THE M 87 GLOBULAR CLUSTER SYSTEM*

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ABSTRACT: We review early and recent photometric studies of the M87 globular cluster system. We also describe recent high quality spectroscopic studies that have been used both to measure the metallicities of M87 globular clusters and to determine the mass of M87's halo.

1. HISTORY

Studies of globular cluster systems around galaxies are useful for many purposes: determining extragalactic distances, probing of galaxy halos and testing theories of galaxy and galaxy halo formation. The M87 system has been particularly heavily studied despite the difficulty of observing faint objects in an extended galaxy halo at the distance of Virgo. M87 is a unique object in our neighborhood. It is the nearest brightest cluster galaxy. It sits at the center of an extended halo of X-ray gas (eg. Fabricant and Gorenstein 1983), although it is *not* at the center of the *galaxy* distribution (Huchra 1985). It has a veritable plethora of globular clusters — the current estimate of clusters around M87 is $\sim 20,000$, giving M87 one of the highest specific frequencies known (eg. Harris 1986). Virgo is also a key cluster in the study of the extragalactic distance scale.

Although nearby extraglactic globular cluster systems were discovered as early as 1930 (Hubble 1932), discovery of the M87 remained for the construction of the great, 5-meter Hale telescope (Baum 1955, Sandage 1961). Most of the early work on the cluster system concentrated on its photometric properties, ie. colors, magnitudes, luminosity function, and the comparison of these properties with those of the much more easily studied cluster systems of our own galaxy and M31. Following Baum's (1955) suggestion, much effort has also been devoted to the use of the M87 cluster system to derive the distance to the Virgo cluster and thus determine the local value of the Hubble constant.

* This work based on observations taken with the MMT, a joint facility of the Smithsonian Institution and the University of Arizona.

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Early photographic efforts to catalog the globular clusters around M87 were able only to distinguish clusters outside the inner few arc minutes of the galaxy; more recent observations with CCD's have allowed the study of the distribution into the galaxy core and thus determination of the system strucural parameters. Most recently, spectroscopic studies are being used to determine both the chemical and kinematical properties of the cluster system. Results of these studies can be compared to the predictions of several different theories of the origin and evolution of globular cluster systems around galaxies and around M87 in particular.

1.1 Photometric Properties

The earliest detailed study of the M87 system was by R. Racine (1968a,b). Racine studied the magnitudes colors of 1000 objects within 7.5' of the galaxy center and brighter than $B = 23.5^m$. Most were also outside 3.5'. Racine concluded that the colors of these clusters were consistent with those of galactic globulars and that the bright end of their luminosity function was similar to those of the galaxy and M31. Racine derived a value of the Virgo cluster distance modulus, $(m - M)_B = 30.7 \pm 0.2$. Racine also noted that the spatial distribution of the clusters in the outer parts of the halo was similar to the galaxy photometric profile.

Further photometric studies have been made by Hanes (1971, 1977, etc.), Ables, Newell and O'Neil (1974), Strom et al. (1981), and Cohen (1986). Hanes derived luminosity functions for the cluster systems of M87 and several other Virgo galaxies in an attempt to study the form of the cluster luminosity function and derive the Virgo distance modulus. Hanes work suggests that the number of globular clusters is proportional to the *mass* of the parent galaxy. Ables et al. (1974) presented electronographic BV photometry for $\sim$ 100 clusters to accurately calibrate exisitng photographic photometry.

Strom et al. (1981) used photographic UBR photometry of $\sim$ 1700 clusters between 1.'5 and 9.'0, and brighter than $B = 23.5^m$ to investigate their color distribution. They confirmed Hanes' luminosity function, discovered a radial color gradient in the clusters (clusters become bluer with increasing radius), discovered a *difference* of $\Delta(U - R) \sim 0.5^m$ between the mean cluster color and the galaxy halo color at the same radius, and found that the cluster luminosities were *not* correlated with color. Strom et al. (1981) interpret the blue colors of the globular clusters to show both a radial metallicity gradient and a difference between the mean cluster metallicity and the halo metallicity. This color difference has recently been confirmed by Cohen (1986, this conference) with CCD photometry.

Membership of the brighter candidate clusters has also been derived by Prociuk (1976), who used proper motions to remove foreground stars.

