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THE LUMINOSITY FUNCTION OF GLOBULAR CLUSTERS

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ABSTRACT

Recent compilations of data on the globular clusters in the Galaxy (Webbink) and M31 (Crampton *et al.*) are used to show that the cluster luminosity functions in these two galaxies do not differ significantly. In both of these Local Group galaxies, the cluster luminosity function peaks at $M_V = -7.1$. Comparison of this value with the maximum in the M87 globular cluster luminosity function recently observed by van den Bergh, Pritchet, and Grillmair yields a value of 74 ± 12 km s^{-1} Mpc for the Hubble parameter. Confidence in this result is, however, undermined by the observation that the shape of the M87 globular cluster luminosity function may differ from that for globular clusters in the Local Group.

Subject headings: clusters: globular — cosmology — luminosity function

I. INTRODUCTION

In a recent paper, van den Bergh, Pritchet, and Grillmair (1985) report that the globular clusters in the Virgo cluster galaxy M87 have a much broader luminosity distribution than do those in the Galaxy (Harris and Racine 1979) and M31 (Racine and Shara 1979). It is the purpose of the present paper to reinvestigate the luminosity function of Local Group globular clusters by using more recent data on the clusters in M31 (Crampton *et al.* 1985) and in the Galaxy (Webbink 1985) to check on the reality of the purported difference between the M87 and Local Group globular cluster luminosity functions.

II. GLOBULAR CLUSTERS IN M31

The luminosity function of 86 clusters in the halo of M31 has been discussed by Racine and Shara (1979), who find that their data can be adequately represented by a Gaussian with $\langle V \rangle = 16.79 \pm 0.12$ and $\sigma_V = 1.13$.

Recently Crampton *et al.* (1985) have published a study of 509 nonstellar objects in and near the Andromeda Nebula, which was based in part on new "grens" observations obtained at the prime focus of the Canada-France-Hawaii telescope. For the present analysis, we shall divide the M31 clusters into three color groups (see Table 1): (*a*) those clusters

TABLE 1

COLORS AND MAGNITUDES OF M31 CLUSTERS

V	$B-V < 0.70$[a]	$0.70 \le B-V < 1.00$[a]	$1.00 \le B-V$[a]	No Colors[a]	Total[a]	Halo[b]
13.7	0	1	0	0	1	1
13.9	0	0	0	0	0	0
14.1	0	1	0	0	1	0
14.3	0	1	1	0	2	1
14.5	0	1	0	0	1	1
14.7	0	2	1	0	3	0
14.9	1	2	1	0	4	1
15.1	1	7	1	0	9	4
15.3	0	6	2	0	8	0
15.5	0	8	2	0	10	1
15.7	0	11	2	1	14	1
15.9	0	11	4	1	16	3
16.1	0	9	7	1	17	8
16.3	2	12	1	0	15	6
16.5	5	10	7	1	23	8
16.7	6	17	14	1	38	12
16.9	10	18	16	3	47	6
17.1	2	14	13	6	35	9
17.3	2	18	13	15	48	6
17.5	13	16	14	12	55	4
17.7	7	6	10	13	36	2
17.9	4	11	6	11	32	3
18.1	2	4	2	20	28	2
18.3	7	1	0	21	29	1
18.5	2	1	0	11	14	0
18.7	1	0	0	11	12	2
18.9	0	0	1	6	7	1

[a] Crampton *et al.* 1985.
[b] Racine and Shara 1979.

with $B-V < 0.70$, which with a galactic foreground reddening $E_{B-V} = 0.10$ (van den Bergh 1977) corresponds to $(B-V)_0 < 0.60$, are predominantly open clusters; (*b*) the overwhelming majority of objects with $0.70 \leq B-V < 1.00$ are probably globular clusters, with perhaps a slight admixture of very old or reddened open clusters at faint magnitudes; (*c*) nonstellar objects with $B-V \geq 1.00$. This category presumably represents a mixture of reddened globular clusters and distant background ellipticals. The sample of clusters with $0.70 \leq B-V < 1.00$ is incomplete at faint magnitudes because of observational selection effects and because not all such clusters have $B-V$ color measurements. If it is *assumed* that the fraction of clusters with measured colors is only a function of V but not of $B-V$, then the true number of clusters is given by the relation

$$N_{cor} = N_{obs}/[1 - F(V)] , \qquad (1)$$

in which $F(V)$ is the fraction of all clusters of magnitude V for which no $B-V$ colors are available. The (smoothed) values of F were derived from the data in Table 1 and are listed in Table 2.

