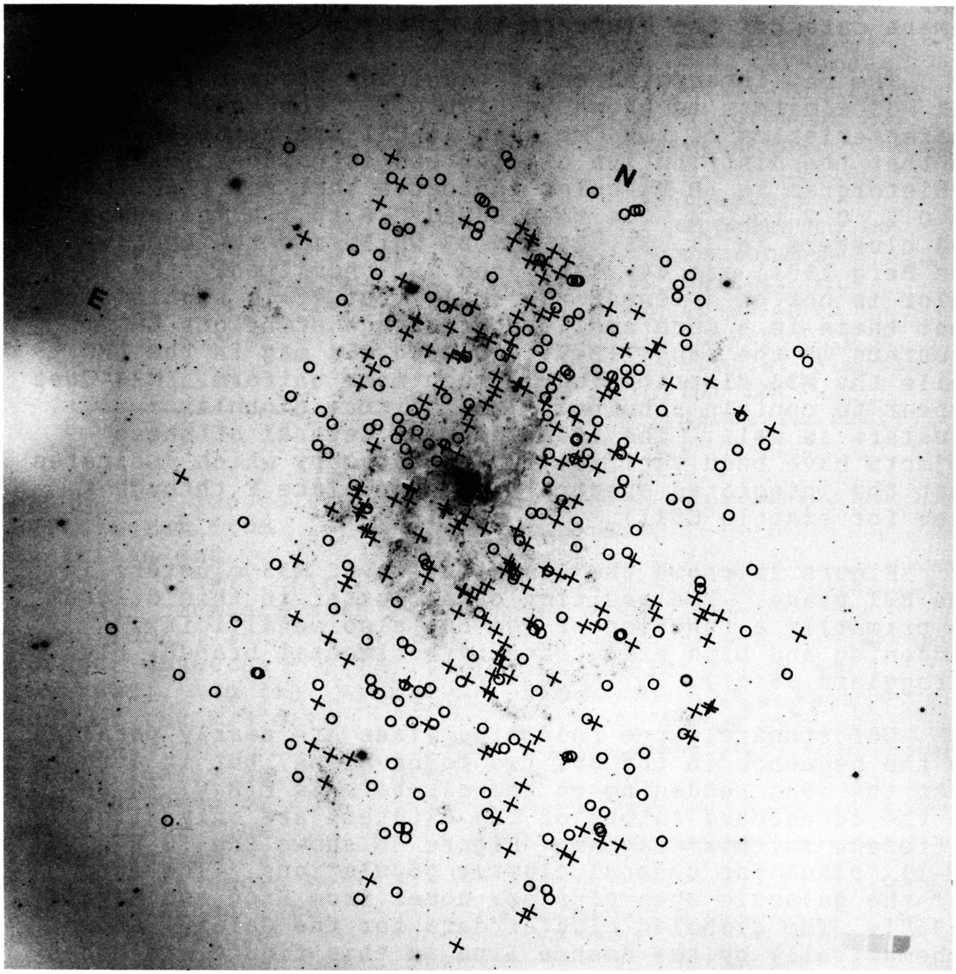

Fig. 1. Spatial distribution of objects classified as clusters (circles) and younger objects (crosses).

3.2 Optical Photometry

It is now of interest to study the cluster population of M33 in even greater depth. To this end CCD frames in B, V and I were obtained at the University of Hawaii 2.2m using the Galileo/IFA 500^2 TI 3 phase CCD. Thirteen frames with 128 objects from the new catalog have been measured with an aperture photometry algorithm. The average seeing on the two photometric nights was ~0.8 arcsec so that the extended profiles of the many of the clusters are quite obvious. The CCD B-V photometry agrees well (0.02 mag) with the previous photoelectric and video camera data for the clusters in common.

The new integrated color-magnitude diagram (CMD) for all M33 clusters is shown in Figure 2. The basic characteristics of the CMD seen in CSI are reinforced here in that the distribution of clusters is uniform in (B-V). A historgram in (B-V) color indicates that for the bins 0 to 0.2, 0.2 to 0.4, 0.4 to 0.6 and 0.6 to 1.0 the number of M33 clusters is 21, 26, 25 and 23 while for the LMC (van den Berg 1981) are 44, 43, 7 and 29. Admittedly the (B-V) color is not on a linear age scale, but it is significant that there is a much smaller percentage of bright LMC clusters in the range (B-V) = 0.2 to 0.4 mag in the LMC while the M33 distribution is much more uniform. M33 does appear to contain a number (~20) of true globular clusters as well. The identities of several of these objects have been verified by spectroscopy which indicates that the integrated spectral types are late F through K (see for example CSII).