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1.2 Globular Clusters and the Virgo Distance

Many authors starting with Baum's (1955) original suggestion have used the luminosity function of M87's globular clusters to derive a distance to M87 and thus to the Virgo Cluster. Their use has fallen in and out of favor as the debate about the Hubble constant raged. Table I summarizes some of the values of the Virgo distance moduli that have been derived over the years:

TABLE I
Virgo Distance Moduli
Derived by Globular Clusters

Baum (1955)	30.2
Racine (1968b)	30.7
Sandage (1968)	31.1
deVaucouleurs (1977)	30.2
Hanes (1977)	30.4
Hanes (1979)	30.7
van Den Bergh (1985)	31.2

The use of globular cluster systems as distance indicators is the subject of many other reviews.

1.3. Spatial Distribution

In addition to the early work of Baum (1955) and Racine (1968a,b), the spatial distribution of M87's globular clusters was also studied photographically by Harris and Smith (1976) and Strom et al. (1981). All the photographic work seemed to confirm the similarity of the spatial distribution of the globular cluster system, $N(r)$, with the distribution of light in the halo, $\Sigma(r)$. Recent CCD studies of clusters in the inner few arc minutes of M87 by van den Bergh et al. (1985; Grillmair, Pritchet and van den Bergh 1986) and by Lauer and Kormendy (1986) now have shown that this similarity is an artifact due to the poor sampling of the clusters at small radii — because photographic plates lack dynamic range — and the similarity of $R^{1/4}$ power laws at large radii. The cluster system is much more extended than the galaxy halo, with an effective radius, r_e, somewhere between 10' and 20' (Grillmair et al. 1986) – 5 to 10 times that of the galaxy halo (eg. de Vaucouleurs and Nieto 1979). Similarly the core radius, r_c, of $\sim$ 90" derived by Lauer and Kormendy (1986) is also much larger than that of M87, $r_c \sim$ 7".

1.4 Spectroscopy

The first crude spectra of M87 globular cluster candidates were taken by Racine, Oke and Searle (1978). These were low quality, low resolution 200" Multichannel scanner observations of three objects. The brightest M87 globular clusters are barely above 20th magnitude in B. From these spectra, Racine, Oke and Searle were able to estimate that the mean metallicity, $[Fe/H]$, of these three clusters was $\sim$ -0.7,

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or one-fifth solar. Since then several groups have tried to obtain higher quality spectra of larger numbers of objects. Huchra and Brodie (1984) found that most of the bright ($B < 19.5^m$) candidates in the list of Strom et al. (1981) were either foreground stars or members of a backgound cluster of galaxies at a redshift of $z \sim 0.09$. Hanes and Brodie (1986) observed five of the brighter globular clusters from Hanes' list and derived a mean $[Fe/H] = -0.5 \pm 0.4$. Huchra and Brodie (1986) and Mould, Oke and Nemec (1986) have observed larger numbers of objects to both measure $[Fe/H]$ and study the dynamics of the globular cluster system. The former study will be reported on below.

2. THE MMT STUDY

Huchra and Brodie (1984; 1986; Brodies and Huchra 1987) have recently obtained spectra of $\sim$ 30 globular cluster candidates surrounding M87. The spectra were obtained with the MMT, and cover the range 3200Åto 7000Åat $\sim$ 7Åresolution. The S/N obtained was sufficient to measure velocities accurate to $\sim$ 75 km/s and to measure line indices for metallicity determinations.

Cluster candidates were taken from the lists of Hanes(1971) and Strom et al. (1981). Globular clusters were identified via their velocities and spectroscopic properties. Almost all of the brightest objects, $B < 19.5^m$, are foreground galactic stars or background galaxies. The fraction of candidates that were *bona fide* globulars rose dramatically below $B \sim 20.5^m$. Figure 1 shows the velocity histogram for the objects with velocities less than 3000 km/s. There is an almost clear separation between clusters and galactic stars. We have observations of 10 clusters.

2.1 Dynamics

The velocity data can be used to derive two different estimates of the mass of the M87 halo – the Virial theorem estimator and the projected mass estimator (Bahcall and Tremaine 1981). The Virial theorem mass for a cluster of N objects is:

$$M_{VT} = \frac{3\pi N}{2G} \frac{\sum_i^N V_i^2}{\sum_{i<j} 1/r_{ij}} \quad ,$$

r_{ij} is the separation between the ith and jth galaxy, V_i is the velocity difference between the ith galaxy and the mean cluster velocity. The projected mass for N objects surrounding a central mass is

$$M_P = \frac{f_p}{GN} \left(\sum_i^N V_i^2 r_i\right) \quad ,$$

where r_i is the separation of the ith galaxy from the centroid. The quantity f_p depends on the distribution of orbital eccentrities for the galaxies and is equal to $32/\pi$ for radial orbits and $16/\pi$ for isotropic orbits. Bahcall and Tremaine (1981) favor the value $24/\pi$ for the projection factor. The parameters we derive are given in Table II.

