THE ASTROPHYSICAL JOURNAL, 203:6–13, 1976 January 1

THE HUBBLE DIAGRAM FOR NUCLEAR MAGNITUDES OF CLUSTER GALAXIES

DANIEL W. WEEDMAN*†
Dyer Observatory, Vanderbilt University
Received 1975 May 19

ABSTRACT

Luminosities within central diameters of about 5 kpc (defined as the nuclear magnitudes) are given for the 10 brightest galaxies in each of nine rich clusters. Corrections required to use these magnitudes as relative distance indicators are discussed. The resulting Hubble diagram shows no evidence for significant non-Hubble velocities for $1000\ \mathrm{km\ s^{-1}} < CZ < 11{,}000\ \mathrm{km\ s^{-1}}$. If the mean magnitudes of the five brightest nuclei in each cluster are considered, the $\sigma(\Delta m)$ from the mean Hubble line is only 0.15 mag and the $\sigma(\Delta \log CZ)$ is 0.029.

Subject headings: cosmology — galaxies: clusters of — galaxies: nuclei — galaxies: photometry

I. INTRODUCTION

A comprehensive series of papers by Sandage and collaborators has led to the conclusion that H_0, the local value of the Hubble constant, has global significance and that cosmic deviations from a smooth Hubble flow are small (Sandage and Hardy 1973; Sandage and Tammann 1975, and references therein). On the other hand, observations exist that are best explained by invoking non-Hubble components in the redshifts of at least some galaxies (e.g., Arp 1971; Burbidge 1973; Tifft 1974). In a recent study undertaken to investigate possible correlations between nuclear magnitudes and redshifts for galaxies within clusters, it was found that the nuclear magnitudes of the Perseus and Coma cluster galaxies did not differ as expected from the Hubble flow (Weedman 1975). In the present paper, nuclear magnitudes of galaxies in other clusters are considered, and it is shown that such magnitudes do in fact generally follow the predictions of the Hubble law.

II. OBSERVATIONS OF NUCLEAR MAGNITUDES

Most recent studies of clusters of galaxies have been directed toward obtaining redshifts and magnitudes for the brightest galaxy in many clusters, with the hope of extending the Hubble diagram to the greatest possible redshifts (Sandage and Hardy 1973). The total magnitudes of these first-ranked galaxies are statistically homogeneous after corrections to within ±0.3 mag if apparent deviations from an isotropic Hubble law are caused only by deviations in the absolute magnitudes of first-ranked galaxies. Uncertainties in the determination of the total magnitude arise because a luminosity profile must be assumed for each galaxy observed, and the angular diameter to a well-defined isophote has to be measured and used with the assumed profile to get the total magnitude (Sandage 1972*a*). These diameter measures have so far been done visually from photographic plates using the background brightness of the night sky as the comparison isophote. There are also uncertainties regarding the homogeneity of absolute total magnitudes for first- and second-ranked cluster galaxies (e.g., Bautz and Morgan 1970; Sandage and Hardy 1973). The Bautz-Morgan method of classifying clusters depends on the contrast between the brightest one or two galaxies and the remaining cluster members. The absolute magnitude of the first-ranked galaxy is a function of Bautz-Morgan cluster type. Corrections for this have been derived by Sandage and Hardy (1973) on a statistical basis by assuming that the observed scatter in the Hubble diagram for first-ranked galaxies arises only because of differences in the absolute magnitudes of these galaxies.

The most comprehensive alternative method used to derive relative cluster distances with a parameter other than the first-ranked galaxy magnitude is the method of Abell, by which a change in slope of the luminosity function for cluster galaxies is assumed to occur at the same absolute magnitude within clusters (Bautz and Abell 1973). This method requires total magnitudes for ~100 galaxies within a cluster. Recent detailed studies of cluster luminosity functions (Oemler 1974) indicate, however, that the slope change in the luminosity function is not very well defined.

In the present paper, we try to approach the problem of relative cluster distances with a different technique in order to confirm independently the results derived from total magnitudes of first-ranked galaxies. Consequently, we define and use nuclear magnitudes of galaxies as measures of relative cluster distances. It is obvious in visual observations or short-exposure photographs that bright cores exist in the centers of all

---

* Visiting astronomer, Kitt Peak National Observatory and Cerro Tololo Inter-American Observatory, operated by the Association of Universities for Research in Astronomy, Inc. under contract to the National Science Foundation.

