THE ASTROPHYSICAL JOURNAL, 249:L47–L50, 1981 October 15

SUPERCLUSTER BRIDGE BETWEEN GROUPS OF GALAXY CLUSTERS

GUIDO CHINCARINI,[1,4] HERBERT J. ROOD,[2,4] AND LAIRD A. THOMPSON[3]
Received 1981 April 17; accepted 1981 July 16

ABSTRACT

Redshifts were obtained for a random sample of 44 galaxies selected from a complete population of 350 galaxies brighter than $m_z \leq 15.7$ in a 332 sq. deg. region between the Hercules group of clusters (A2151, A2152, and A2147) and the A2199/A2197 group. A plot of redshift versus declination reveals a bridge of galaxies connecting the two groups. The bridge contains 33 of the 44 galaxies sampled. The redshifts vary smoothly along the bridge by 2000 km s^{-1} from the Hercules region to the A2199/A2197 region. The groups are separated by 44 h^{-1} Mpc (Hubble constant $H = 100h$ km s^{-1} Mpc^{-1}), and the bridge is tilted 27° off the plane of the sky. Apart from two sparsely populated associations of galaxies with dimensions $\gtrsim 15$ Mpc, the foreground volume is devoid of galaxies.

Subject heading: galaxies: clusters of

I. INTRODUCTION

In their extensive investigation of the group of galaxy clusters A2151, A2152, and A2147 in the constellation Hercules, Tarenghi *et al.* (1979, 1980) found that the dispersed component of galaxies surrounding the rich clusters has an rms line-of-sight velocity dispersion of 1400 km s^{-1}. If the dispersed component traces the supercluster in which the rich clusters are imbedded, and if the velocity dispersion were caused entirely by the Hubble flow, then the indicated line-of-sight depth of the surveyed part of the supercluster is $\sim 50\ h^{-1}$ Mpc (Hubble constant $H = 100h$ km s^{-1} Mpc^{-1}). Since the transverse dimension of the survey region is $\sim 10\ h^{-1}$ Mpc, it seemed likely that the supercluster extends across the sky beyond the surveyed region. As a preliminary test of this hypothesis, we plotted redshift versus declination for a strip with a $1^{\rm h}30^{\rm m}$ width in right ascension passing through the Hercules survey area. The data, taken from the *Second Reference Catalogue of Bright Galaxies* (de Vaucouleurs, de Vaucouleurs, and Corwin 1976, hereafter RC2), indicate that the supercluster extends to and beyond the groups A2199/A2197.

As early as 1961, Abell (1961) suggested that A2151, A2152, A2147, A2162, A2199, and A2197 are part of the same supercluster, and this structure can readily be seen on an Aitoff equal area projection of the celestial sphere showing the locations of the Abell clusters in distance classes 0–2 (Chincarini and Rood 1979). This evidence is suggestive but not definitive because the redshifts in the RC2 are taken from a heterogeneous variety of sources, and the surface distribution of rich clusters in itself tells us nothing about whether they are immersed in a dispersed supercluster component of galaxies. However, some further evidence that such a large structure exists is indicated by the surface distribution of radio sources (Burns and Owen 1979) and bright Sc galaxies (Chincarini and Rood 1979).

To establish definitively whether the Hercules and A2199/A2197 groups are located in a common supercluster, we have obtained redshifts for a random sample of galaxies drawn from the area of sky which falls between these two groups of clusters. We find that the two groups of clusters are, indeed, connected by a bridge of galaxies. This discovery is especially significant in three ways: (1) This is the first bridge found to connect *groups* of Abell clusters, as distinguished from serial connections between *single* Abell clusters. (2) With a length of approximately 50 h^{-1} Mpc, this is the largest contiguous supercluster yet observed. The structure may be even larger if, as we suspect, the supercluster extends farther to the south beyond the Hercules region. (3) Finally, this is the first bridge which has an observed tilt relative to the plane of the sky. Although such tilts are fully expected in a three-dimensional geometrical interpretation of the data, and hence are not surprising, others (Tifft and Gregory 1979) have ascribed special significance to the coincidence that most nearby superclusters have major axes in the plane of the sky. Under

[1]Department of Physics and Astronomy, University of Oklahoma, and European Southern Observatory.
[2]Princeton, New Jersey.
[3]Institute for Astronomy, University of Hawaii.
[4]Visiting Astronomer, Kitt Peak National Observatory, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

such circumstances the redshift distribution produces the false appearance of concentric redshift shells.

II. OBSERVATIONS AND RESULTS

A sample of 44 galaxies was selected from a complete population of 350 galaxies with photographic magnitudes $m_z \leq 15.7$ (Zwicky *et al.* 1960–1968) in a 332 sq. deg. region between the Hercules group and the A2199/A2197 group. The selection, random in both location and magnitude, is homogeneous, i.e., average parameters derived from the sample should be identical to those for the entire population but reduced in statistical significance by a factor of $(350/44)^{1/2}$. The spectral observations were obtained in 1980 June with the image intensified dissector scanner (IIDS) on the Kitt Peak National Observatory (KPNO) 2.1 m telescope and were reduced by conventional techniques immediately thereafter at KPNO headquarters in Tucson, Arizona. We are not reporting here the redshifts for the individual galaxies, accurate to ~ 100 km s^{-1}, because we intend to reduce the spectral scans again using the cross-correlation technique. Moreover, we intend to obtain more redshifts to complete our sample and to increase substantially the statistical significance of our results.