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Zinn, R. 1985, *Astrophys. J.* **293**, 424.

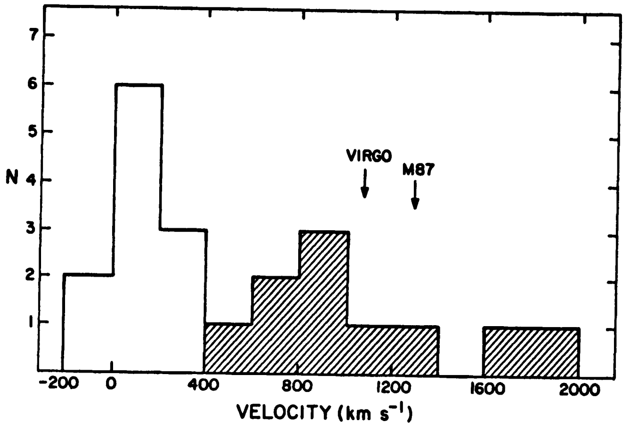

Fig. 1. Velocity histogram for objects around M87. The objects identified as globular clusters are crosshatched.

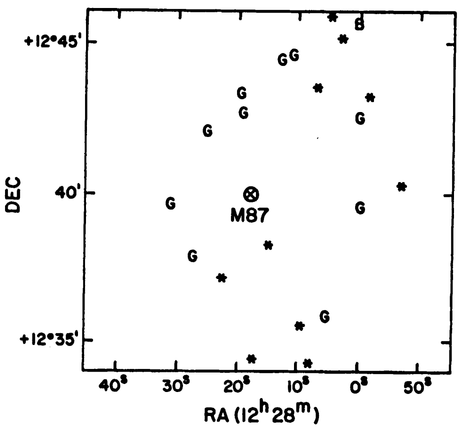

Fig. 2. Spatial distribution of objects observed around M87. Globular clusters are marked 'G', galactic stars are '*', and the compact companion galaxy, NGC 4486B, is marked 'B'.

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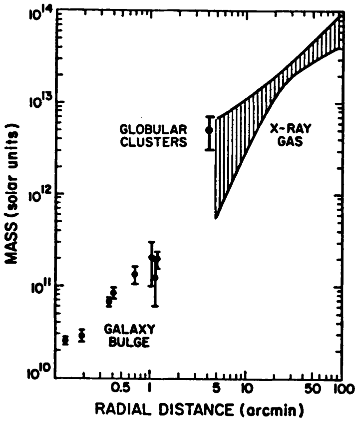

Fig. 3. Mass estimate from the globular cluster system compared to the mass versus radius derived from the X-ray halo and from inner stellar velocity dispersion measurements (Sargent et al. 1978).

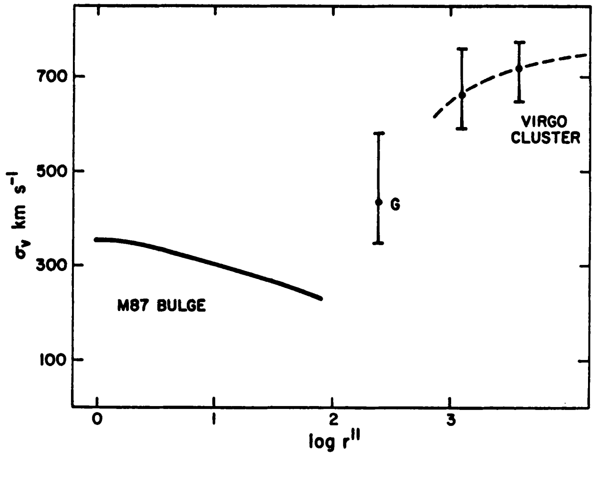

Fig. 4. Velocity dispersion as a function of radius for the M87-Virgo Cluster system.