† On leave, 1974–1975, at School of Physics and Astronomy, University of Minnesota.

elliptical and most spiral galaxies. These are a consequence of the increased star densities in such nuclei, except in very rare cases such as the nuclei of Seyfert galaxies. Tifft (1963) has discussed the usefulness of nuclear magnitudes and colors for the study of galaxy classifications and magnitude-redshift diagrams. The advantages of measuring nuclear magnitudes for reasonably nearby clusters are severalfold. Such observations are easy, even with small telescopes, because the nuclear regions of galaxies (meaning the central region with a diameter of ~ 5 kpc) are of high surface brightness. Nuclear magnitudes can also be used without much concern for the galaxy type involved. Bright galaxies in clusters are virtually all ellipticals or lenticulars, and the similarities among the nuclei of such galaxies mean that a discussion of nuclear magnitudes refers to a homogeneous stellar population (Morgan and Osterbrock 1969). The choice of an aperture diameter for defining a "nuclear magnitude" is not critical (Weedman 1975), although the shape of the luminosity profile is such that apertures ~ 5 kpc in diameter are most appropriate.

Nuclear magnitudes are potentially useful as distance indicators only because galaxies do have rapidly brightening luminosity profiles in their centers. If galaxies were of constant surface brightness throughout, the observed magnitude would obviously scale with redshift, regardless of the actual distance, if the observing aperture were inversely scaled to the redshift. As a consequence of the shape of the luminosity profile within a central diameter of about 10 kpc, however, the nuclear magnitude is quite sensitive to changes in galaxy distance. Using the luminosity profile in the nuclear regions discussed below, one would find, for example, that a change from 3.5 kpc to 7 kpc in the absolute diameter of the observing aperture (as projected on the galaxy) would change the observed magnitude by 0.6. Were the projected aperture diameter to change from 3.5 to 7 kpc because of a doubling of the galaxy's distance, the net change in observed nuclear magnitude would be $+0.9$ mag, whereas the total galaxy magnitude would change by 1.5 mag because of the increase in distance. In magnitude units, the nuclear magnitudes are therefore somewhat more than one-half as sensitive to distance changes as are total magnitudes.

There are extreme differences between the apertures used to define nuclear magnitudes and those that would be needed to measure the total galaxy magnitudes used by Sandage. For example, a $10''.1$ aperture is used below for the Perseus cluster, whereas Sandage's (1972*a*) V_{26} magnitude would correspond to a $4'$ aperture at this cluster's redshift. The concentration of luminosity in the nuclei is illustrated by a comparison of nuclear and total magnitudes. For NGC 4889 in Coma, Sandage (1972*b*) gives a total magnitude V_{26} of 11.8, while the nuclear $V(7''.6)$ listed below is 14.3. Even for this supergiant galaxy, 10 percent of the total luminosity out to an isophote of 26 mag per square arcsecond is contained within a $7''.6$ aperture. For the fainter NGC 4881, the $7''.6$ aperture contains 23 percent of the luminosity in V_{26}.

The primary disadvantage of measuring nuclear magnitudes is the necessity of observing regions of the same absolute diameter within the different galaxies to be compared. This means, for studies of clusters, that the observing apertures have to be scaled to the redshifts, and luminosity profiles for the inner regions of galaxies have to be known to correct for slightly different aperture sizes. Should non-Hubble components of the cluster redshifts be detected, an iterative procedure would have to be used to derive the true aperture correction that applies for the actual cluster distance. In order to subtend a nuclear diameter of ~ 5 kpc with conveniently usable apertures ($\gtrsim 5$ arcsec), observations are restricted to clusters with Hubble velocities $< 10^4$ km s^{-1}, if $H_0 = 50$ km s^{-1} Mpc^{-1}. In this paper, nuclear magnitudes are given for the 10 brightest galaxies in each of nine clusters. These are Virgo, Centaurus (NGC 4696), Hydra I (A 1060), Perseus, A 1367, Coma, Hercules, A 1185, and A 2147. These particular clusters were chosen for this program because they are sufficiently rich and condensed that there is little uncertainty regarding cluster membership for the brighter galaxies. The clusters are all morphologically similar in having several conspicuously bright members; none are of Bautz-Morgan class I.