Figure 3a shows the distribution of M33 clusters in the BVI plane. The position of a cluster in this diagram is primarily a function of age but also metallicity, reddening and blue star content (horizontal branch, blue stragglers, etc.).

Unfortunately the reddening lines are nearly parallel to the sequence in the BVI two color plane, but it appears that the mean reddening to the clusters is E(B-V) ~0.09 so the dereddened colors of the clusters are only slightly different in this diagram. Figure 3b shows the $(B-V)_0$ vs $(V-I)_0$ plane for several cluster populations. The data for the galactic open clusters comes from Kron and Mayall (1960). The globular cluster data for the Galaxy, shown schematically by the dashed line in this figure are Hanes and Brodie (1985). The galactic open clusters and globulars blend with the M33 sequence. The bulk of the M33 tend to be bluer in (B-V) at a given (V-I) than galactic clusters but the scatter is large.

A rough age calibration could be derived by considering the ages of the galactic clusters derived from Janes' and Adler's (1982) compendium. The ages assigned to M33 clusters agree for the most part with the ages for the M33 clusters in CSII and with the ages assigned by Sharov and Lyutyj (1984) from UBV photometry. By assigning ages according to the line shown in Figure 3b the age distribution of the clusters can be examined. After assigning ages to the clusters, an S index for each object can be derived using Elson and Fall's relation (1985b;

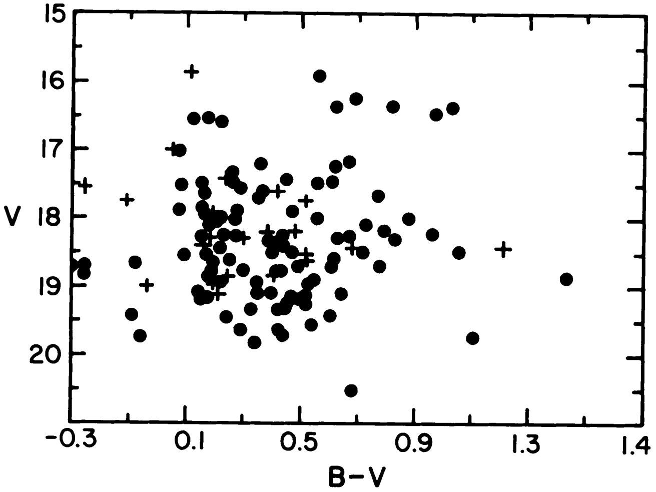

Fig. 2. The new integrated color-magnitude diagram of M33 clusters. The distribution of clusters appears to be reasonably uniform in (B-V) when compared to a similar diagram for LMC clusters (CSI).