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TABLE II
DYNAMICAL PARAMETERS

	Virial Theorem	Projected Mass
Mass	$5.31 \times 10^{12}\ M_\odot$	$6.08 \times 10^{12}\ M_\odot$
error	$\pm 1.97 \times 10^{+12}\ M_\odot$	$\pm 2.24 \times 10^{+12}\ M_\odot$
R_H	$14.7\ kpc$	
R_P		$16.6\ kpc$
CT	9.0×10^{-4} Hubbles	
$< v >$	$1090\ \pm 262\ km\ s^{-1}$	
$< \sigma_v >$	$436^{+143}_{-\ 72}\ km\ s^{-1}$	

R_H and R_P are the mean harmonic radius and the projected radius, respectively. CT is the cluster system crossing time in units of the Hubble time (we assume a *distance* to M87 of 15.7 Mpc, which, combined with a Virgo infall velocity of $250 km/sec$ implies a Hubble constant of 82 $km/s/Mpc$). The photometry of Aaronson and Mould (1981) implies that $L \sim 4.1 \times 10^{10}\ L_\odot$ inside 18 kpc, which means that the enclosed, integrated mass-to-light ratio, $(M/L)_B \sim 150$. In an annulus between 2' and 5', $M_P \sim 5 \times 10^{12}$, and L $\sim 1.4 \times 10^{10}$, so $(M/L)_{B,ann} \sim 360$. The mass we derive is in good agreement with the mass derived from studies of the X-ray halo (Fabricant and Gorenstein 1983, see Figure 3), although the cluster velocity dispersion is almost a factor of two higher than the predicted stellar velocity dispersion (Stewart et al. 1984). The large velocity dispersion of the outer cluster system combined with the extened distribution of the clusters relative to the galaxy bulge probably indicates that the cluster system is dynamically evolved and that clusters at large radii are predominantly on circular orbits. We believe that it is also important to remember that M87 lies at the center of the Virgo cluster — the velocity dispersion of the globular clusters is higher than that of the stars in the halo but half that of the galaxy cluster (Figure 4).

3.2 Metallicity

Cluster metallicities can also be derived from narrow band indicies and colors (Burstein et al. 1984; Hanes and Brodie 1986; Huchra et al. 1986). The best of these are the Mgb and MgH indices, the G band, the blue and ultraviolet CN features and the H+K index, although H+K tends to sature above $[Fe/H] \sim -1$. The mean metallicity we derive is $[Fe/H] \sim -0.7 \pm 0.3$, which is in good agreement with the values of -0.5 ± 0.4 of Hanes and Brodie (1986) and of -1.2 ± 0.2 of Mould et al. (1986), although those two determinations do not agree. The mean metallicites of several globular cluster systems (Huchra et al. 1986) as well as that of 11 Virgo dwarf galaxies are compared in Table III.

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TABLE III
GLOBULAR CLUSTER SYSTEM METALLICITIES

[Fe/H] Zinn 1985 Scale

Fornax Globulars	-1.8
Virgo Dwarf Galaxies	-1.6
Mean of Galactic Globulars	-1.4
M31 Globulars	-1.3
M87 Globulars	-0.7

The data for M87 appear to confirm the trend of increasing mean metallicity with galaxy luminosity/mass. The metallicities of individual clusters are spread over a large range, as in the galaxy and M31. We do not find any evidence for a radial gradient in metallicity (Figure 5), but the data are too sparse to perform a strong test.

3. SUMMARY

3.1 Distance to Virgo and H_o

Almost all of the early work gave $H_o$between 80 and 100 $km/s/Mpc$ uncorrected for Virgo infall. The most recent attempt by van den Bergh (1985), which includes the effect of Virgo flow, gave $\sim$ 75 $km/s/Mpc$. This value is not far from that currently advocated by the Infrared Tully-Fisher consortium (Aaronson et al. 1986).

In recent reviews of the distance scale problem, however, Sandage and Tammann give the globular cluster luminosity function a grade of $D+$ as a distance indicator. The major difficulty is that most of the well studied systems outside the local group are in elliptical galaxies, while the calibrating systems are all in Sb spirals — the galaxy and M31. This author also wishes to urge caution regarding use of the M87 system until a better understanding of the formation and evolution of cluster systems around giant, X-ray gas rich, central cluster elliptical galaxies is achieved.