Previous data exist for Virgo, Perseus, and Coma. New photoelectric *UBV* photometry for the 10 brightest galaxies in each of the remaining clusters has been obtained. Observations of the Centaurus and Hydra I galaxies were made with the 36 inch (91 cm) telescope at Cerro Tololo Inter-American Observatory in 1974 March. These were part of a more extensive study of these particular clusters being undertaken by L. P. Bautz, W. R. Forman, M. G. Smith, and myself. The Hercules cluster and A 1185, 1367, and 2147 were observed with the 84 inch (2.1 m) telescope at Kitt Peak National Observatory in 1975 April. Because these were generally the more distant clusters and required smaller apertures, the television acquisition system and computer-controlled photometer were used (Kinman and Mahaffey 1974). All transformations to the *UBV* system were made using the equatorial standards of Landolt (1973). Identification charts for the new observations are given in Figure 1. More than 10 galaxies were observed in each cluster so that a selection of the 10 brightest was made using the observed nuclear magnitudes. Galaxies with the brightest nuclear magnitudes are not necessarily those that appear brightest on the Sky Survey. The new data are in Table 1; the numbers in the table and charts are the same. The galaxies are arbitrarily ordered by their observed V magnitudes. Local standard stars were defined in each cluster and were observed frequently during the galaxy observations with the same apertures used for the galaxies. The rms deviation of these standard observations about their adopted means was 0.01 mag to 0.02 mag in all filters. Most galaxies were observed twice by independently recentering them in the aperture. The centering errors should be the primary source of uncertainty in the measured nuclear magnitudes, but the mean differences between the

TABLE 1

PHOTOMETRY OF TEN BRIGHTEST CLUSTER GALAXIES

	CENTAURUS			HYDRA I			A 1367		HERCULES		A 1185		A 2147	
NUMBER	$V(16''.5)$	$(B-V)$	$(U-B)$	$V(16''.5)$	$(B-V)$	$(U-B)$	$V(7''.0)$	$(B-V)$	$V(7''.0)$	$(B-V)$	$V(7''.0)$	$(B-V)$	$V(7''.0)$	$(B-V)$
1.......	12.98	1.10	0.62	13.22	1.07	0.65	14.50	1.05	15.12	1.07	15.09	1.05	15.22	1.15
2.......	13.28	1.10	0.72	13.23	1.02	0.66	14.61	1.01	15.22	1.17	15.13	1.09	15.22	1.14
3.......	13.29	1.14	0.79	13.25	0.93	0.47	14.61	1.05	15.24	1.16	15.37	1.08	15.27	1.07
4.......	13.47	1.13	0.70	13.51	1.14	0.59	14.76	1.03	15.30	1.23	15.52	1.15	15.58	1.09
5.......	13.52	1.07	0.57	13.59	1.02	0.62	14.78	0.97	15.48	0.81	15.57	1.07	15.58	1.15
6.......	13.60	1.11	0.67	13.63	1.06	0.62	14.94	1.06	15.50	1.05	15.78	1.01	15.60	1.10
7.......	13.62	1.04	0.64	13.68	1.04	0.54	15.14	0.96	15.51	1.15	15.79	1.18	15.68	1.07
8.......	13.63	1.09	0.68	13.91	1.08	0.68	15.15	0.97	15.55	1.17	15.91	1.05	15.69	1.03
9.......	13.86	0.99	0.64	13.94	1.05	0.60	15.23	1.08	15.55	1.11	15.94	1.04	15.70	1.17
10.......	13.86	1.04	0.55	14.09	0.99	0.77	15.34	1.02	15.59	1.21	15.95	1.11	15.88	1.07

values measured are only 0.03 mag in V, 0.02 mag in $(B-V)$, and 0.05 mag in $(U-B)$ for the $16''.5$ aperture observations at CTIO. These differences for the $7''.0$ observations at KPNO are 0.04 mag in V, 0.05 mag in $(B-V)$, and 0.10 mag in $(U-B)$. The excessive scatter in the $(U-B)$ results at KPNO arose because many of the observations were made with a bright moon, so the sky background exceeded the galaxy brightness in the U filter. Because of the large uncertainties, and because they are not needed in the present analysis, these $(U-B)$ colors are not tabulated.