The corrected cluster luminosity function given in Table 2 is plotted in Figure 1. The figure shows that the data are well represented by a Gaussian with $V_{max} = 17.2$ and $\sigma = 1.2$ mag, except for $V > 18$ where the cluster sample is undoubtedly incomplete. It is of interest to note that the M31 halo cluster luminosity function derived by Racine and Shara (1979) peaks

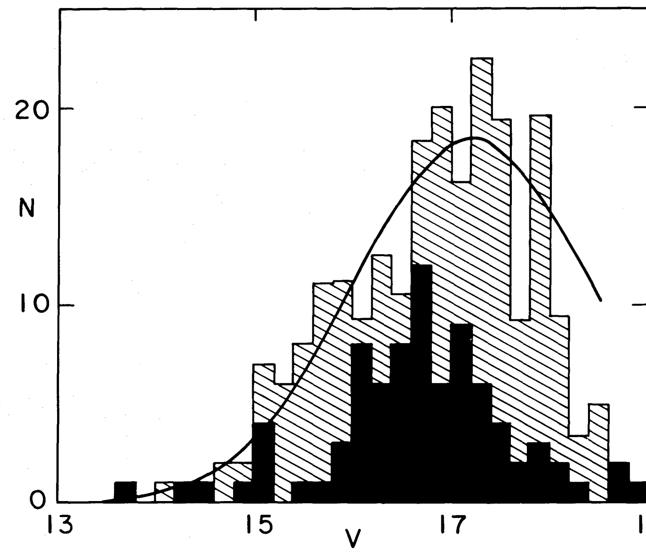

FIG. 1.—Luminosity function of clusters with $0.70 \leq B-V < 1.00$ in M31. Smooth curve is a Gaussian with $V(\max) = 17.2$ and $\sigma = 1.2$ mag. Lower histogram shows the luminosity function of the halo of M31 derived by Racine and Shara (1979).

TABLE 2

NUMBER OF M31 GLOBULAR CLUSTERS

V	N_{obs}[a]	F[b]	N_{cor}[c]
13.7	1	0.00	1.0
13.9	0	0.00	0.0
14.1	1	0.00	1.0
14.3	1	0.00	1.0
14.5	1	0.00	1.0
14.7	2	0.00	2.0
14.9	2	0.00	2.0
15.1	7	0.00	7.0
15.3	6	0.00	6.0
15.5	8	0.01	8.1
15.7	11	0.01	11.1
15.9	11	0.02	11.2
16.1	9	0.03	9.3
16.3	12	0.04	12.5
16.5	10	0.05	10.5
16.7	17	0.07	18.3
16.9	18	0.10	20.0
17.1	14	0.14	16.2
17.3	18	0.20	22.5
17.5	16	0.27	19.3
17.7	6	0.35	9.2
17.9	11	0.44	19.6
18.1	4	0.58	9.5
18.3	1	0.71	3.4
18.5	1	0.80	5.0
18.7	0	0.87	0.0
18.9	0	...	...

[a] Observed number of clusters with $0.70 \leq B-V < 1.00$.

[b] Fraction (smoothed) of Crampton *et al.* clusters that do not have $B-V$ colors.

[c] Corrected number of globulars $N_{cor} = N_{obs}/(1-F)$.

at $V = 16.8$, which is 0.4 mag brighter than the value derived from the data by Crampton *et al.* (1985). It appears likely that this difference is due to incompleteness in the M31 halo cluster sample. For an M31 distance modulus $(m - M)_V = 24.32 \pm 0.11$ (van den Bergh 1977) the peak of the M31 cluster luminosity function is situated at $M_V = -7.1$, with an estimated uncertainty of ~ 0.2 mag.

The luminosity function of clusters with $0.70 \leq B-V < 1.00$ in M31 contains 138 objects with $V < 17.2$. Assuming symmetry about $V(\max) = 17.2$ yields a total cluster population of 276. The luminosity of M31 (corrected for internal absorption) is $M_V = -21.6$ (de Vaucouleurs 1958; Sandage and Tammann 1981; van den Bergh 1977), so that the specific cluster frequency (Harris and van den Bergh 1981) is $S = 0.6$, which is quite typical of spiral galaxies (van den Bergh and Harris 1982). Since the present cluster sample was restricted to objects with $B-V < 1.00$, some heavily reddened clusters have undoubtedly been omitted from the sample. In the extreme case where the dust layer in M31 is assumed to be very thin, dense, and uniform, exactly half of all clusters would be excluded from the sample, yielding $S = 1.2$. It is, therefore, concluded that the true value of S for M31 probably lies in the range $0.6 < S < 1.2$.

III. GLOBULAR CLUSTERS IN THE GALAXY

Recently Webbink (1985) has given a detailed rediscussion of the properties of presently known Galactic globular clusters. The luminosity function of all 148 globulars listed in his compilation is shown in Figure 2. Since selection effects affecting the discovery of high- and low-latitude clusters are quite different, differences might have been expected between the luminosity functions of globulars with $|b| = < 10°$ and $|b| \geq 10°$. No significant difference is, however, found between these two subsamples of Webbink's data.