3.2 Chemical Probe of Galaxy Halo

If the colors for the M87 clusters are related to metallicity in the same way as in the galaxy and M31 (a pretty safe bet), then the work of Racine (1968b), Strom et al. (1981) and Cohen (1986) tells us that:

A. The M87 clusters are similar in properties and range of properties to galactic and M31 globular clusters.

B. There is a metallicity gradient in both the cluster system and halo.

C. The globular clusters are more metal poor than the halo at the same projected radius.

In addition, spectroscopic studies indicate that the M87 clusters are probably slightly more metal rich on average than galactic or M31 clusters. The values of $[Fe/H]$ derived in the recent studies range between -1.2 and -0.5. This agrees with

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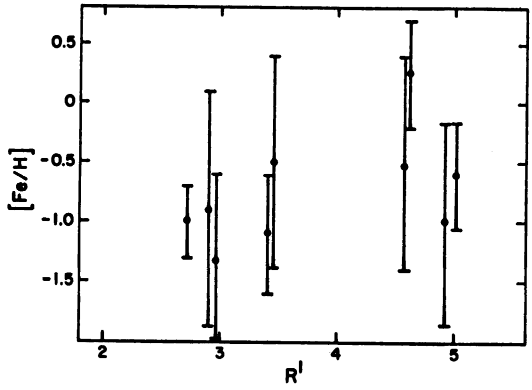

Fig. 5. Metallicity estimates for individual M87 globular clusters plotted as a function of radial distance from the galaxy center.

the general trend of mean metallicity versus luminosity seen in local group globular cluster systems and in elliptical galaxies.

3.3 Dynamical Probe of Galaxy Halo

Globular clusters can be used as 'test particles' to study halos of galaxies. The structure of the cluster system can describe the shape of the gravitational potential well and the kinematics can be used to measure the mass of the galaxy's halo. Globular clusters themselves probably contribute only slightly to the overall mass of the halo.

Although early work on the structure of the M87 cluster system indicated that at large radii, $\mu(r)_{Halo} = N(r)_{Glob}$, the best recent work shows that $R_c^G >> R_c^H$ as well as $R_e^G >> R_e^H$. The gloubular cluster system is much more extended than the galaxy halo.

The recent kinematic studies of small numbers of clusters find that the velocity dispersion of the cluster system is $\sim 400\ km/s$. This is higher than that of the galaxy bulge but still lower than that of the surrounding cluster of galaxies. The galaxy mass estimated from these studies is slightly less than $10^{13}\ M_\odot$ inside a radius of 20 kpc. This is in good agreement with the mass of the halo estimated by assuming that the X-ray halo is in hydrostatic equilibrium. The integrated mass-to-light ratio out to this radius is then $(M/L)_B \sim 150$, in solar units.

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3.4 Formation of Globulars and the Galaxy Halo

Several theories for the formation of globular cluster systems have been proposed over the years, and all have their attractive features and problems. M87 is a key galaxy in these theories because of its very large specific frequency of clusters (it has about 5 times as many as its sister galaxy M49, which is, in fact, the brightest galaxy in the Virgo cluster (Aaronson and Mould 1981). Some theories have been proposed specifically *for* M87, because of its special place at the galaxy cluster core. The theories can be roughly categorized as:

A. Formation in Place
   1. Halo/Globulars Coeval (Peebles and Dicke 1968)
   2. Clusters before Halo (Fall and Rees 1985)

B. Stripping and Accretion - (eg. Forte et al. 1982)

The metallicity difference between clusters and halo is an argument in favor of either accretion or formation of clusters before the halo. The acrretion process, however, is probably *not* efficient enough to create *all* of M87's system (eg. Muzzio et al. this conference). The metallicity versus galaxy luminosity relation also argues against accretion of stripped globulars from dwarf galaxies.

In any case, the cluster system distribution and kinematics indicate that it is very likely that the M87 cluster system has evolved (eg. Chernoff et al. 1986, and this conference). Evolution will make it even more difficult to disentangle the origins of the cluster system.

REFERENCES

Aaronson, M., Bothun, G., Mould, J., Huchra, J., Schommer, R. and Cornell, M. 1986 Astrophys. J. **302**, 536.

Aaronson, M. and Mould, J. 1981 Publ. Astron. Soc. Pacific **93**, 20.

Ables, H., Newell, E. and O'Neill, E. 1974 Publ. Astron. Soc. Pacific **86**, 311.

Bahcall, J. and Tremaine, S. 1981 Astrophys. J. **244**, 805.

