THE ASTROPHYSICAL JOURNAL, **238**:458–470, 1980 June 1

A DISTANCE SCALE FROM THE INFRARED MAGNITUDE/H I VELOCITY-WIDTH RELATION. II. THE VIRGO CLUSTER

JEREMY MOULD
Hale Observatories,[1] Carnegie Institution of Washington; and Kitt Peak National Observatory[2]

MARC AARONSON[3]
Steward Observatory, University of Arizona

AND

JOHN HUCHRA[3]
Harvard-Smithsonian Center for Astrophysics
Received 1979 October 3; accepted 1979 December 3

ABSTRACT

Recently published 21 cm profiles and new infrared measurements permit a rediscussion of the luminosity/velocity-width relation for the Virgo cluster. The size of the current sample (23 galaxies) allows us to test the significance of the Hubble type as a second parameter in the Tully-Fisher diagram. We find no support for the recent conclusions of Roberts that *at a given luminosity* earlier-type galaxies have larger velocity widths. On the contrary, S0-Sab galaxies in Virgo may even have marginally smaller velocity widths. No other morphological-type dependence is seen in the infrared luminosity/velocity-width diagram.

From the calibration presented in the first paper of the series, a distance modulus of 30.98 $\pm$ 0.09 is deduced for the Virgo cluster (adopting a Hyades modulus of 3.29 mag, and excluding zero-point error). This result is independent of the limiting magnitude of the sample both optically and at 21 cm. The absence of any such bias is encouraging for later work on more distant clusters. Our Virgo modulus is in excellent agreement with the mean value we obtain from nine other distance techniques of 30.98 $\pm$ 0.08 mag.

Finally, from an improved determination of the mean recession velocity of the Virgo cluster (1019 $\pm$ 51 km s^{-1}), the Hubble ratio for the cluster is found to be 65 $\pm$ 4 km s^{-1} Mpc^{-1}.

Subject headings: cosmology — galaxies: clusters of — galaxies: photometry — galaxies: redshifts — radio sources: 21 cm radiation

I. INTRODUCTION

The distance to the Virgo cluster has long been a benchmark in the astronomical distance scale. Many determinations of the Hubble constant are based on the Virgo velocity-distance ratio. However, secondary distance indicators, such as the diameters of H II regions and the luminosity function of globular clusters, require limiting measurements at Virgo. This restriction does not apply to the Tully-Fisher relation, for which limiting measurements with current techniques extend to many times the Virgo distance.

In the present series of papers (see Aaronson, Mould, and Huchra 1980; hereafter Paper I), the Virgo cluster takes on a new significance. First, as the apparent dynamical center of the Local Supercluster, the Virgo core is the reference point for a kinematical study of the Supercluster itself. Second, the large population in the Virgo cluster of galaxies of all morphological type makes it a testing ground for the Tully-Fisher relation. We can examine the intrinsic dispersion of the relation and the question of morphological-type dependence.

A considerable amount of new 21 cm data has been accumulated for spirals in Virgo since the pioneering paper of Tully and Fisher (1977). We now have infrared measurements for all the additional galaxies which are relevant according to the criteria of Paper I. These are presented in § II together with further large-aperture measurements in the original sample. The complete luminosity/velocity-width diagram is examined in § III, especially with regard to possible morphological-type dependence. In § IV we reexamine the mean redshift of the Virgo cluster and present a revised distance modulus and Hubble ratio (§ V). Our distance modulus is shown to agree with results from many other techniques. This discussion (§ VI) is based on a new modulus to the M101 group and a revised absolute-magnitude, luminosity-class calibration determined in the Appendix.

[1] Operated jointly by the Carnegie Institution of Washington and the California Institute of Technology.

[2] Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[3] Visiting astronomer at Kitt Peak National Observatory.

II. DATA

According to the criteria adopted in Paper I, we consider only disk galaxies that are inclined more than 45° and with extended H I emission. Table 1 is a compilation of all the 21 cm data of which we are aware for galaxies that meet these criteria and that fall within a 6° circle centered on NGC 4486. The most recent data are from a survey of relatively early-type galaxies in the Virgo region by Krumm and Salpeter (1979). Two galaxies observed by them (NGC 4385 and 4694, both with $\Delta V = 99$ km s^{-1}) have been excluded as point sources of H I. Two further galaxies (NGC 4413 and 4419) have been omitted, as their velocity widths are highly uncertain. Following Aaronson, Huchra, and Mould (1979, hereafter AHM), we have excluded the background galaxy IC 769.

TABLE 1

21 cm Data for Virgo Galaxies

Name (1)	i (deg) (2)	ΔV_{20} (km s^{-1}) (3)	S/N (4)	Reference (5)	Notes (6)
NGC 4178......	77	285	6.5	1	a
		350	3	2	
NGC 4192......	78	455	7	1	
		500	3	2	
		470	...	3	
NGC 4206......	78	294	3	1	
NGC 4216......	81	524	...	3	
NGC 4294......	70	265	2.5	2	
		244	5	4	
		240	15	9	
NGC 4380......	58	280	4	6	b
NGC 4388......	81	393	...	3	
		405	3	5	c
UGC 7513......	90	284	3.5	1	
NGC 4438......	71	360	...	3	
NGC 4450......	53	313	6	6	b
NGC 4498......	59	185	5	1	
NGC 4501......	64	532	6	1	
		181	...	2	
		536	5	5	
NGC 4519......	48	227	10	5, 7	d
NGC 4522......	79	228	...	5, 7	
NGC 4532......	70	265	10	1	e
		256	12	5	f
NGC 4535......	42	292	15	1	f, g
		310	5	2	
		310	10	5	e
UGC 7737......	66	130	3	1	
NGC 4550......	79	291	3	9	
NGC 4569......	64	348	...	3	
NGC 4651......	59	377	6	1	a
		395	11	5	
		385	5.5	8	
NGC 4654......	55	302	6.5	1	
		315	...	4	
NGC 4698......	68	434	6	5, 7	h
		422	6	6	b
NGC 4758......	82	205	5	1	

Notes.—[a] The inclination is taken from reference (1). [b] See text regarding treatment of this "mapping profile." [c] This was remeasured by us as a single profile at the 50% level. Conversion to ΔV at 20% was made by multiplying by 1.07. [d] Danver's 1942 inclination of 26° was ignored. [e] Broad wing visible. [f] Broad wing not visible. [g] Included since our axial ratios formula suggests $i = 46°$ compared with Danver's 1942 $i = 42°$. [h] Inclination following Fisher and Tully 1977.

References.—(1) Tully and Fisher 1977. (2) Davies and Lewis 1973. (3) Helou, Salpeter, and Krumm 1979. (4) Shostak 1978. (5) Huchtmeier, Tammann, and Wendker 1976. (6) Krumm and Salpeter 1979. (7) Sandage and Tammann 1976*b*. (8) Grewing and Mebold 1975. (9) Peterson 1978.

Included in Table 1 (column [2]) is the adopted inclination of the tangent plane of the galaxy to the celestial sphere. Adopting the procedure given in Paper I, we have generally preferred inclinations from Danver (1942), when available. Otherwise, they have been calculated from the axial ratios in the *Second Reference Catalogue* (de Vaucouleurs, de Vaucouleurs, and Corwin 1976, hereafter RC2), using the Holmberg formula with a small correction term (i.e., eq. [4] of Paper I). In a few cases noted in Table 1, further adjustment was made according to the optical appearance of the spiral arms, as judged by ourselves, Tully and Fisher (1977), and/or Fisher and Tully (1977).