Inspection of Figure 2 shows that the luminosity function of Galactic globular clusters is nonsymmetrical with a long tail extending to faint luminosities. This deviation from a Gaussian is statistically significant, having $\gamma_1 = \pm(0.56 \pm 0.20)$. With

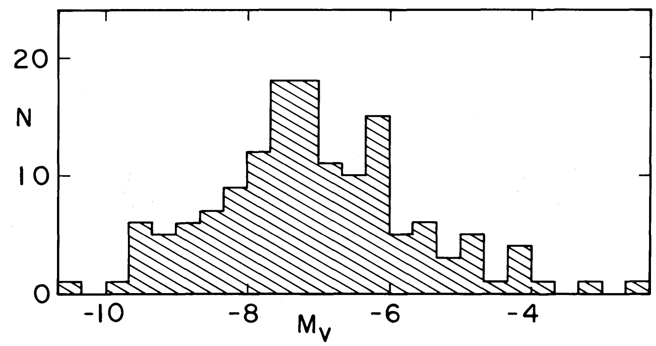

FIG. 2.—Luminosity function of Galactic globular clusters (one object at $M_V = -1.7$ is not plotted). Note that the luminosity function is asymetrical with a long tail extending to faint magnitudes.

$\gamma_2 = 0.74 \pm 0.40$, the cluster luminosity function is also slightly leptokurtic (e.g., Chambers 1952, p. 30). It seems quite probable that some of the clusters in the faint tail of the Galactic globular cluster luminosity function are objects that have suffered dramatic mass loss resulting from tidal interactions with the Galaxy. A possible example of such an object is the cluster E3 with $M_V = -4.2$ (van den Bergh, Demers, and Kunkel 1980).

To minimize the bias introduced by the faint tail of the Galactic globular cluster luminosity function we shall, quite arbitrarily, neglect the three faintest globular clusters (Pal 1, $M_V = -2.5$; AM 4, $M_V = -1.7$; and Pal 13, $M_V = -3.3$) in Webbink's sample. For the remaining 145 clusters, $\gamma_1 = \pm(0.14 \pm 0.20)$ and $\gamma_2 = -0.24 \pm 0.40$; i.e., the distribution is not significantly different from a Gaussian. The distribution of these clusters is characterized by $\langle M_V \rangle = -7.11 \pm 0.11$ and $\sigma = 1.35$ mag. The mean magnitude of Galactic globulars is seen to be identical to the value $\langle M_V \rangle = -7.1 \pm 0.2$ obtained for M31. The dispersion is, however, somewhat larger than the value $\sigma = 1.17$ that Harris and Racine (1979) obtained from a sample of 93 Galactic globular clusters.

For $V < 18.0$ ($M_V < -6.32$), the corrected luminosity function of globular clusters in M31 (see Table 2 and Fig. 1) should be reasonably complete. A Kolmogoroff-Smirnoff test shows that one cannot reject the hypothesis that the luminosity functions of the globular clusters with $M_V < -6.32$ in M31 and in the Galaxy were drawn from the same parent population. Since there is no statistically significant difference between the M31 and Galaxy cluster luminosity functions, they will be regarded as being similar in the subsequent discussion.

IV. DISCUSSION

a) Differences between the M87 and Local Group Cluster Luminosity Functions

Recently van den Bergh, Pritchet, and Grillmair (1985) have determined the luminosity function of the globular cluster system surrounding M87 from CCD photometry down to $B = 25.4$. Their data, which are reproduced in Table 3, show that the M87 luminosity function peaks at $B(\max) = 25.0 \pm 0.3$. Adopting $\langle B-V \rangle = 0.80$ for the M87 clusters (Racine 1968; Ables, Newell, and O'Neil 1974) and $M_V(\max) = -7.1$ (see §§ II and III of this paper) yields an apparent visual distance modulus $(m - M)_V = 31.30$ for the Virgo Cluster. With a foreground absorption $A_B = 0.09$ (Burstein and Heiles 1984), the corresponding distance