The data to be used for galaxies in Virgo, Perseus, and Coma are reproduced in Table 2. The nuclear magnitudes for the 10 brightest galaxies in the Perseus and Coma clusters are from Weedman (1975). (The Perseus sample is slightly different from the other clusters. The brightest nucleus in the Perseus cluster is the Seyfert galaxy NGC 1275, but it is omitted here because it is so obviously anomalous. Another bright Perseus galaxy, NGC 1265, should probably have one of the 10 brightest nuclei, but it could not be measured reliably because a bright star is superposed close to the nucleus.) The data for the Virgo cluster galaxies are taken from Tifft (1969); Tifft's photometry was not in the *UBV* system but has been transformed by de Vaucouleurs (1961). By comparing the transformed *UBV* magnitudes with Tifft's original data, we adopt the following empirical relations to go from Tifft's 1, 2, 3, 4 magnitudes to *UBV* magnitudes:

$$(B-V) = +0.10 + 0.58(2-4)\,,$$

$$V = (4) + 0.21 + 0.26(B-V)\,.$$

All observations of nuclear magnitudes in the tables are listed as $V(d'')$ where d'' is the diameter of the observing aperture. All data correspond to apertures that are approximately scaled inversely with the cluster redshifts. Before attempting to apply the remaining aperture corrections and corrections for differential galactic absorption, we compare the observed nuclear magnitudes.

III. NUCLEAR MAGNITUDES AND THE HUBBLE DIAGRAM

In Figure 2 are plotted the individual, uncorrected nuclear magnitudes from Tables 1 and 2. The relative magnitudes of individual cluster galaxies scale approximately the same, although the richer clusters (Perseus, Coma, and Hercules) have flatter distributions, as would be expected. It is notable that the differences in nuclear magnitudes among the brightest galaxies in a cluster are significantly less than differences in total magnitudes. For example, the difference in V_{26} between NGC 4889 (the brightest Coma galaxy) and

TABLE 2

INDIVIDUAL NUCLEAR MAGNITUDES OF TEN BRIGHTEST CLUSTER GALAXIES

	VIRGO		PERSEUS		COMA	
NUMBER	Object	$V(38''.7)$	Object	$V(10''.1)$	Object	$V(7''.6)$
1...........	N 4472	10.42	CR 25	14.12	N 4889	14.32
2...........	N 4649	10.53	CR 43	14.35	N 4865	14.70
3...........	N 4486	10.70	CR 37	14.39	N 4895	14.85
4...........	N 4374	10.72	CR 30	14.43	N 4898W	14.99
5...........	N 4382	10.82	CR 38	14.44	N 4908	15.08
6...........	N 4526	10.95	CR 29	14.46	N 4874	15.09
7...........	N 4552	11.00	I 310	14.52	N 4881	15.11
8...........	N 4406	11.00	CR 3	14.53	N 4869	15.13
9...........	N 4621	11.09	CR 8	14.56	N 4045	15.14
10...........	N 4365	11.18	CR 12	14.62	N 3973	15.15