Baum, W. 1955 Publ. Astron. Soc. Pacific **67**, 328.

Brodie, J. and Huchra, J. 1987 in preparation.

Burstein, D., Faber, S., Gaskell, M. and Krumm, N. 1984 Astrophys. J. **287**, 586.

Chernoff, D., Kochanek, C. and Shapiro, S. 1986 Astrophys. J., in press.

de Vaucouleurs, G. 1977 Nature **266**, 126.

de Vaucouleurs, G. and Nieto, J.-L. 1979 Astrophys. J. **230**, 697.

Fabricant, D. and Gorenstein, P. 1983 Astrophys. J. **267**, 535.

Fall, M. and Rees, M. 1985 Astrophys. J. **298**, 18.

Forte, J. C., Martinez, R. E. and Muzzio, J. C. 1982 Astron. J. **87**, 1465.

Grillmair, C., Pritchet, C. and van den Bergh, S. 1986 Astron. J. **91**, 1328.

Hanes, D. A. 1971 M. Sc. Thesis, U. of Toronto.

https://doi.org/10.1017/S0074180900042522 Published online by Cambridge University Press

Hanes, D. A. 1977 Mem. Roy. Astron. Soc. **84**, 45.
Hanes, D. A. and Brodie, J. 1986 Astrophys. J. 300, 279.
Harris, W. E. and Smith, M. G. 1976 Astrophys. J. **207**, 1036.
Harris, W. E. 1986 Astron. J. **91**, 822.
Hubble, E. P. 1932 Astrophys. J. **76**, 44.
Huchra, J. 1985 in The Virgo Cluster, O.-G. Richter and B. Binggelli, eds., ESO, Garching, p. 181.
Huchra, J. and Brodie, J. 1984 Astrophys. J. **280**, 547.
Huchra, J. and Brodie, J. 1986 Astron. J., in press.
Huchra, J., Stauffer, J. and Brodie, J. 1986, in preparation.
Lauer, T. and Kormendy, J. 1986 Astrophys. J. Letters 303, L1.
Mould, J. R., Oke, J. B. and Nemec, J. M. 1986 Astron. J., in press.
Peebles, P. J. E. and Dicke, R. 1968 Astrophys. J. 154, 891.
Prociuk, I. 1976 M. Sc. Thesis, Univ. of Toronto.
Racine, R. 1968a Publ. Astron. Soc. Pacific **80**, 326.
Racine, R. 1968b Journal Roy. Astron. Soc. Canada, **62**, 367.
Racine, R., Oke, J. B. and Searle, L. 1978 Astrophys. J. **223**, 82.
Sandage, A. 1961 in The Hubble Atlas of Galaxies, Carnegie Inst. of Washington, Washington, DC.
Sandage, A. 1968 Astrophys. J. Letters **152**, L149.
Sargent, W. L. W., Young, P. J., Boksenberg, A, Shortridge, K., Lynds, C. R. and Hartwick, F. D. A. 1978 Astrophys. J. **221**, 831.
Stewart, G. C., Canizares, C. R., Fabian, A. C. and Nulsen, P. E. J. 1984 Astrophys. J. **278**, 536.
Strom, S. E., Forte, J. C., Harris, W. E., Strom, K. M., Wells, D. C. and Smith, M. G. 1981 Astrophys. J. **245**, 416.
van den Bergh, S., Pritchet, C. and Grillmair, C. 1985 Astron. J. **90**, 585.

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DISCUSSION

MUZZIO: Our more recent results suggest that massive central galaxies may increase their globular cluster population indeed, but by not more than about 40%; thus, I do not think now that it is possible for M 87 to get three times the "normal" population by taking its globular clusters from other galaxies. Besides, I have just found that our original idea that the central giant galaxies capture globular clusters from dwarf galaxies was wrong: the mean magnitude difference between the donor galaxy and the capturing galaxy is about 1.4 mag and one cannot have a large metallicity difference from so similar galaxies.

HUCHRA: I agree. It is not likely that the very large frequency of clusters around M 87 is due entirely to capture, but the process probably does operate at some level and it will be the larger galaxies that contribute the most.

GNEDIN: Yesterday H. Harris told about possible connection between globulars and jets. What is the situation in this case? Is there a possible correlation between jets and globular clusters?

HUCHRA: I don't know. Most of the globular clusters we've studied are, in fact, not in the quadrant of the jet.