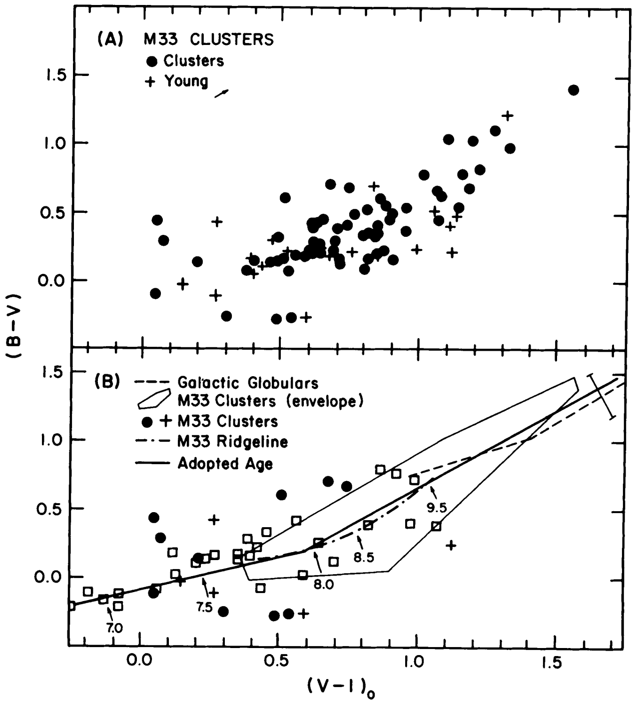

Fig. 3. Two-color BVI diagram from Christian and Schommer (1987). In (a) M33 clusters are shown (dots) and younger objects (crosses). In (b) most of the M33 data is shown schematically as the area enclosed by the solid line. The ridge line of M33 clusters is shown by the dot-dashed line, while the younger objects are shown explicitly because they scatter widely in this plane. The data for galactic open clusters from Kron and Mayall (1960) are shown as boxes, and the locus of galactic globulars from Hanes and Brodie (1985) is shown as a dashed line where the error bar indicates the scatter in the data. Finally the bold line shows the line chosen for the age calibration. Ages are indicated.

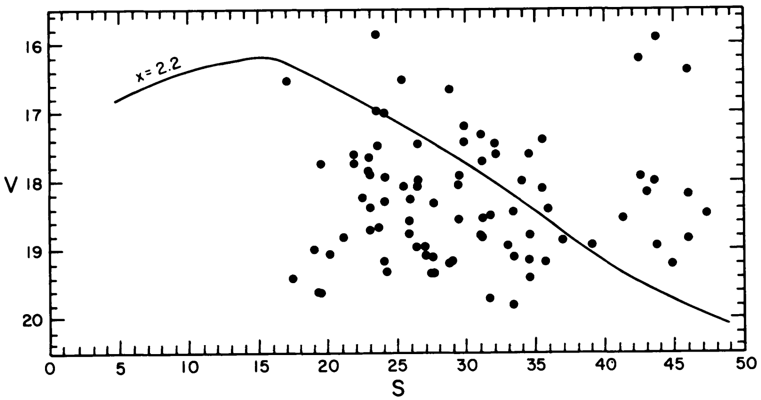

Fig. 4. The V magnitude vs. S diagram for M33, where the ages determined in Figure 3b have been transformed to Elson and Fall's (1985b) S parameter. This diagram is used to choose a mass limited sample of clusters

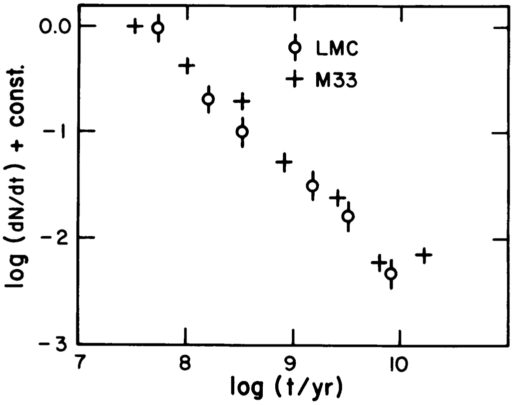

Fig. 5. The age distribution of M33 clusters (crosses) and LMC clusters (circles). The LMC data is taken from Elson and Fall (1985b). The data is not corrected for "completeness" but it is anticipated that the selection effects in the two samples may be similar. Both samples are mass limited using an x=2.2 IMF.

their Figure 2). The magnitude vs. S figure (Figure 4) analogous to Elson and Fall's Figure 3 is used to select the mass limited sample of M33 clusters. The sample is selected with the x = 2.2 IMF similar for the LMC sample. The uncorrected age distributions for the LMC and M33 clusters are shown in Figure 5 where it is seen that the two distributions are nearly identical. Considering that the selection effects may be similar this figure implies that the age distributions in the two galaxies are much flatter than an IMF with x = 2.2. As Elson and Fall (1985b) discuss, only the richest clusters in the Galaxy follow this relation. One wonders whether the fainter open clusters in either M33 or the LMC follow the IMF with x = 2.2 as the galactic open clusters do, i.e., that the flatness in the age distribution is a function of mass.