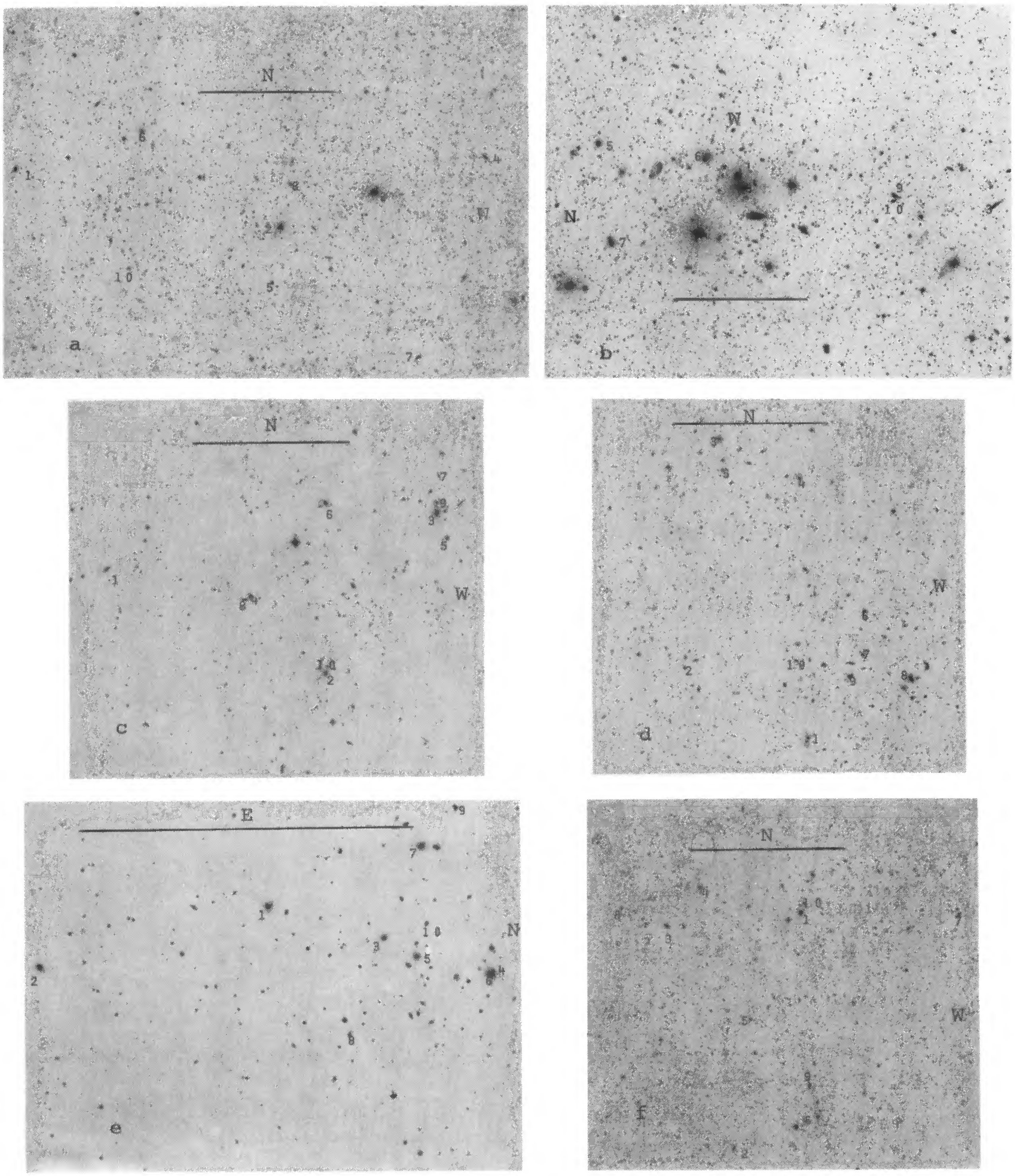

FIG. 1.—Finding charts for galaxies observed in the clusters (*a*) Centaurus, (*b*) Hydra I, (*c*) A 1367, (*d*) Hercules, (*e*) A 1185, (*f*) A 2147. Scale bars are 20′ long. All photographs reproduced from the red prints of the National Geographic Society—Palomar Observatory Sky Survey except for (*b*), which is from a IIa-O plate obtained with the Curtis Schmidt telescope at Cerro Tololo.

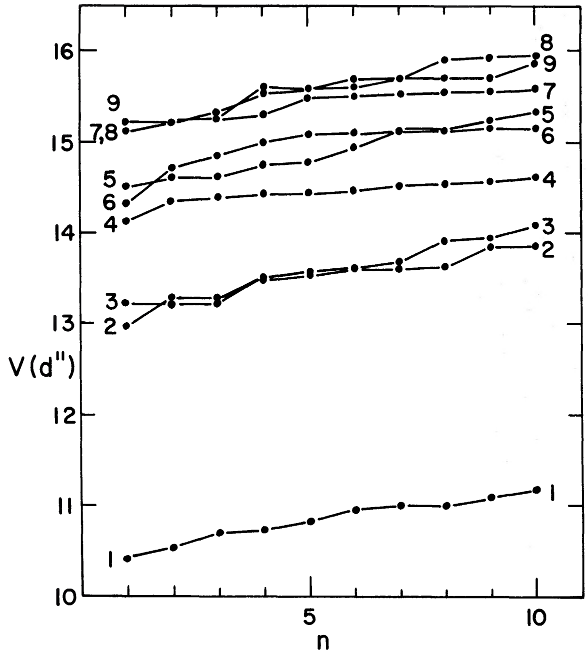

FIG. 2.—Individual nuclear magnitudes of galaxies in Tables 1 and 2. Data for individual clusters numbered according to redshift ordering in Table 3.