Column (3) of Table 1 gives the velocity width (ΔV_{20}) at the 20% level. We have checked that the published values correspond to our definition of ΔV_{20} in Paper I and where necessary have adjusted them. Also included is an estimate of the rms signal-to-noise ratio (S/N) of the profile in column (4). As in Paper I, no correction to the line widths has been made for instrumental resolution or internal galaxy turbulence.

In general, the agreement in ΔV from different sources is good ($\pm 3\%$) for profiles with S/N ≥ 5. A number of discrepancies are noticeable with the work of Davies and Lewis (1973) whose S/N is generally low. Some of the more recent data were obtained at Arecibo, where the small beamwidth resolves large spirals at the Virgo distance. In these cases we have adopted the value of ΔV given by Helou, Salpeter, and Krumm (1979), who assert that the velocity difference at the 35% level on opposite off-center H I profiles corresponds roughly to the 20% points on a "whole galaxy" profile. We have followed the same procedure for NGC 4450 and 4698, for which Krumm and Salpeter (1979) give only ΔV_{50}. Comparison of the "mapping results" with integrated velocity widths for NGC 4192 and 4698 indicates good correspondence between the two techniques, but a larger overlap sample with true integrated profiles would be useful to test this further.

Table 1 contains an additional 12 galaxies to those studied by AHM. All of these have now been measured in the IR (Table 2) following the procedures described in Paper I. In Table 2 the diameters D_1 in column (2) are taken directly from the RC2, except that a cutoff[4] is applied in the inclination correction to D_{25} (see Paper I). With the galactic reddening model adopted in Paper I, log D_1 is identical to log $D(0)$ in the RC2 for galaxies at the latitude of the Virgo cluster. The magnitudes are recorded in column (3), the diaphragm

[4] This is relevant only in the case of UGC 7513.

TABLE 2

NEW INFRARED MEASUREMENTS IN VIRGO

Name (1)	log D_1 (2)	H (3)	Aperture Size A (4)	log A/D_1 (5)	Tel. (6)
NGC 4192	1.87	7.94	110.6	−0.60	KP36
		7.64	165.2	−0.43	
NGC 4216	1.78	7.51	81.2	−0.65	KP36
		7.42	102.2	−0.54	
		7.31	110.6	−0.51	
		7.12	165.2	−0.34	
NGC 4294	1.40	10.94	40.6	−0.57	KP36
		10.67	51.8	−0.46	
NGC 4380	1.51	9.96	51.8	−0.57	KP36
		9.46	81.2	−0.38	
NGC 4388	1.58	9.10	51.8	−0.64	KP36
		8.78	81.2	−0.45	
UGC 7513 (IC 3322A)	1.40	11.06	36.2	−0.62	KP84
		10.80	45.0	−0.52	
NGC 4438	1.88	8.21 ± 0.04	99.9	−0.66	KP16
		7.64	159.3	−0.46	
		7.52	216.0	−0.32	
NGC 4450	1.65	8.51	51.8	−0.71	KP36
		8.09	81.2	−0.52	
		7.91	102.2	−0.41	
NGC 4501	1.78	7.50	81.2	−0.65	KP36
		7.16	110.6	−0.51	
		6.91	165.2	−0.34	
NGC 4519	1.46	10.79	51.8	−0.52	KP36
		10.38 ± 0.04	81.2	−0.33	
NGC 4522	1.45	10.62	51.8	−0.51	KP36
		10.24	81.2	−0.32	
NGC 4535	1.80	8.55	110.6	−0.53	KP36
		8.02	165.2	−0.36	
UGC 7737	1.10	14.51 ± 0.10	22.5	−0.53	KP84
NGC 4569	1.90	7.79	99.9	−0.68	KP16
		7.41	159.3	−0.48	
		7.20	216.0	−0.34	
NGC 4698	1.57	8.66	51.8	−0.63	KP36
		8.28	81.2	−0.44	

size A is given in arcseconds in column (4), and the telescope used is shown in column (6). Statistical uncertainties in the photometry are ≤ 0.03 mag, except where noted.

In addition to the 12 new galaxies, three of the galaxies from AHM (NGC 4192, 4501, and 4535), which had required growth-curve extrapolation were remeasured with larger apertures (Table 2). Good agreement was found with previous results, except in the case of NGC 4535, whose integrated luminosity was determined to be 0.28 mag brighter, owing to an unexpected steepening of the growth curve.

The final values of $H_{-0.5}$, obtained by interpolating growth curves for each galaxy at log $A/D_1 = -0.5$, are recorded in Table 3. (Justification for the use of this particular reference isophote is given in Paper I.) With the exception of the above three galaxies, for which more data are now available, values of $H_{-0.5}$ from AHM were adopted unchanged, as no additional corrections were required. At the Virgo latitude, no galactic reddening correction to the magnitudes is needed. The correction to $H_{-0.5}$ for the change of isophotal diameter with redshift (Paper III, in preparation) is also neglected. Morphological types in Table 3 are from the RC2.

The adopted values of $\Delta V_{20}(0)$ (the corrected edge-on velocity width) are also given in Table 3. These are means of the values in Table 1, weighted by S/N and corrected by the cosecant of the inclination. Values of ΔV_{20} with less than half the maximum S/N were given zero weight. No correction was made to $\Delta V_{20}(0)$ for the relativistic Doppler effect $(1 + z)$, which is negligible at the Virgo redshift.

III. INFRARED/H I RELATION

a) *Tully-Fisher Diagram*

Infrared magnitudes are plotted against the corrected velocity widths in Figure 1. Four objects in this diagram are denoted by special symbols, as they fail to meet, or are marginally acceptable by, the criteria of Paper I. These objects are NGC 4438, a badly distorted interacting galaxy; UGC 7737, a dwarf irregular with no hint of organized spiral structure; and NGC 4519 and 4535, whose inclinations are uncertain. The notes

TABLE 3

MAGNITUDES, VELOCITY WIDTHS, AND DISTANCE MODULI

Name	Type	$H_{-0.5}$ (mag)	$\Delta V(0)$ (km s^{-1})	$m - M$	Notes
NGC 4178	SB(rs)dm	10.14	292	31.02	
NGC 4192	SX(s)ab	7.77	465	30.67	
NGC 4206	SA(s)bc:	10.34	301	31.36	
NGC 4216	SX(s)b:	7.33	531	30.81	
NGC 4294	SB(s)cd	10.77	260	31.15	
NGC 4380	SA(rs)b?	9.78	330	31.20	
NGC 4388	SA(s)b	8.86	398	31.09	
UGC 7513	SB(s)cd	10.75	284	31.51	
NGC 4438	SA(s)0 pec:	7.75	381	29.79	a
NGC 4450	SA(s)ab	8.06	392	30.22	
NGC 4498	SX(s)cd	10.77	216	30.34	
NGC 4501	SA(rs)b	7.15	594	31.12	
NGC 4519	SB(rs)d	10.75	305	31.82	b
NGC 4522	SB(s)cd:	10.60	232	30.48	
NGC 4532	IBm	10.45	277	31.10	
NGC 4535	SX(s)c	8.46	447	31.19	b
UGC 7737	IBm:	14.46	142	32.15	c
NGC 4550	SB0+?	9.14	296	30.08	d, e
NGC 4569	SX(rs)ab	7.45	387	29.56	d
NGC 4651	SA(rs)c	8.66	453	31.45	
NGC 4654	SX(rs)cd	8.80	377	30.79	
NGC 4698	SA(s)ab	8.40	462	31.28	
NGC 4758	SBb?	11.23	207	30.62	

[a] Interacting with NGC 4435; given zero weight.
[b] Inclination uncertain; given half weight.
[c] An irregular dwarf (see text); given zero weight.
[d] Zero weight given in final distance determination.
[e] Magnitude from Persson, Frogel, and Aaronson 1979.