Elson and Fall also argue that the smoothly declining age distribution suggests that the number of true globulars in the LMC is indeed small. However in M33 the age distribution seems to flatten out as shown by the last point in Figure 6, that is, the number of globular aged clusters does not follow smoothly from the other data. However selection effects (i.e. the globulars are preferentially observed?) could enhance this last data point. As Elson and Fall mention this diagram does not indicate that star formation in the LMC has been "bursty" yet the histogram of clusters in (B-V) suggests otherwise. It is clear that more complete samples may aid in determining whether the cluster formation histories in Local Group galaxies has been episodic or not.

3.3 Infrared Photometry

Persson et al. have shown that infrared photometry can be a tracer of carbon star content in integrated systems as well as being used to establish a longer wavelength base for stellar population studies. Cohen, Persson and Searle (1984) have used a number of photometric indices including infrared colors to examine a few M33 clusters. Aaronson, Riecke and Christian (unpublished) have also obtained JHK photometry for some of the brighter clusters. The sample is still small but the photometry suggests that some M33 clusters may indeed contain carbon stars. In collaboration with H. Zinneker and R. Cannon a more extensive survey will be accomplished for population synthesis to probe the existence of carbon stars in M33 clusters as well as to examine the metallicities of clusters as measured by the (J-K) color (Frogel et al. 1980). The more uniform distribution of ages in M33 should allow a reasonable test of carbon star production rates as well as examination of metallicity and population effects in cluster systems.

4. OTHER RESULTS

4.1 Luminosity Function

Elson and Fall (1985a) have discussed the properties of the luminosity function of LMC clusters in relation to galactic open clusters. They find that the differential luminosity function of the LMC clusters, which is dominated by clusters younger than 10^{10} years resembles the luminosity function for galactic open clusters (Figure 6). They further argue that luminosity functions of young to intermediate aged clusters are biased at the faint ends due to observational limits and that there is no evidence that the LMC "populous" clusters follow the universal luminosity function of galactic and M31 globular clusters. In fact Elson and Fall (1985a) maintain that the luminosity function of the LMC clusters follow a power law $\phi(B) \sim L^{-\alpha}$ where $\alpha \sim 1.5$. The differential luminosity function of the M33 clusters is also shown in Figure 6 as well where an apparent blue distance modulus $(m-M)_B$ = 24.6 has been adopted (Christian and Schommer 1986). It is seen that the M33, LMC and galactic open clusters all have similar differential luminosity functions, rising in the similar way.

The luminosity histograms for the (B-V) color bins <0.3 mag, 0.3 to 0.6 mag and <0.6 mag are shown in Figure 7. The luminosity functions for clusters with ages $<10^{10}$ years are clearly rising at V=19.0 mag. There is evidence for "fading" in the intermediate aged group in that the brightest clusters with 0.3 < (B-V) < 0.6 are fainter in V than the brightest young clusters.

The luminosity histogram of the measured globulars, (B-V) > 0.6 mag (Table I) is shown in Figure 7c. The luminosity function does not resemble the qaussian galactic globular or M31 globular luminosity functions although the number of objects (25) is very small for statistical purposes. In particular the four clusters brighter than V = 16.4 mag (three of which have been verified with spectroscopy) stand out. These four objects are located at projected distances <9 arcmin (~1.8 kpc) from the center of the galaxy. The mean V magnitude of all the red clusters is ~18.0 mag with σ=1.1 mag. It is possible that some of the bluer clusters in the sample are in fact intermediate aged clusters, so assuming that the mean reddening is E(B-V)=0.09 mag and taking the red clusters with $(B-V)_0$ > 0.6 mag one obtains <V> ~ 17.8 mag with σ = 1.0. The dispersion here is similar to that for galactic and M31 globulars yet the implied mean absolute usual magnitude $<M_V>$ is ~-6.7 mag assuming an apparent B distance modulus of 24.6 mag to M33. [This assumes $(m-M)_0$ = 18.5 mag for the LMC, a relative distance modulus of 5.7 from the LMC to M33 (Christian and Schommer 1986) and a mean reddening of E(B-V) = 0.09 mag for the red clusters]. It is interesting to note that the mean <V> magnitude for clusters at projected galactocentric distances <10 arcmin (~2kpc) is 17.4 while the more distant objects have <V>=18.4. While it is true that there are three primary selection effects influencing the data; namely (1) the small number of objects surveyed; (2) the selection of fields for the CCD survey and (3) the identification of objects in the central parts of M33 is biased towards brighter objects due to severe background contamination, it is unlikely that many bright objects at large radii have been missed. In fact most of the bright distant red objects in the M33 field identified by ourselves and Melnick and D'Odorico (1978) have turned out to be galaxies as determined from their