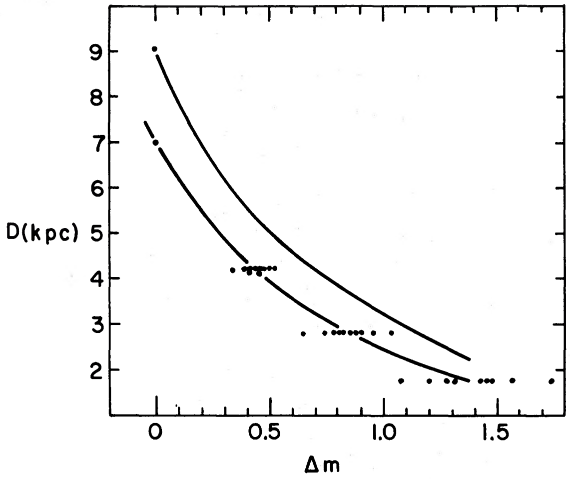

FIG. 3.—Empirical growth curves determined from observations of Virgo cluster galaxies (*points and lower curve*) and Perseus cluster galaxies (*upper curve*). Normalization and use of curves described in text.

NGC 4881 (the seventh brightest) is 2.0 mag from Sandage (1972*b*). But the difference in nuclear magnitude between these two galaxies is only 0.8 mag. Because the nuclear magnitudes of first-ranked galaxies are not particularly bright relative to fainter cluster members, the Hubble diagrams that follow, which are based on means of several cluster members, are not heavily weighted by the first-ranked galaxy.

The data in Tables 1 and 2 and Figure 2 can be smoothed by considering the mean nuclear magnitudes of the cluster galaxies. For the n brightest galaxies, these means are

$$\overline{V}_n = \frac{\sum_n V_n}{n} \,.$$

In order to use the nuclear magnitudes as relative distance indicators, we must assume that the mean absolute nuclear magnitude for the n brightest nuclei is constant for different clusters. We can then construct a Hubble diagram after correcting the observed nuclear magnitudes for aperture effects, K-dimming, and galactic absorption. These corrections are all made differentially relative to the Virgo cluster and are given in Table 3. The aperture corrections are made by assuming that the cluster distances are scaled with their redshifts and that the mean luminosity profile for the brightest galaxies is the same as the observed mean profile for the Virgo galaxies contained in Table 2. These 10 Virgo galaxies are plotted in Figure 3 using the multiaperture data in Tifft (1969), normalized to a 64".5 aperture and transformed to V magnitudes as described above. A mean growth curve (shown in Fig. 3) is then applied to all nuclear magnitudes in the other clusters by changing all aperture diameters to absolute diameters, assuming $H_0 = 50 \text{ km s}^{-1} \text{ Mpc}^{-1}$. This mean curve in Figure 3 can then be used to derive the aperture corrections, which are the magnitude differences taken from the curve between the aperture actually used and the adopted standard aperture of 4.2 kpc diameter. While the growth curve adopted was taken from Virgo cluster galaxies, a virtually identical curve within the apertures of interest can be obtained from the Perseus galaxies in Table 2. This

TABLE 3

CORRECTIONS TO NUCLEAR MAGNITUDES

Parameter	Virgo	Centaurus	Hydra I	Perseus	A 1367	Coma	Hercules	A 1185	A 2147
Redshift (km s^{-1})	1120	3390	3450	5470	6120	6840	10230	10470	10530
Aperture (kpc)	4.20	5.43	5.52	5.36	4.15	5.04	6.94	7.11	7.15
Aperture, Δm	0.0	+0.23	+0.24	+0.22	0.0	+0.17	+0.43	+0.45	+0.45
Mean $(B-V)$	0.96	+1.08	+1.04	+1.19	+1.02	+1.03	+1.11	+1.08	+1.10
Mean $(B-V), z=0$	0.95	+1.05	+1.01	+1.14	+0.96	+0.96	+1.01	+0.98	+1.00
$A_V = 3E_{B-V}$	0.0	−0.30	−0.18	−0.57	−0.03	−0.03	−0.18	−0.09	−0.15
$K_V, \Delta m$	0.0	−0.02	−0.02	−0.03	−0.04	−0.04	−0.06	−0.06	−0.06
Total correction to $\overline{V}_n, \Delta m$	0.0	−0.09	+0.04	−0.38	−0.07	+0.10	+0.19	+0.30	+0.24
corrected V_1(4.2 kpc)	10.42	+12.89	+13.26	+13.74	+14.43	+14.42	+15.31	+15.39	+15.46
corrected $\overline{V}_5$(4.2 kpc)	10.64	+13.22	+13.40	+13.97	+14.58	+14.89	+15.46	+15.64	+15.61
corrected $\overline{V}_{10}$(4.2 kpc)	10.84	+13.42	+13.65	+14.06	+14.84	+15.06	+15.60	+15.91	+15.78