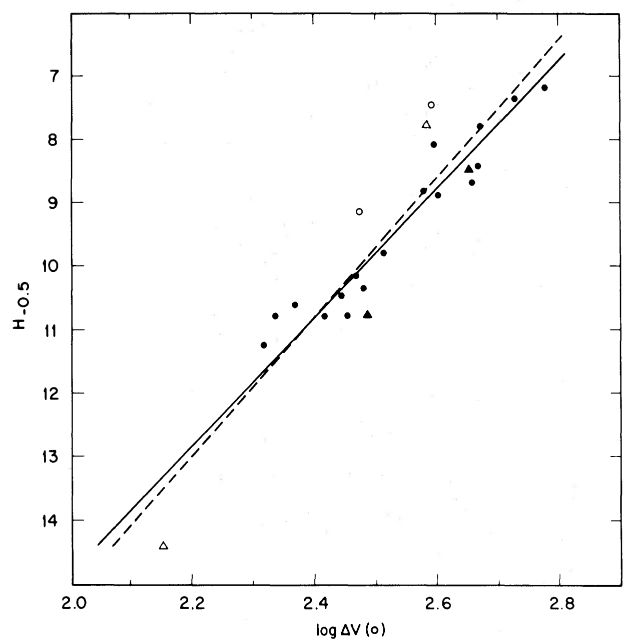

FIG. 1.—The Tully-Fisher diagram for the Virgo cluster. Triangular symbols denote galaxies given low weight on the basis of the criteria in Paper I (solid triangles, half weight; open triangles, zero weight). The dashed line indicates the regression of log $\Delta V(0)$ on $H_{-0.5}$ with these weights (§ III*b*). To derive eq. (1) (*solid line*), two more galaxies were zero weighted (§ III*c*). These are denoted by open circles.

to Table 3 indicate the weights given to these objects in the regressions which follow.

The degree of correlation in the Tully-Fisher diagram for the large Virgo sample we now have is a very strong demonstration of the validity of the luminosity/velocity-width relation. Before using this relation to derive a distance modulus for Virgo, we examined the distribution of residuals about the correlation in Figure 1 for possible second parameter effects.

b) The Question of Morphological-Type Dependence

The basis of the correlation seen in Figure 1 is a relation between rotational velocity and galactic mass, which can be identified with luminosity for constant M/L. However, the great variety in spiral rotation curves, which underlies the simplicity of the correlation, suggests that we look for further parameters governing the relation. A likely candidate is the Hubble type, which connects spiral galaxies into a natural sequence by using criteria such as the appearance of the spiral structure and the bulge-to-disk ratio. We note first that there is a clear connection between Hubble type and luminosity in the sense that late-type galaxies tend to be fainter (see Strom 1980 for a recent discussion). Luminosity and Hubble type are not orthogonal parameters. Hence, even if there is no intrinsic dependence of velocity width on Hubble type,

TABLE 4

RESIDUALS IN THE LUMINOSITY/VELOCITY-WIDTH RELATION WITH MORPHOLOGICAL TYPE

Sample	Magnitude	Regression Intercept	Regression Slope	Mean Residuals and Uncertainties: Log $\Delta V(0)$ (S0–Sab)	Mean Residuals and Uncertainties: Log $\Delta V(0)$ (Scd–Sm)
Roberts	M_{pg}	0.833	−0.083	0.11 ± 0.01	-0.05 ± 0.015
Roberts	M_K	0.771	−0.073	0.08 ± 0.01	-0.03 ± 0.015
Virgo	H	3.371	−0.090	-0.04 ± 0.03	$+0.00 \pm 0.015$

a corelation will appear through the luminosity dependence.

Roberts (1978) has tested the Tully-Fisher relation for dependence on morphological type as a second parameter. His Figure 11 illustrates the segregation he sees in the relation in the sense that *at a given luminosity* earlier-type galaxies have larger values of $\Delta V(0)$. This effect is quantified in Table 4, where we present the results of regression of log $\Delta V(0)$ on M_{pg}. The data are taken from Roberts's Table 2 and are weighted by the number of points in each bin. The excess log $\Delta V(0)$ for types S0–Sab and the deficiency for types Scd–Sm relative to the mean relation are evident in line 1 of Table 4.

What is the cause of this segregation, and does it extend to the IR? One possibility is a variation of mass-to-light ratio with morphological type. Evidence that later-type galaxies have lower M/L_B has been presented by Faber and Gallagher (1979). The apparent deficiency in velocity width for late-type galaxies, for example, might thus be explained as a luminosity excess.

This proposition can be tested in two ways. First, we can estimate the effect of changing from photographic (blue) luminosities to IR luminosities by using the mean *UBVK* colors of spiral galaxies tabulated by Aaronson (1979) and by Huchra (1977). In the IR M/L appears to be more nearly constant with morphological type (AHM), as the slope of the IR/H I relation is close to the dynamical value of 10 (see also Faber and Gallagher 1979). Line 2 of Table 4 indicates that indeed the morphological-type residuals in Roberts's sample are reduced (but not removed) by substituting IR luminosities.

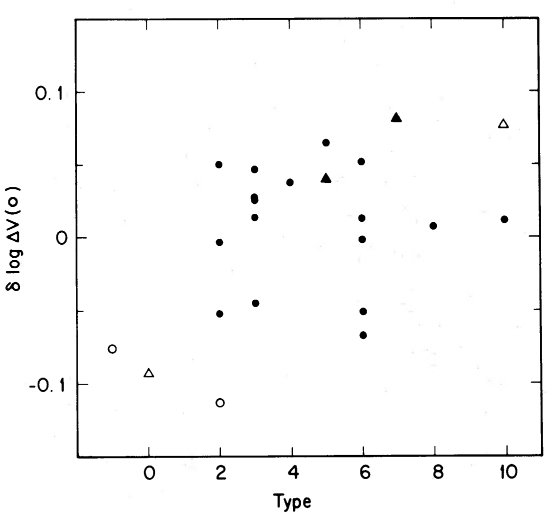

FIG. 2.—Residuals from the regression of log $\Delta V(0)$ on $H_{-0.5}$ plotted against Hubble type (coded as in the RC2). The symbol key is that of Fig. 1.

Second, we can examine the current Virgo sample for morphological-type dependence. The advantages of this sample over that of Roberts are considerable. In particular, distance-dependent errors are eliminated; the depth dispersion of the cluster, if spherical, is less than 0.2 mag for a 6° radius. Moreover, the sample volume in Virgo is the same for all types. In Roberts's field sample, subsets of successively later Hubble type tend to be drawn from their individually smaller magnitude-limited volumes. Because of the Malmquist bias, each subset tends to have a higher slope than that of the mean relation over all types. This may have some bearing on the herringbone structure of Roberts's Figure 11. Finally, the weaker selection criteria in Roberts's sample must lead to increased scatter, owing to the presence of galaxies with small and uncertain inclinations.[5]

The disadvantage of the Virgo sample, of course, is small number statistics. Results of the regression of log $\Delta V(0)$ on $H_{-0.5}$ for 20 full-weight points are given in line 3 of Table 4. It is evident that in spite of the small sample quite good limits can be put on the residuals for early- and late-type galaxies. The results are not consistent with the type dependence seen by Roberts. In particular, we disagree at the 2 σ level with the statement that late-type galaxies *at a given luminosity* have systematically lower velocity widths, and at the 4 σ level with the opposite statement for early-type galaxies.