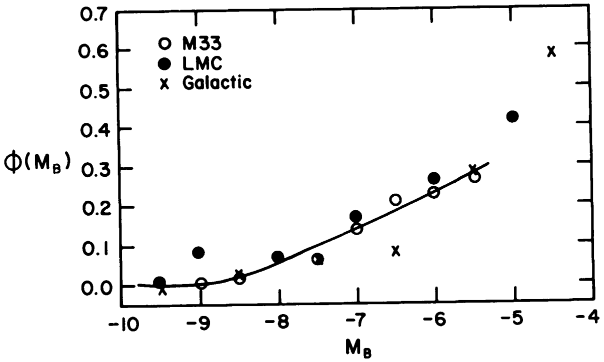

Fig. 6. The differential luminosity function for the LMC (filled circles), galactic open clusters (x's) and M33 clusters (open circles). All three distributions follow a power law L_B^{α} where Elson and Fall (1985a) adopt α=1.5.

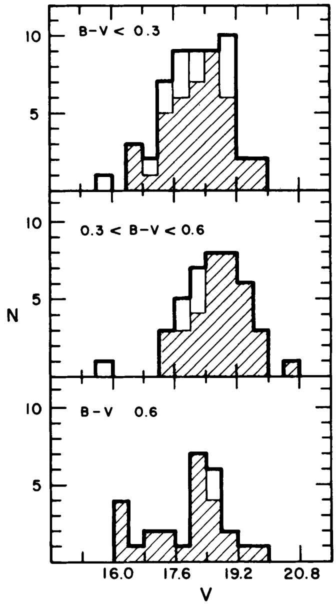

Fig. 7. V luminosity histograms for three color groups: (a) (B-V) <0.3 mag, (b) 0.3 < (B-V) <0.6 mag and (c) (B-V) > 0.6 mag (globulars).

radial velocities (Table II) and most distant positively identified bright cluster is C39 which is an intermediate aged cluster. It should be noted that this trend for the brightest clusters to be more centrally concentrated has been reported for the M31 globulars by Crampton et al (1985).

4.2 Kinematics

In the LMC it appears that the clusters are distributed in disk like structures where the inclination of the disk varies with age. Considering that M33 is a *bona fide* spiral galaxy, it is of interest to study the kinematic of the cluster population as a function of age. Velocities of several M33 clusters have been obtained (Cohen, Persson and Searle 1984; CSII). In addition several more velocities have been obtained with the MMT Schectograph and reduced with a cross correlation technique. A summary of all velocities with rms error σ < 50 km/sec appear in Table 3 where the clusters have been divided into the same color bins as for Figure 7. It is obvious from column 4 in this table that the young and intermediate aged clusters follow the HI disk reasonably well. The red clusters are much more randomized suggesting a halo structure as in other spiral galaxies. The red clusters do not exhibit any rotation at levels <50 km/sec. The youngest clusters tend to follow more closely the HI rotation, but more spectra are required to study in detail the kinematics of each age group.

4.3 Chemical Enrichment

Aaronson (1986) has discussed the chemical enrichment histories of the Galaxy, the LMC and the SMC as traced from the stellar populations. From the current data it appears that the Galaxy underwent rapid chemical enrichment while the enhancement in the MC was much more "leisurely" as can be seen in Figure 8, adapted from Aaronson's Figure 1. A look at the chemical enrichment history of M33 can be derived from spectroscopy of the clusters with ages assigned from the BVI data as described above. Metallicities are estimated from the M_{HK} vs Hβ data in CSII. M33 has a radial abundance gradient as evidenced from HII region surveys described by Pagel and Edmunds (1981). These data are also shown in Figure 8. In anticipation of metallicity differences between inner and outer regions in M33 the clusters are plotted so that clusters at projected radii <10 arcmin are distinguished from the inner clusters. Also shown is the data point from Mould and Kristian's (1986) study of the halo population in M33.