curve, normalized to a 9.02 kpc ($17\farcs0$) aperture, is also shown in Figure 3 and is derived from the multiaperture data in Weedman (1975).

It would be possible to derive precise aperture corrections for individual galaxies by multiaperture photometry. However, the differential corrections to the data required are small because the apertures used scale to similar absolute diameters. Therefore, a mean profile can be adopted without the introduction of serious errors. All data are corrected to the Virgo $V(38\farcs7)$ nuclear magnitudes, which corresponds to an absolute diameter of 4.20 kpc (for $H_0 = 50$ km s^{-1} Mpc). The absolute diameters of the nuclear regions observed in the other clusters with the apertures used are listed in Table 3. The aperture corrections listed are the difference in nuclear magnitude between that observed and that which would have been observed with a 4.20 kpc aperture, assuming the Virgo growth curve shown in Figure 3.

Adopted cluster redshifts are also listed in Table 3. That for the Coma cluster is the mean of 75 galaxy velocities in Tifft (1972), and that for the Perseus cluster is the mean of the 50 velocities in Chincarini and Rood (1971). For Virgo, the adopted cluster velocity depends on whether the E (elliptical and lenticulars) or S (spiral) cloud is used. The apparent velocity segregation between ellipticals and spirals would probably not be recognized in a more distant cluster for which fewer velocities were available, so a mean velocity for the Virgo cluster is adopted from all 68 galaxies, both E and S, recognized by de Vaucouleurs and de Vaucouleurs (1973) as cluster members. In neither Virgo, Perseus, nor Coma is the adopted velocity significantly different from that used by Sandage and Hardy (1973). For the other clusters, we adopt the Sandage and Hardy velocities, except for A 1185, for which Peterson's (1970) velocity is used.

Galactic absorption corrections are made empirically using the differences in color for the nuclei observed in different clusters. These corrections are also made differentially relative to the Virgo cluster. We assume that the mean intrinsic $(B - V)$ colors of the 10 nuclei in Tables 1 and 2 are the same in all clusters, so that the apparent differences, after correcting to zero redshift (Sandage 1972*b*), are due to galactic reddening. The sources for the $(B - V)$ colors are the same as those used for the V magnitudes. The mean observed colors, corrections to zero redshift, and final differential absorption corrections $A_V = 3.0E_{B-V}$ are given in Table 3. Corrections for K-dimming that are tabulated are taken from Sandage (1973).

Having applied these corrections to the nuclear magnitudes, a Hubble diagram can be constructed using mean nuclear magnitudes in the nine clusters. The appearance of this diagram depends only slightly on the value of n chosen. The diagram for $\overline{V}_5$ is shown in Figure 4; this conforms extremely well to what would be expected for an isotropic expansion that included even the Virgo cluster. The σ about the mean line shown (of slope 5) is 0.15 mag. If the Hubble diagram is constructed for V_1, the σ is 0.18 mag, and this increases to 0.20 mag if the $\overline{V}_{10}$ are used. In all three cases, the Virgo point lies slightly above the mean line but would fall precisely on the mean Hubble line for the other clusters if the adopted Virgo velocity were decreased from 1120 km s^{-1} to 1050 km s^{-1}. The dispersion in velocity about the mean line in the $\overline{V}_5$ diagram is $\Delta \log CZ = 0.029$. This corresponds to a maximum dispersion in Z of $\Delta Z = 0.07Z$. While this value is substantially less than the $\Delta Z = 0.115Z$ derived by Sandage (1972*c*) from first-ranked galaxy total magnitudes, the two results are comparable regarding real uncertainties in distance because the nuclear magnitudes are only slightly more than half as sensitive to distance changes as are total magnitudes (§ II, above).