VANDENBERGH: Could you say anything about your brightest object for color (B-V) = 1.35?

HUCHRA: It is possible that it is a star (galactic). It is also possible that the photometry is wrong.

HESSER: How low is the velocity of your brightest (and reddest) cluster?

HUCHRA: It is one of the lower velocity objects, $V_{Heliocentric}$ ~ 700 km/s.

GOODMAN: You did not tell us how you selected your objects for spectroscopic study, except to say that they were bright and red, but in view of the fact that only a third of the objects turned out to be globular clusters, can you say something about the completeness of the photometric surveys of cluster systems?

HUCHRA: This is a toughie since our "selection" criteria changed with time and observing conditions. Initially we observed in magnitude order (brightest to faintest) and almost all of the very bright objects were stars or background galaxies. As we got smarter (i.e. removing stars by eliminating high proper motion objects, strange colors) and went fainter - the fraction of globular clusters went way up. Almost all objects fainter than 21st are indeed globular clusters. The

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photometric surveys aren't bad when you get fainter.

HANES: I'm very excited to see these reliable velocities coming out, especially as one who ha tried and failed to get them myself! But some measure of the difficulty may be indicated by an inconsistency between your results for object IV-94 (which you call a globular cluster) and those of Mould, Oke and Nemec (who call it a background galaxy, with a velocity ~2900 km/sec.

HUCHRA: Yes. I'd love to see their spectrum, but can't really comment on the difference until I do.

CAYREL: Is M 87 actually globular cluster rich per unit mass, in comparison with other less massive elliptical galaxies?

HUCHRA: I haven't looked at that correlation at all but I can say that it is probably the case that computing the frequency per unit mass will decrease the scatter. M 87 is much more massive (4x) than M 49 and has 3 or 4 times the number clusters although the same luminosity.

HARRIS: The fact that the specific frequency (number per unit light) is roughly constant for E galaxies over a factor of more than 1000 in luminosity might itself be interesting. The reason is that, if small elliptical galaxies have a lower M/L than large ellipticals, it means that the small ellipticals were actually more efficient at forming clusters than the big galaxies were.

HUCHRA: I think that the constancy of M/L for galaxies as a function of L over large ranges of L is actually a very, very important point. This is seen in things like the Tully-Fisher relation for spirals and Faber-Jackson relation for ellipticals where the slopes of those relations indicate that the M/L for such galaxies varies by less than a factor of 2 over several orders of magnitude in luminosity.

ZINNECKER: As far as the Hubble constant is concerned: when you correct the Hubble constant derived from the peak of the M 87 globular cluster luminosity function for the infall velocity of the galaxy towards Virgo, it becomes uncomfortably high to accommodate the ages of the galactic globular clusters. This begs the question: how could one reduce the globular cluster ages (to ~10 Gyr say)?

HUCHRA: Ah yes. The Hubble constant. My belief is that we're really not in trouble yet - the lowest globular cluster ages and the longest expansion times from H_o just about overlap. I think the value of H_o is still pretty soft, we've seen in the last decade several major changes in fundamental calibrators - revision of the Hyades distance modulus, a change in the galaxy scale from 10 to 8 kpc, etc. More such things are bound to come, especially with ST, and each one can change H_o by 20 or 30%. I believe that it is also the case that cluster ages may change. When I first got into the H_o game and got (with Marc

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Aaronson and Jeremy Mould) a high value, in conflict with the cluster ages, Al Cameron, a pundit on stellar interiors, said to me "don't worry too much just yet, after all we still can't get the structure of the Sun - the solar neutrino flux - right".

LILLER: You mentioned that the background of the galaxy gave problems. Could you say a little about how this component was subtracted from your spectra?

HUCHRA: We used a two aperture (sky subtracting) spectrograph and both switched the object between aperture and rotated (you get that free of charge with the MMT) to sample the sky.

NEMEC: Mould, Oke and Nemec (1986 preprint) find a mean metal abundance of the 27 globular clusters in the sample $<[Fe/H]> = -1.2 \pm 0.2$ i.e. no more than a factor of 2 more metal rich than the galactic globular cluster system. There is no evidence for the existence of young luminous LMC-like clusters in the M 87 system.

HUCHRA: Sorry, I'd only heard third party that you guys had gotten $[Fe/H] \sim -1$. I also agree, Jean and I found no objects which could be called young clusters.

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