It is clear that at each age there is a dispersion in the abundances. It also appears that the inner population follows an enrichment history similar to the LMC while the outer objects have a history more similar to the SMC. That is, the chemical enrichment history is a function of radius in M33. In the mean M33 is more metal poor than the solar neighborhood at a given age although at the current epoch solar metallicities appear to have been achieved in the inner most regions. The oldest stellar population, namely the globulars and the halo population cover a range in metallicity from $2.2 < Fe/H < -1.0$ with no known clusters as enriched as the galactic globular 47 Tuc or the red M31 globular clusters.

For some of the intermediate aged clusters the assigned metallicities suggest some clusters in M33 are more metal rich than LMC clusters. In fact comparison of several clusters (eg. U83, C27 and H21: CSII) do appear to have stronger metal lines than LMC clusters (eg. NGC2209: Rabin 1982) at a given Hβ strength.

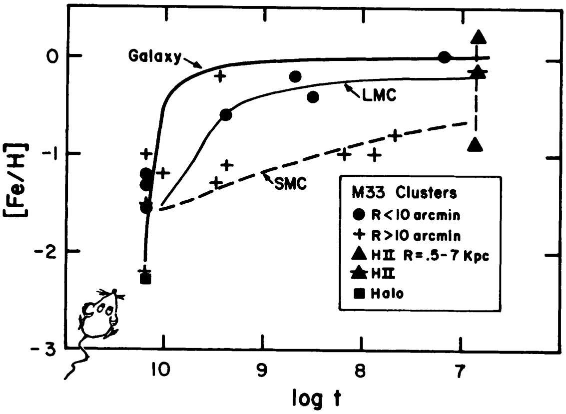

Fig. 8. The chemical enrichment history of the Galaxy, LMC and SMC (adapted from Aaronson 1986). The data for M33 suggest that the inner regions of the disk were enriched more rapidly than the outer regions.

5. SUMMARY

The investigation of star clusters in M33 has been very useful as a probe of the stellar population in that galaxy. The main results to date have been:

(1) M33 contains a substantial population of massive clusters that are more or less evenly distributed in color. The color distribution appears more uniform than for LMC clusters, but the mass limited (uncorrected) age distributions of M33, the LMC and the high richness class galactic open clusters are similar.

(2) JHK photometry suggests that several of the clusters may have carbon stars although further investigation is required to fully map the carbon star production rate in M33 clusters as a function of age.

(3) The optical luminosity functions of three main color groups, (B-V) < 0.3 mag, 0.3 < (B-V) < 0.6 mag and (B-V) > 0.6 mag (globulars) show that the luminosity functions are still rising at V = 19.5 and there is some evidence for luminosity fading in the intermediate color group. The luminosity function for the globulars does not resemble the "universal" gaussion function found in M31 and the galaxy. The mean V magnitude is much fainter than expected although the selection effects may dominate the small sample. There also is evidence that the mean <V> for the inner clusters is higher than that for the outer (R>10arcmin) clusters. It is true that fainter clusters may be missed in the inner regions but it is very unlikely that bright clusters have not been found in the relatively clean outer regions of the M33 disk.

The differential luminosity function of all M33 clusters resembles strongly the function for LMC and galactic open clusters following an exponential of the form

$\phi(B) \alpha L^{-\alpha}$ where $\alpha = 1.5$.

(4) The chemical enrichment history of M33 appears to be less dramatic than that for the galaxy. The outer part of the disk shows a gradual enrichment similar to the SMC while the inner regions are more similar to the LMC. Some clusters at a given age and Hβ strength appear to be stronger lined than corresponding LMC clusters. The chemical enrichment history of M33 appears to be a function of position in the disk.

(5) The kinematics of the clusters, based on a small sample of objects suggests that the globular clusters have randomized velocities but no appreciable rotation in excess of 50 km/sec. The velocities of young and intermediate aged clusters are disk like, so at some point M33 experienced a disk collapse as for other spiral galaxies. The chemical enrichment history is to be studied in greater detail to detect any evidence of the collapse on the enrichment. It may be that the inner disk has collapsed rapidly causing rapid enrichment but he outer disk has collapsed more slowly.

The work related to the M33 cluster photometry and spectroscopy is being done in collaboration with R. Schommer. We wish to acknowledge support of NSF grant AST 8412515.