The distribution of residuals with morphological type in Figure 2 bears out these results. If there is any correlation present, it is in the opposite sense to that found by Roberts, namely that the S0–Sab galaxies have intrinsically lower velocity widths. If this effect is real, there may be a connection here with the existence of unresolved H I distributions in some S0 galaxies (e.g., NGC 4385 and 4694; Krumm and Salpeter 1979). Early-type galaxies with a velocity-width

[5] The effects of relaxing the inclination selection criterion are well illustrated in the controversy between Sandage and Tammann (1976*b*) and Fisher and Tully (1977).

deficiency may simply have disks of H I which are radially truncated relative to the visible disk of stars. To forestall any such effects on our distance determinations, we specifically exclude S0 galaxies in our calculation of the Virgo distance modulus (§ V). This exclusion is implicit in more distant clusters where S0's are not detected. The calibration sample of Paper I contains no S0's.

In summary, we believe the results here and in Paper I strongly argue against a Hubble-type dependence for later-type galaxies in the IR/H I relation. We cannot be positive at present as regards early-type disk galaxies, since there is no consensus in the results discussed above and those reported by Van Woerden (1979), Gouguenheim (1979), and Rubin (1979). Further investigation of possible second-parameter effects might be usefully directed toward the bulge-to-disk ratios in these systems.

c) *Least-Squares Fit*

Because of the large size of the sample, the Virgo cluster receives high weight in the empirical determination of the slope of the IR/H I relation required in Paper I. We have used the fitting technique of AHM to obtain a least-squares solution to the data in Table 3. In particular, the adopted errors in $\log \Delta V_{20}(0)$ and $H_{-0.5}$ were 0.03 dex and 0.1 mag, respectively. The solution is

$$H_{-0.5} = 9.76 - 10.19[\log \Delta V_{20}(0) - 2.5]\,, \quad (1)$$

with a variance ($S_{y/x}$) of 0.42 mag. The galaxy NGC 4569 was given zero weight in this solution, as a 3.5 σ deviate from the final relation. While it might be argued that NGC 4569 is a foreground object (it is, in fact, the largest spiral in the 6° circle), its negative systemic velocity makes its most probable location the cluster core itself. A true global profile of this galaxy would be a valuable check on the mapping results quoted in Table 1. Note that, following the discussion in § III*b* above, the S0 galaxy NGC 4550 has also been excluded from the equation (1) regression.

IV. THE MEAN REDSHIFT OF THE VIRGO CLUSTER

Because the determination of the Hubble modulus and any anisotropy associated with it critically depends on velocity, we have used all the presently available galaxy radial-velocity data to rederive the mean cluster redshift. Davis *et al.* (1980) have compiled a catalog of the best available galaxy velocities, from which we have computed a mean Virgo redshift, using the following two criteria: (1) only galaxies with galactocentric velocity (corrected by 300 cos $l^{\rm II}$ sin $b^{\rm II}$ km s^{-1}) between -550 and 2500 km s^{-1} are included, and (2) only galaxies located within 6° of the Virgo center are included. As there is some disagreement concerning the location of the cluster center, we have considered several possibilities. The results are summarized in Table 5.

TABLE 5

MEAN VELOCITY OF VIRGO IN 6° CIRCLE

CENTER (1950)			$\langle V \rangle$	$\langle V \rangle$	
α	δ	N	UNWEIGHTED (km s^{-1})	WEIGHTED[a] (km s^{-1})	NOTES
$12^{\rm h}25^{\rm m}$	+13°06′	108	1066 ± 68	. . .	b
12 27	+13 30	182	1022 ± 54	1008 ± 54	c
12 27	+13 30	180	1018 ± 53	1004 ± 53	c, d
12 25	+13 06	188	1029 ± 53	1009 ± 53	e
12 25	+13 06	186	1025 ± 52	1005 ± 52	d, e
12 28.5	+12 40	195	1032 ± 51	1020 ± 51	f
12 28.5	+12 40	194	1031 ± 51	1019 ± 51	f, g

[a] Luminosities are adopted from Zwicky, Herzog, and Wild 1961.

[b] Position and mean redshift from Sandage and Tammann 1976*a*.

[c] Position following de Vaucouleurs and de Vaucouleurs 1973.

[d] Background galaxies NGC 4152 (see Sandage and Tammann 1976*a*) and IC 769 (see AHM) excluded.

[e] Position from Sandage and Tammann 1976*a*.

[f] Position centered on NGC 4486.

[g] IC 769 excluded (NGC 4152 no longer in circle).

Following arguments presented by van den Bergh (1977; see also Fig. 9 of Tully and Fisher 1977), we choose NGC 4486 as the location of the cluster center. Because we are interested in the dynamical center of the cluster, we believe the luminosity-weighted mean is preferable and adopt a mean cluster redshift of 1019 ± 51 km s^{-1}. This value is substantially lower than the often-used value of 1100 km s^{-1} found by Sandage and Tammann (1976*a*). However, our result is based on redshifts of 194 galaxies, almost double the Sandage and Tammann sample. Furthermore, their value of 1100 km s^{-1} drops to 1066 ± 68 km s^{-1} when they include late-type galaxies. This is in reasonable agreement with the analogous solution of 1029 ± 53 obtained here (Table 5). As shown in Table 5, the result does not significantly change with unweighted solutions and/or differing cluster center locations. Finally, we note that the lowness of this value is probably not due to an increasing number of foreground galaxies entering the sample as the magnitude limit is increased—the mean redshift in all comparison *field* samples *increases* as fainter galaxies are added.

V. DISTANCE MODULUS AND HUBBLE RATIO FOR VIRGO

Individual distance moduli for the galaxies in the sample were determined from the magnitudes and velocity widths in Table 3 by means of the absolute calibration from equation (6) of Paper I, whose zero point is determined by using only the Sandage-Tammann distances to M31 and M33. These values of $m - M$ are given in Table 3 and lead to a mean Virgo modulus of 30.98 ± 0.09 mag or 15.7 ± 0.7 Mpc. The uncertainty in the zero point of the absolute calibration should be added to this formal value. From Paper I, we estimate this uncertainty to be ±0.2 mag. We stress that this zero-point uncertainty is of no

TABLE 6

DISTANCE MODULI BINNED BY REDSHIFT

Velocity Interval ($km\ s^{-1}$)	n	$m - M$ (mag)	$\sigma/\sqrt{n}$ (mag)
<500	5	31.0	± 0.1
500–1500	7.5	31.1	± 0.2
>1500	5.5	30.8	± 0.2

TABLE 7

DISTANCE MODULI BINNED BY HUBBLE TYPE

Type	n	$m - M$	$\sigma/\sqrt{n}$
S0–Sab	4	30.6	± 0.3
Sa–Sab	3	30.7	± 0.3
Sb–Sc	7.5	31.1	± 0.1
Scd–Im	7.5	31.0	± 0.2
Sa–Im	18	31.0	± 0.1

concern as regards the relative distance moduli of Virgo and other clusters.