TABLE 3

M87 AND LOCAL GROUP LUMINOSITY FUNCTIONS

VIRGO		ANDROMEDA		GALAXY	
B	$N_{obs}(<B)$	V	$N_{cor}(<V)$	M_V	$N(<M_V)$
21.2[a]	7	13.35[b]	0	−10.87[c]	0
21.4	14	13.55	0	−10.67	0
21.6	16	13.75	1	−10.47	0
21.8	23	13.95	1	−10.27	1
22.0	26	14.15	1	−10.07	1
22.2	43	14.35	3	−9.87	2
22.4	57	14.55	4	−9.67	2
22.6	74	14.75	5	−9.47	8
22.8	92	14.95	6	−9.27	10
23.0	112	15.15	14	−9.07	13
23.2	133	15.35	19	−8.87	14
23.4	156	15.55	26.1	−8.67	19
23.6	184	15.75	38.2	−8.47	22
23.8	220	15.95	46.4	−8.27	28
24.0	257	16.15	59.8	−8.07	32
24.2	296	16.35	69.1	−7.87	38
24.4	339	16.55	79.5	−7.67	46
24.6	398	16.75	97.6	−7.47	57
24.8	452	16.95	117.2	−7.27	66
25.0	513	17.15	134.4	−7.07	77
25.2	571	17.35	153.9	−6.87	91
25.4	611	17.55	179.2	−6.67	93

[a] $B = 21.2$ corresponds to $M_B = -10.12$ in Virgo.
[b] $V = 13.35$ corresponds to $M_B = -10.12$ in M31.
[c] $M_V = -10.87$ corresponds to $M_B = -10.12$ in Galaxy.

modulus in blue light is $(m - M)_B = 31.32$. This value was used to convert the B values in Table 3 to M_B. In this table, the data on the luminosity function of Galactic globulars were taken directly from Webbink (1984) under the assumption that $\langle (B-V)_0 \rangle = 0.75$ for Galactic globular clusters. Information on the M31 globulars with $0.70 \leq B-V < 1.0$ was taken from Crampton *et al.* (1985). These data were corrected for incompleteness using the correction factors listed in Table 2. A mean color index $\langle B-V \rangle = 0.85$ was assumed for the M31 clusters, which all have $0.70 \leq B-V < 1.00$.

The combined luminosity function of the M31 and Galactic globular clusters (which will subsequently be referred to as the Local Group luminosity function) may be derived from the M31 and Galaxy data given in Table 3.

A Kolmogoroff-Smirnoff test shows that there is only a 6% probability that the M87 and Local Group cluster samples were drawn from the same parent population. The deviations between these two luminosity functions are in the sense that M87 contains a larger fraction of luminous globular clusters than does the Local Group. This result suggests that (1) the luminosity function of the M87 cluster system differs from that of Local Group galaxies; or (2) van den Bergh, Pritchet, and Grillmair (1985) have adopted too faint a value for $B(\max)$ of the M87 cluster system, i.e., they have overestimated the distance modulus of the Virgo Cluster; or (3) the adopted distance of M31 is slightly in error. Increasing its distance modulus by 0.2 mag would increase the probability that the M87 and Local Group cluster systems have been drawn from the same parent population to 11%. A definitive decision on these questions must, however, await a study of the M87 cluster system that extends to a magnitude level substantially fainter than $B = 25.4$. Alternatively the distance modulus of M87 might be determined by an independent technique such as the observation of novae (Pritchet and van den Bergh 1985).

b) Distance to the Virgo Cluster

The distance to the Virgo Cluster galaxy M87 may be determined by *assuming* that the maximum of the M87 globular cluster luminosity function occurs at the same magnitude as it does in the Local Group. It should, however, be emphasized that confidence in the correctness of the distance so obtained is undermined by the observation that the M87 and Local Group cluster luminosity functions probably have somewhat different shapes.

With $B(\max) = 25.0 \pm 0.3$, corresponding to $V(\max) = 24.2 \pm 0.3$ in M87, and $M_V(\max) = -7.1 \pm 0.1$ in the Local Group, it follows that $(m - M)_V = 31.3 \pm 0.32$. Adopting $A_B = 0.09$ (Burstein and Heiles 1984) and, hence, $A_V = 0.07$, one then has $(m - M)_0 = 31.23 \pm 0.32$. The corresponding distance to the Virgo Cluster is 17.6 ± 2.6 Mpc.

According to Huchra, Davies, and Latham (1984), the Virgo Cluster has a mean redshift $\langle v \rangle = 1055 \pm 40$ km s^{-1}. It is presently believed (e.g., Yahil 1984) that the infall velocity is 250 ± 50 km s^{-1}, so that the cosmological redshift of the Virgo Cluster becomes $v = 1305 \pm 64$ km s^{-1}. Substituting this result and $D = 17.6 \pm 2.6$ Mpc into the relation $v = HD$ yields a Hubble parameter $H = 74 \pm 12$ km s^{-1} Mpc^{-1}. It should, of course, be emphasized that the real uncertainty of this result [which is due to the assumption that the M87 globulars have the same $M_V(\max)$ as do those in the Local Group] is not reflected in the small formal mean error of the result quoted above.

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