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TABLE I.

Red Clusters

Cluster	V	radius(')
U 49	16.25	8.3
R 13	16.36	2.9
R 12	16.38	4.5
R 15	16.38	4.9
R 14	16.48	3.2
M 9	17.12	10.0
C 20	17.16	18.4
U 77	17.19	5.7
H 38	17.25	10.6
H 21	17.46	9.0
C 36	18.00	13.9
C 38	18.10	17.9
C 18	18.17	15.9
H 10	18.23	10.1
C 3	18.26	19.1
C 32	18.29	6.6
U 137	18.30	14.3
C 21	18.60	11.3
U 23	18.70	11.0
C 9	18.71	15.7
S 24	18.49	18.5
S 72	18.49	7.0
S 247	18.87	19.9
U 67	19.11	6.8
S 161	19.43	9.7
S 160	19.73	10.0
U 7	20.51	16.2

TABLE II.

Compendium of Velocities

THE GOOD		SIG <+/- 50 KM/SEC		
I.D.	B-V	Vel +/-	V-V(HI)	ref
Young				
M 4	0.21	-255	10	CPS
M 6	0.21	-245	15	CPS
U 62	0.12	-220,-255	15,20	CSII, CPS
U 138	0.18	-116 +/- 41	<5	MMT
Intermediate				
C 27	0.37	-210	24	CSII
C 39	0.56	-145	0	CSII
Old				
C 20	0.77	-160,-62	85	CSII,MMT
H 21	0.61	-165	40	CSII
H 38	0.83	-200	80	CSII
U 49	0.68	-185,-125,-91	50,100	CSII, CPS, MMT
M 9	0.72	-300	115	CSII
R 12	0.77	-190	12	CSII
R 14	0.68	-125	62	CSII
U 137	0.83	-7 +/- 29	100	MMT
H 10	0.96	-284 +/-39	65	MMT
THE BAD		(Galaxies)		
MD18		20,500		MMT
MD57		10,260		MMT
MD58		37,066		MMT
MD53		>20,000		MMT
U 90		30,500		MMT
THE UGLY				
Many		(To be remeasured)		

Notes: MMT = MMT spectra obtained by Huchra, Bothun, Schommer, and Christian
CPS = Cohen, Persson, and Searle (1984)
MD = Melnick and D'Odorico (1978)

DISCUSSION

ALCAINO: It is interesting to notice that the color-magnitude diagram of the integrated light of the clusters in M 33 does not show the clear dichotomy among blue and red objects seen in both Magellanic Clouds, in spite of the similarities suggested in your talk about the clusters in these galaxies. Are the four bright ($V \sim 16$) red ($B-V>0.6$) clusters shown in your luminosity function of red clusters true globular clusters?

CHRISTIAN: The histogram in (B-V) indicates that the LMC clusters are not as evenly distributed as the M 33 clusters so that one may think that M 33 has had a much more continuous cluster formation rate than the LMC. The four bright red clusters have been measured spectroscopically. Their integrated spectral types are G0, G4 and late F.

RICHER: Your comment about the M 33 clusters being a good place to look for the onset of the carbon star phenomenon, is this based on the fact that the age distribution is more continuous in M 33 than that for the LMC?

CHRISTIAN: Yes, it seems that the distribution of (B-V) colors for the clusters suggests that there are plenty of clusters at each age. The CCD data sample about 30% of the galaxy so one anticipates that there are many clusters at a given age. It would be interesting to sample the clusters with a fine age resolution and look for the onset of carbon star production.

KING: Will these clusters be good HST targets for the study of horizontal branches? And could you remind us of the distance modulus of M 33? I believe Sandage has recently revised it on the basis of a correction to Hubble's photometry.

CHRISTIAN: Some of the M 33 clusters would be excellent targets for color-magnitude diagram studies. I know of a few groups writing proposals to do this. The distance modulus we used was 24.6 in V-apparent. the revised modulus proposed by Sandage based on Hubble's data is a complicated issue and is a subject of a new preprint discussing CCD data relative to Hubble's data. The full description of this work is beyond the scope of the M 33 cluster work presented here.