As shown in Table 6, no correlation is observed between these distance moduli and the systemic velocities of individual galaxies, confirming the assertion by Helou, Salpeter, and Krumm (1979) that the low- and high-velocity galaxies are at the cluster distance. The mean velocity of the Table 6 galaxies is $\langle V \rangle = 1096 \pm 191\ km\ s^{-1}$, in good agreement with the cluster redshift found in § IV, which suggests there is little systematic difference in distance between the present sample and the Virgo cluster as a whole. The distribution of distance moduli (Fig. 3) offers no support for the hollow-shell model for spirals in rich clusters discussed by Dickens and Moss (1977), although such an effect might be smeared out by the intrinsic dispersion in the IR/H I relation.

The present sample can be used to test for possible selection effects. Grouping the distance moduli by Hubble type, we obtain the mean values listed in Table 7. As expected from the discussion in § III*b*, there is no significant difference between the results for different types, except perhaps for the earliest types. Next we examine the effect of the optical magnitude limit. Table 8 indicates that selection of the brightest cluster galaxies induces no significant bias in the resultant distance modulus. The magnitudes used in Table 8 are from Zwicky, Herzog, and Wild (1961), the same primary selection source we will rely on in Paper III. A more serious selection effect in limiting programs is the strength of the 21 cm signal. The H I emission flux density ($\log S_H$) is available for half the program galaxies from the RC2. For most other objects, we calculated $\log S_H$ from the H I mass and equation (43) in the RC2. The data are binned (in intervals of 0.4 dex) in Table 9. We conclude that no significant bias would result from nondetection of the fainter half of the sample. Finally, we examine the data for possible systematic errors in the inclination correction. Table 10 shows that there is no significant difference in the mean derived distance moduli between galaxies in different inclination ranges for $i > 45°$.

In spite of changes in the absolute calibration over that used by AHM and the doubling of the sample, our result for the Virgo distance is essentially unchanged. Finally, adopting the redshift for Virgo discussed in § IV, we derive a Hubble ratio of $65 \pm 4\ km\ s^{-1}\ Mpc^{-1}$. The zero-point uncertainty in $m - M$ is not included here. As we shall see in Paper III, this value differs significantly from H_0 outside the Local Supercluster.

VI. COMPARISON WITH OTHER METHODS

In this section we discuss the distance modulus of Virgo obtained from a number of differing techniques. All of these methods are consistent, within the errors, with the distance modulus derived in the previous section. Note that we have adjusted all distance moduli where appropriate to correspond with a Hyades modulus of 3.29 mag (Paper I).

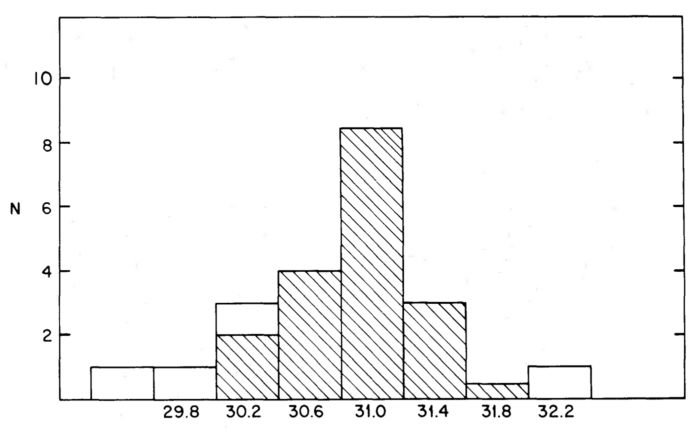

FIG. 3.—The distribution of distance moduli. The bin size was ±0.2 mag about the indicated central value. The unshaded areas represent zero weighted galaxies.

TABLE 8

DISTANCE MODULI BINNED BY APPARENT MAGNITUDE

m (Zwicky)	n	$m - M$	$\sigma/\sqrt{n}$
10.5–12	6.5	30.9	± 0.2
12–13	6.5	31.0	± 0.2
13–14.5	5	31.0	± 0.2

a) *Resolution Difference*

Sandage and Tammann (1976*b*; hereafter ST7) have argued that the modulus difference between M101 and the Virgo galaxy M100 is ~2 mag, from a comparison of the resolvability of stars. They thus obtain a Virgo modulus of 31.56 ± 0.5. Using the revised M101 modulus of 29.15 ± 0.2 mag derived in the Appendix (a value 0.41 mag smaller than that of Sandage and Tammann), we obtain a Virgo modulus of 31.15 ± 0.5.

b) *Luminosity Class*

The most recent luminosity class calibration of Sandage and Tammann is quoted in ST7 as giving a Virgo distance modulus of 31.70 ± 0.11 mag. As discussed in the Appendix, Kennicutt (1979) has rederived this result, using isophotal diameters of H II regions rather than eye-measured diameters of Sandage and Tammann (1974*a*, hereafter ST1). Kennicutt finds a systematic error present in the Sandage-Tammann diameters such that the latter tend to *overestimate* the distance for small (i.e., more distant) H II regions. Kennicutt (1979) further argues that ambiguity in how to calibrate the H II region diameter–luminosity-class relation leads directly to uncertainty in the absolute-magnitude–luminosity-class calibration. Kennicutt, in fact, proposes a range in calibration which, with the revised M101 modulus of 29.15 mag, leads to a Virgo distance modulus of 30.91–31.35 mag. Note that the low number in this range, 30.91 mag, is the direct analog of the Sandage-Tammann procedure. Furthermore, as we show in the Appendix, the M101 distance of 29.15 mag implies that it is this low modulus which is to be preferred.

For further comparison, we have used the luminosity index distances in de Vaucouleurs's (1979) Table 1 for 17 spirals in the 6° circle to obtain a Virgo modulus of 30.83 ± 0.4 mag. Rezeroing this result by 0.42 mag (see Paper I) gives 31.25 mag.

c) H II *Region Size*

ST7 derive a modulus of 31.73 ± 0.3 mag based on their measured H II region diameters for the single Virgo galaxy M100. Kennicutt's (1979) measurements and our revised M101 distance lead to a modulus range of 30.93–31.47 mag. This is a difficult observation, and the uncertainty is large. The lowest value is again the direct analog of the Sandage-Tammann procedure and is to be preferred (Appendix).

TABLE 9

DISTANCE MODULI BINNED BY H I FLUX

$\log S_{\rm H}$	n	$m - M$	$\sigma/\sqrt{n}$
1.7–1.3	5	31.1	± 0.2
1.3–0.9	5	31.1	± 0.1
<0.9	4	30.8	± 0.2

TABLE 10

DISTANCE MODULI BINNED BY INCLINATION

cosec i	i	n	$m - M$	$\sigma/\sqrt{n}$
1.49–1.33	42–49	2	31.5	± 0.3
1.32–1.16	50–60	5	30.8	± 0.2
1.15–1.00	61–90	12	31.0	± 0.1

d) *Globular Clusters*

This method has the advantage that it is tied to RR Lyrae stars and thus independent of the Cepheid scale and Hyades modulus. However, the technique rests on the assumption that globular clusters in Local Group spirals and dwarf ellipticals can be compared with those in Virgo giant ellipticals.