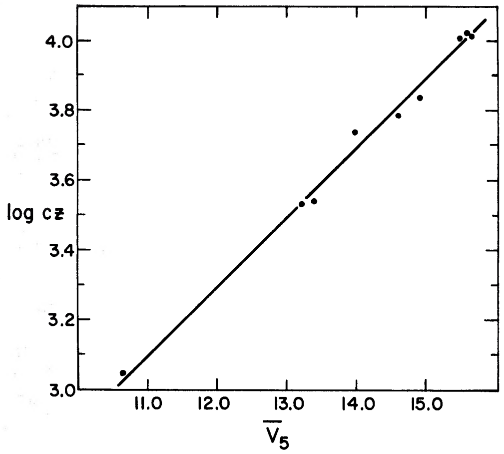

FIG. 4.—Hubble diagram for the totally corrected mean nuclear magnitudes for the five brightest galactic nuclei in each cluster, from Table 3.

The results of this study are therefore completely consistent with those expected from an isotropic Hubble expansion for velocities 1000 km s^{-1} $< CZ <$ 11,000 km s^{-1}. The earlier comparison of nuclear magnitudes for Perseus and Coma galaxies that did not conform to the expectations of the Hubble law (Weedman 1975) arose because the Perseus and Coma points happen to deviate in opposite signs from the mean Hubble line. In addition, the Perseus cluster point is now seen to have a greater deviation than any of the other eight clusters considered. It appears that the analysis of the nuclear magnitudes of galaxies does not in general give any significant evidence for non-Hubble redshifts. If it is assumed that the distances to clusters of galaxies are scaled precisely with their redshifts, this data then demonstrates a remarkable homogeneity in the nuclear magnitudes of bright galaxies.

I thank Dr. T. D. Kinman for helpful advice regarding the use of the computer-controlled photometer at Kitt Peak, and Dr. M. G. Smith for many interesting discussions during mutual initiation into the problems of observational cosmology. I also acknowledge the National Science Foundation, Astronomy Section, for partial support of this research.

REFERENCES

Arp, H. 1971, *Science*, **174**, 1189.
Bautz, L. P., and Abell, G. O. 1973, *Ap. J.*, **184**, 709.
Bautz, L. P., and Morgan, W. W. 1970, *Ap. J.* (*Letters*), **162**, L149.
Burbidge, G. R. 1973, *Nature Phys. Sci.*, **246**, 17.
Chincarini, G., and Rood, H. J. 1971, *Ap. J.*, **168**, 321.
de Vaucouleurs, G. 1961, *Ap. J. Suppl.*, **5**, 233.
de Vaucouleurs, G., and de Vaucouleurs, A. 1973, *Astr. and Ap.*, **28**, 109.
Kinman, T. D., and Mahaffey, C. T. 1974, *Pub. A.S.P.*, **86**, 336.
Landolt, A. U. 1973, *A.J.*, **78**, 959.
Morgan, W. W., and Osterbrock, D. E. 1969, *A.J.*, **74**, 515.
Oemler, A., Jr. 1974, *Ap. J.*, **194**, 1.
Peterson, B. A. 1970, *A.J.*, **75**, 695.
Sandage, A. 1972*a*, *Ap. J.*, **173**, 485.
———. 1972*b*, *ibid.*, **176**, 21.
———. 1972*c*, *ibid.*, **178**, 1.
———. 1973, *ibid.*, **183**, 711.
Sandage, A., and Hardy, E. 1973, *Ap. J.*, **183**, 743.
Sandage, A., and Tammann, G. A. 1975, *Ap. J.*, **197**, 265.
Tifft, W. G. 1963, *A.J.*, **68**, 302.
———. 1969, *ibid.*, **74**, 354.
———. 1972, *Ap. J.*, **175**, 613.
———. 1974, *ibid.*, **188**, 221.
Weedman, D. W. 1975, *Ap. J.*, **195**, 587.

DANIEL W. WEEDMAN: Dyer Observatory, Box 1803, Vanderbilt University, Nashville, TN 37235