ZINN: If I remember the recent work of Elson & Fall correctly, they found that the age distribution of the clusters in the LMC was similar to that of the open clusters in the Milky Way, except that there is a tail of the LMC distribution indicating that: it has relatively more clusters with ages $\sim 5 \times 10^9$ yrs. (I don't remember the precise age range). Can you clarify whether or not you find a similar effect among the M 33 clusters?

CHRISTIAN: The age distribution for the LMC and galactic open clusters apparently matches for younger clusters, i.e., those younger than ~10^9 yr. The data is normalized at the young end. In the vicinity of 10^9 yr. the applied completeness corrections become significant. The flatness of the corrected counts could largely be due to the completeness corrections. The uncorrected counts indicate that the number of globular clusters in the LMC is expected to be small. Whether the M 33 data really turns up at the oldest data point is not clear because the CCD data was selected perhaps preferentially near globular clusters. The M 33 data turns up at ages ~ 5×10^9 yrs only if the LMC completeness corrections are valid and applicable to M 33 data. The match between uncorrected counts in M 33 and the LMC at all ages could be taken as evidence that the age distributions are the same if one believes that the selection and completeness effects are the same in the two samples. However, it is disturbing that the uncorrected counts match as well as they do because the M 33 sample was assembled in a relatively "cavalier" way with rather crude ages so one wonders how valid these age distributions are. Secondly, some LMC fields show that the history of star formation may be episodic yet this is not seen in the age distributions. We can see a significant difference in the (B-V) histograms of the M 33 and LMC clusters so that one would expect the age distributions to be <u>different</u>. It will be interesting, eventually, to study the detailed age distributions with finer age resolution as a function of position in both galaxies. As well, we want to know the age distribution of the massive (high richness class) clusters in the galaxy which are apparently similar to the LMC clusters and by reference the M 33 clusters. It would also be interesting to study the age distributions of "classical" open clusters in all three galaxies.

NEMEC: Do you see any evidence for rotation in the M 33 star cluster system? And, would your survey have identified outlying globular clusters such as NGC 2419 in the Galaxy?

CHRISTIAN: At the level of ~50 km/sec we have not detected rotations in the globular clusters. For young clusters we find $V/\sigma \sim 5$, that is they rotate with the disk. The mean velocity difference for clusters younger than 10^{10} years is 12 km/sec from the projected line-of sight HI velocity. The red clusters have $V\sigma \sim 0.5$ but the sample is small. We intend to obtain more velocities this fall. We would have difficulty finding objects that are very compact in any part of the Galaxy. If all the "missing" red clusters are located in the outer regions, they would need to be exceedingly compact yet very bright, 16.5 - 17.5 in V. I still suspect that the missing clusters, if they exist, are in the inner regions that are difficult to sample.

MCCARTHY: Do you detect any traces of TiO in any of your spectral data from M33?

CHRISTIAN: No. The spectra were mostly in the blue region and the features were H and K, G Band, Mg etc.

ZINNECKER: I'd like to reemphasize that the clusters in M 33 constitute perhaps the best template system for observational population synthesis (optical and infrared), given their wide spread in age and metallicity and given the favorable face-on orientation of this disk galaxy.

CHRISTIAN: I agree and I anticipate that very exciting work will be done in the next few years. With higher resolution we will be in a good position to understand the evolutionary history of an entire disk galaxy.

RAMAMANI: How does the extent of the globular cluster system in M 33 compare with the extent of the Galaxy?

CHRISTIAN: The red clusters are centrally concentrated in the Galaxy. The intermediate age clusters are found near the outer regions. Even if the missing red clusters are found, they are likely to be near the central region, where the selection effects are more severe.

HATZIDIMITRIOU: What kind of errors do you have for the integrated V magnitude and (B-V) color for the clusters of your sample?

CHRISTIAN: Approximately 0.04 mag in V - the error is, of course, worse for fainter magnitudes - and 0.05 to 0.07 mag in (B-V).

GRAHAM: Any data on ellipticity of the globular clusters?

CHRISTIAN: No. The seeing for the CCD data was very good (0.8 arcsec) so that the clusters are clearly seen to have extended profiles. We have not seen any obvious ellipticity (except for the objects which turned out to be galaxies) but marginal ellipticity has not been really tested for.