Using the brightest globular cluster, ST7 find a Virgo modulus of 31.45 ± 0.5. Hanes (1977) has argued against this procedure because of the difficulty in identifying the brightest globular cluster (see also de Vaucouleurs 1977) and instead fits the shape of the globular cluster luminosity function to find a modulus of 30.40 ± 0.50 mag. Using a luminosity function extended one full magnitude deeper, Hanes (1979) finds a modulus of 30.70 ± 0.30 mag, while with basically the same data Harris and Racine (1979) determine a modulus of 30.90 ± 0.30 mag. We adopt the mean of these two results as the best current value from this technique.

e) *Velocity Ratio*

If neither the M101 group nor the Virgo cluster is significantly perturbed relative to a smooth Hubble flow, their velocity ratio will give an indication of their relative distance moduli. From this method, ST7 obtain a Virgo modulus of 31.75 ± 0.42 mag. Using the mean Virgo redshift of 1019 ± 51 given here, an M101 group redshift of 402 ± 4 (Sandage and Tammann 1974*b*, hereafter ST3), and an M101 group modulus of 29.15 ± 0.2 mag (Appendix), we obtain a Virgo modulus of 31.17 ± 0.35 mag. (Note that the result is still meaningful in the context of the deceleration model discussed in Paper III.)

f) *Color-Magnitude Diagram*

Visvanathan (1978) has compared the color-magnitude diagram of Local Group galaxies with early-type galaxies in Virgo and finds a modulus of 30.73 ± 0.39 mag. (We have increased his result by 0.13 mag for his adopted M31 distance.)

g) *Color-Magnitude–Luminosity-Class Method*

Visvanathan and Griersmith (1979) have determined an apparent-magnitude–luminosity-class relation for galaxies at the distance of Virgo by translating galaxies in nearby groups to the Virgo distance, using color-magnitude diagrams. Then, with the luminosity class calibration of Sandage and Tammann (1974*c*, hereafter ST4), they find a Virgo modulus of 31.52 ± 0.16 mag. Kennicutt's (1979) measurements and the revised M101 distance lead to a value in the range 30.68–31.12 mag. The lowest value is the direct analog of the Visvanathan and Griersmith (1979) procedure and is preferred (Appendix).

h) *Supernovae*

Distance moduli from supernovae can be obtained statistically relative to nearby galaxies or theoretically from the Baade-Wesselink technique (Baade 1926; Kirshner and Kwan 1974). Using the former method, ST7 find the relative distance modulus between M101 and Virgo to be 2.25 ± 0.85 mag and thus obtain a Virgo modulus of 31.81 ± 0.85 mag. The revised M101 distance yields a Virgo modulus of 31.40 $\pm$ 0.85 mag.

The Baade-Wesselink method has the great advantage of being completely independent of the conventional distance ladder. However, its application is still beset with a number of technical difficulties (e.g., see Schurmann, Arnett, and Falk 1979). A good illustration of current uncertainty in the theory is given by the recent changes in the theoretical absolute magnitude for Type I supernovae. Branch and Patchett (1973) found $\langle M_{pg} \rangle = -20.8 \pm 0.8$; in a later study Branch (1977) derived $\langle M_{pg} \rangle = -20.25 \pm 0.31$; while in the most recent study Branch (1979) obtained $\langle M_{pg} \rangle = -19.62 \pm 0.57$ mag. Using the early 1973 value and data for six Type I Virgo supernovae, ST7 find a Virgo modulus of 32.91 ± 0.9 mag. The latest value of $\langle M_{pg} \rangle$ yields 31.73 ± 0.62 mag.

For Type II supernovae, work by Kirshner and Kwan (1974) suggests $\langle M_{pg} \rangle = -17.6$ mag, although Schurmann, Arnett, and Falk (1979) have shown that this value is rather model-dependent. Sandage and Tammann (ST7) use the Kirshner-Kwan result and the mean apparent magnitude of three Type II Virgo supernovae to find a modulus of 31.35 ± 0.8 mag. Recently, however, Carney (1980) and Branch *et al.* (1980) have applied the Baade-Wesselink technique directly to supernova 1979c in M100. Carney (1980) derives a Virgo modulus of 30.53 ± 0.13 mag, while Branch *et al.* (1980) find a modulus of about 32.0 $\pm$ 0.6 mag. The difference in these results may be regarded as a true indication of the uncertainty in this method. Taking a simple mean of the four values 31.40, 31.73, 31.35, and 31.27 (the last being an average of the Carney 1980 and Branch *et al.* 1980 results) leads

TABLE 11

COMPARISON OF VIRGO DISTANCE MODULI[a]

Method	Result	Source
a) Resolution difference	31.56 ± 0.50	ST7
	31.15* ± 0.50	This paper[b]
b) Luminosity class	31.70 ± 0.11	ST7
	30.91* – 31.35	Kennicutt (1979) and this paper
	31.25 ± 0.14	de Vaucouleurs (1979*b*) and this paper
c) H II region size	31.99 ± 0.30	ST7
	30.93* – 31.47	Kennicutt (1979) and this paper
d) Globular cluster	31.45 ± 0.50	ST7
	30.70 ± 0.30	Hanes (1979)
	30.90 ± 0.30	Harris and Racine (1979)
	30.80* ± 0.30	Adopted mean
e) Velocity ratio	31.75 ± 0.42	ST7
	31.17* ± 0.35	This paper
f) Color-magnitude diagram	30.73* ± 0.39	Visvanathan (1978)
g) C-M–LC method	31.52 ± 0.16	Visvanathan and Griersmith (1979)
	30.68* – 31.12	Revised in this paper
h) Supernova: Type I[c]	31.81 ± 0.85	ST7
	31.40 ± 0.85	This paper[b]
Type I[d]	32.91 ± 0.90	ST7 and Branch and Patchett (1973)
	31.73 ± 0.62	This paper and Branch (1979)
Type II[d]	31.35 ± 0.80	ST7
	31.27 ± 0.74	Carney (1980) and Branch *et al.* (1980)
	31.44* ± 0.30	Adopted mean
i) Magnitude–SB relation	31.04* ± 0.56	Holmberg (1958) and this paper
Mean of * values	30.98 ± 0.08	
IR/H I method	30.98 ± 0.09	

[a] Where appropriate, the results have been adjusted to a Hyades modulus of 3.29 mag.

[b] Rezeroed to revised M101 distance.

[c] Relative to M101.

[d] Baade-Wesselink technique.

to 31.44 mag, to which we attach an error of 0.3 mag and adopt as the Virgo distance modulus given by supernovae from all methods.

i) *Magnitude-Surface Brightness Relation*

Holmberg (1958) has found a relation between apparent magnitude and corrected mean surface brightness S_0' for Virgo cluster galaxies. A mean of the two regressions given by Holmberg (1958, p. 70) yields $m = 3.89S_0' - 48.1$. The relation can then be calibrated absolutely by using the mean surface brightness for a nearby galaxy whose distance is known. Applying the method to the five galaxies M31, M33, M81, NGC 2403, and M101, using Holmberg's (1958) data (corrected for internal absorption following his prescription and galactic extinction with $A_B = 0.13[\csc(b) - 1]$), gives a Virgo distance of 31.04 ± 0.56. In deriving this result we have used the Sandage-Tammann distances to all galaxies except M101, for which $m - M = 29.15$ mag is adopted (Appendix).

j) *Summary*

In Table 11 we have summarized the various results discussed above. An unweighted mean of nine starred (*) values in Table 11 yields a Virgo modulus of 30.98 ± 0.08 mag, in excellent agreement with the value of 30.98 ± 0.09 mag obtained from the IR/H I relation. We conclude that there are no significant discrepancies between the Virgo distance given by the infrared Tully-Fisher technique and that given by any other method.

We thank R. Kennicutt, S. Strom, and P. Schechter for several useful conversations; and the anonymous referee for his careful reading of the manuscript. This work was partially supported with funds from NSF grants AST 76-81874, AST 76-22991, and AST 79-21663.

APPENDIX

VALUE AND IMPLICATIONS OF THE M101 GROUP DISTANCE

The M101 group distance is critical for six of the Virgo distance estimates discussed in § VI. Sandage and Tammann (ST3) determined an M101 group modulus of 29.56 ± 0.3 mag based on three methods: brightest supergiants, H II region diameters, and luminosity classes. There are two reasons for reexamining these results. First, Kennicutt (1979) has obtained isophotal H II region diameters for nearly all the galaxies used by ST3 and ST4. Kennicutt's data indicate the presence of significant systematic errors in many of the eye-measured Sandage and Tammann diameters. Second, three additional distance techniques are now available and can be applied to the M101 group. We turn now to a discussion of the various methods.

a) H II *Region Sizes*

Sandage and Tammann (ST3) determine a distance modulus of 29.60 ± 0.13 mag to the M101 group, using a calibration determined by a least-squares fit of the H II region diameter-luminosity class (*d*, LC) relation for Local Group and NGC 2403–M81 group galaxies. They argue that M101 itself has anomalously large H II regions (but normal absolute magnitude) and should be given zero weight. The analogous (*d*, LC) relation from Kennicutt (1979) yields an M101 modulus of 28.82 ± 0.10 mag ($N = 6$) including M101, or 28.86 ± 0.11 mag ($N = 5$) excluding M101.

b) *Brightest Stars*

Based on their determination of the brightest blue supergiants in the M101 group, ST3 obtain a group modulus of 29.53 ± 0.30 mag.

c) *Infrared*/H I *Relation*

In Paper I we determined an M101 group modulus of 29.16 ± 0.35 mag from the three dwarf members NGC 5204, NGC 5585, and Ho IV.

d) *Supernovae*

Schurmann, Arnett, and Falk (1979) obtain a modulus of 29.32 ± 0.3 mag based on supernova 1970g in M101. This result is a revision of the value of $\sim 29.0 \pm 1.0$ mag first obtained by Kirshner and Kwan (1974), using the Baade-Wesselink technique.

e) H II *Region Velocity Dispersions*

Melnick (1977) has discovered a relation between the velocity dispersion and size of an H II region. Applying his calibration to the M101 group, he finds a modulus of 28.94 ± 0.39 mag. Note that this result is based entirely on eye-measured H II region diameters.

TABLE 12

DISTANCE MODULI TO M101

Method	$m - M$ (mag)	Weight
H I region sizes	28.84 ± 0.10	2
IR/H I	29.16 ± 0.35	2
Supernova	29.32 ± 0.30	2
H II region velocity dispersions	28.94 ± 0.39	1
Brightest stars	29.53 ± 0.30	1/2
Luminosity classes	29.23 ± 0.21	0
Unweighted mean ($N = 6$)	29.17 ± 0.10	
Weighted mean ($N = 5$)	29.11 ± 0.10	
Adopt	29.15 ± 0.20	

f) *Summary*

Distances from the five methods discussed above are summarized in Table 12. An unweighted mean yields a modulus of 29.16 ± 0.13; a mean weighted according to the final column in Table 12 gives 29.11 ± 0.10. The most discrepant value is the ST3 distance from brightest stars. However, we feel this result is very uncertain (cf. ST3 and de Vaucouleurs 1978), and we believe it should be assigned low weight. In particular, recent 4 m plates taken by S. Strom (1979, private communication) indicate the presence of supergiant stars in the outer regions of M101 brighter than those found by ST3, who surveyed only the inner one-third of the galaxy.

For further comparison, de Vaucouleurs's (1978) distance to M101, based on *his* calibration of H II region sizes and brightest stars, is 28.5 ± 0.3. We might adjust this value by 0.57 mag to 29.07 mag to account for the mean difference between the primary indicator scales of de Vaucouleurs and those of Sandage and Tammann (see Paper I).

g) *Absolute-Magnitude–Luminosity-Class Relation*

The procedure employed by both ST4 and by Kennicutt (1979) for obtaining the absolute-magnitude–luminosity-class or (M, LC) relation is to first use the H II region (d, LC) relation to obtain distances to a number of nearby field galaxies. With these distances, the galaxy apparent magnitudes can be converted to absolute magnitudes, and the run of the latter with luminosity class can be derived. Kennicutt (1979) argues that this is a precarious procedure, given the difficulty in choosing a calibration for the (d, LC) relation. In the following discussion we shall attempt to settle the calibration question by demanding that the luminosity-class distance to the M101 group agree with that from the five other methods discussed above. (This is the reason for assigning zero weight to our final luminosity-class distance to M101 in Table 11.)

To begin with, we note that the (M, LC) relation derived in ST4 is based on the (d, LC) relation used in ST3 to derive the H II region size distances to the M101 group, i.e., it is a least-squares fit to only the Local Group and the NGC 2403–M81 group and requires extrapolation beyond luminosity classes ≤II. M101 itself lies considerably above the extrapolated relation (see ST1, Fig. 11), which, as previously mentioned, Sandage and Tammann suggest is due to anomalously large H II region sizes. In ST4 two arguments are presented for justifying this extrapolation. First, they find that the mean absolute magnitude for Sc I galaxies agrees well with that of M101 itself at their distance modulus of 29.56 mag (which further supports their claim of anomalously large M101 H II regions). Second, they find that the shape of the (M, LC) relation for field galaxies is similar to the (m. LC) relation for Virgo galaxies.

Several significant new results emerge from the work of Kennicutt (1979). First, it is convincingly demonstrated that the H II region sizes in M101 are not anomalously large (see Kennicutt's Fig. 7). Second, with the analogous (d, LC) relation to that of ST3, the absolute magnitude of M101 is no longer consistent with the mean of other Sc I galaxies; rather, it becomes by far the brightest Sc I in the entire sample (e.g., Kennicutt's Table 4). Kennicutt concludes that the question of how to construct the (d, LC) relation is very uncertain. He proposes a range of calibrations between which, he argues, it is difficult to choose. The "minimum" solution is the analog of the Sandage-Tammann result and gives the smallest distances; the "maximum" solution is forced to fit through M101 itself and gives the largest distances. The difference between these two solutions leads to an uncertainty of ~40% in distance. Curiously, the shape of both the minimum and maximum (M, LC) relations is consistent with the (m, LC) relation for Virgo, which would seem to negate the ST4 argument concerning the shape of *their* relation.

However, Kennicutt has assumed *a priori* the Sandage-Tammann M101 distance of 29.56 mag. We have rederived both the minimum and maximum (M, LC) relations, using the data in Kennicutt's Tables 3 and 4 and an adopted M101 modulus of 29.15 mag. The results are presented in Table 13; the corresponding distance uncertainty is now only ~20%. In deriving the results for luminosity class IV, the bin was supplemented with two additional absolute magnitudes: those for NGC 247 from Paper I and NGC 4656/7 from ST4.

TABLE 13

REVISED LUMINOSITY CLASS CALIBRATION

Type	Minimum[a] $-\langle Mpg \rangle$ (mag)	Maximum[b] $-\langle Mpg \rangle$ (mag)
I	20.72	21.21
II	19.47	20.10
II–III	19.21	19.46
III	18.63	18.99
III–IV	17.94	18.30
IV	17.76	17.88
IV–V	16.49	16.52
V	14.72	14.72

[a] Determined from an H II region diameter–luminosity class relation fit to the Local and NGC 2403–M81 groups only.

[b] Determined from an H II region diameter–luminosity class relation which is forced through M101.

In Table 14 we compare the distances to the M101 group found by applying minimum and maximum solutions analogous to those in Table 13, *except that now all M101 group members have been excluded from the calibration.* Note that we have assigned a weight of 0.25 to the galaxy NGC 5477, whose Zwicky magnitude is uncertain. (It was assigned a weight of 0.5 in ST3 for determining the M101 group distance and 0.0 in ST4 for determining the [M, LC] relation.) The minimum calibration gives a distance in good agreement with that from five other methods, and we suggest that it should be preferred. This minimum calibration also gives reasonable consistency between the H II region sizes and the absolute magnitude of M101 itself.

h) *Conclusions*

Based on the discussion in this Appendix, we propose a new M101 group distance modulus of 29.15 $\pm$ 0.2 mag. This value is 0.41 mag less than the one obtained by ST3, but is still comfortably greater than the lower limit they give using three arguments: resolvability, lack of red supergiants, and lack of Cepheids. We have shown that this new distance implies the "minimum" (M, LC) calibration in Kennicutt's (1979) notation is to be preferred.

TABLE 14

LUMINOSITY CLASS DISTANCE TO M101 GROUP

Name	Type	$m - M$ Minimum (mag)	$m - M$ Maximum (mag)	Weight
M101	I	28.88	29.44	1
NGC 5204	IV	29.37	29.56	1
NGC 5474	IV	28.97	29.16	1
NGC 5477	IV–V	31.04	31.08	1/4
NGC 5585	IV	29.00	29.19	1
Ho IV	IV–V	29.49	29.53	1
Mean	...	29.23	29.46	...
	...	$\pm$0.21	$\pm$0.18	...

REFERENCES

Aaronson, M. 1979, *Ap. J.* (*Letters*), **221**, L103.
Aaronson, M., Huchra, J. P., and Mould, J. R. 1979, *Ap. J.*, **229**, 1 (AHM).
Aaronson, M., Mould, J. R., and Huchra, J. P. 1980, *Ap. J.* (in press) (Paper I).
Baade, W. 1926, *Astr. Nachr.*, **228**, 359.
Branch, D. 1977, *M.N.R.A.S.*, **179**, 401.
———. 1979, *M.N.R.A.S.*, **186**, 609.
Branch, D., McCall, M., Rybski, P., Uomoto, A., Wills, B., and Wills, D. 1980, *Bull. AAS*, **11**, 694.
Branch, D., and Patchett, B. 1973, *M.N.R.A.S.*, **161**, 71.
Carney, B. 1980, Preprint.
Danver, C. G. 1942, *Ann. Obs. Lund.*, No. 10.
Davies, R. D., and Lewis, B. M. 1973, *M.N.R.A.S.*, **165**, 231.
Davis, M., Huchra, J. P., Latham, D. W., and Tonry, J. 1980, in preparation.
de Vaucouleurs, G. 1977, *Nature*, **266**, 126.
———. 1978, *Ap. J.*, **224**, 710.
———. 1979, *Ap. J.*, **227**, 729.
de Vaucouleurs, G., and de Vaucouleurs, A. 1973, *Astr. Ap.*, **28**, 109.
de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G. 1976, *Second Reference Catalogue of Bright Galaxies* (Austin: University of Texas Press) (RC2).
Dickens, R. J., and Moss, C. 1977, *M.N.R.A.S.*, **178**, 701.
Faber, S. M., and Gallagher, J. S. 1979, *Ann. Rev. Astr. Ap.*, **17**, 135.
Fisher, J. R., and Tully, R. B. 1977, *Comm. Ap.*, **7**, 85.
Gouguenheim, L. 1979, in *Photometry, Kinematics, and Dynamics of Galaxies*, ed. D. S. Evans (Austin: University of Texas Press), p. 201.
Grewing, M., and Mebold, U. 1975, *Astr. Ap.*, **42**, 119.
Hanes, D. A. 1977, M.N.R.A.S., **180**, 309.
———. 1979, *M.N.R.A.S.*, **188**, 901.

Harris, W. E., and Racine, R. 1979, *Ann. Rev. Astr. Ap.*, **17**, 241.
Helou, G., Salpeter, E. E., and Krumm, N. 1979, *Ap. J.* (*Letters*), **228**, L1.
Holmberg, E. 1958, *Medd. Lund Obs.*, Ser. 2, No. 136.
Huchra, J. P. 1977, *Ap. J. Suppl.*, **35**, 171.
Huchtmeier, W. K., Tammann, G. A., and Wendker, H. J. 1976, *Astr. Ap.*, **46**, 381.
Kennicutt, R. C. 1979, *Ap. J.*, **228**, 696.
Kirshner, R. P., and Kwan, J. 1974, *Ap. J.*, **193**, 27.
Krumm, N., and Salpeter, E. E. 1979, *Ap. J.*, **228**, 64.
Melnick, J. 1977, *Ap. J.*, **213**, 15.
Persson, S. E., Frogel, J. A., and Aaronson, M. 1979, *Ap. J. Suppl.*, **39**, 61.
Peterson, S. 1978, Ph.D. thesis, Cornell University.
Roberts, M. S. 1978, *A.J.*, **83**, 1026.
Rubin, V. 1979, private communication.
Sandage, A. R., and Tammann, G. A. 1974*a*, *Ap. J.*, **190**, 525 (ST1).
———. 1974*b*, *Ap. J.*, **194**, 223 (ST3).
———. 1974*c*, *Ap. J.*, **194**, 559 (ST4).
Sandage, A. R., and Tammann, G. A. 1976*a*, *Ap. J.* (*Letters*), **207**, L1.
———. 1976*b*, *Ap. J.*, **210**, 7 (ST7).
Schurmann, S. R., Arnett, W. D., and Falk, S. W. 1979, *Ap. J.*, **230**, 11.
Shostak, G. S. 1978, *Astr. Ap.*, **68**, 321.
Strom, S. E. 1980, *Ap. J.*, in press.
Tully, R. B., and Fisher, J. R. 1977, *Astr. Ap.*, **54**, 661.
van den Bergh, S. 1977, *The Evolution of Galaxies and Stellar Populations*, ed. B. M. Tinsley and R. B. Larson (Connecticut: Yale University Observatory), p. 19.
Van Woerden, H. 1979, in *Photometry, Kinematics, and Dynamics of Galaxies*, ed. D. S. Evans (Austin: University of Texas Press), p. 300.
Visvanathan, N. 1978, *Astr. Ap.*, **67**, L17.
Visvanathan, N., and Griersmith, D. 1979, *Ap. J.*, **230**, 1.
Zwicky, F., Herzog, E., and Wild, P. 1961, *Catalogue of Galaxies and Clusters of Galaxies* (Pasadena: California Institute of Technology), Vol. **1**.

MARC AARONSON: Steward Observatory, University of Arizona, Tucson, AZ 85721
JOHN HUCHRA: Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138
JEREMY MOULD: Kitt Peak National Observatory, P.O. Box 26732, Tucson, AZ 85726