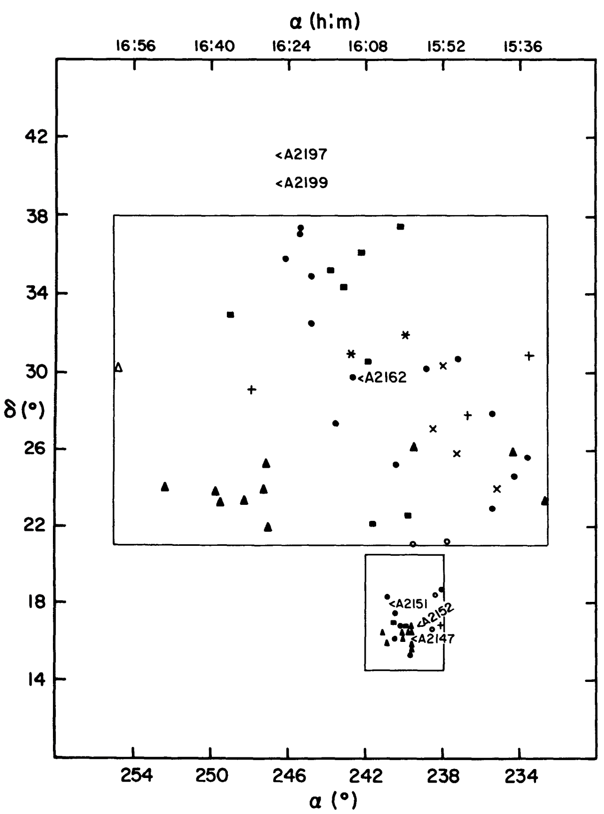

FIG. 1.—We plot in this diagram the celestial coordinates of the observed galaxies, which are indicated by symbols corresponding to ranges in redshift. Information is presented for both the 332 sq. deg. region surveyed in this study and for the 23.5 sq. deg. region of Tarenghi *et al.* (1979, 1980). For the latter region the locations of 20 randomly selected galaxies (44/350 of the total number observed) are plotted. The locations of Abell clusters are also marked. Redshift ranges: 3700 km s^{-1} (+); 3700–5700 km s^{-1} (O); 5700–8570 km s^{-1} (×); 8570–9598 km s^{-1} (■); 9598–10,628 km s^{-1} (●); 10,628–14,000 km s^{-1} (▲); 14,000 km s^{-1} (∗).

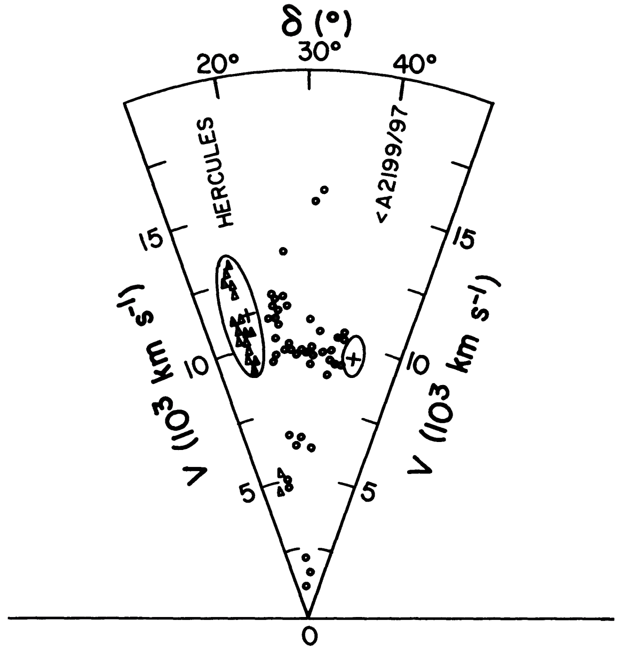

FIG. 2.—Redshift vs. declination for the galaxies indicated in Fig. 1. The two groups of Abell clusters are represented by large oval outlines. Data for Hercules (triangles in the diagram) are from Tarenghi *et al.* (1979, 1980) and the oval for A2199/A2197 is from Thompson and Gregory (1981). Open circles represent our new redshift measurements.

In Figure 1 we have plotted the celestial coordinates of the observed galaxies, which are indicated by symbols corresponding to ranges in redshift. Information is presented for both the 332 sq. deg. region surveyed for this study and the 23.5 sq. deg. region surveyed to near completion by Tarenghi *et al.* (1979, 1980). For this latter region, the locations of 20 randomly selected galaxies (44/350 of the total number observed) are indicated. Figure 2 is a plot of line-of-sight velocity versus declination (the Hercules group and A2199/A2197 are located very roughly north-south of one another) for the galaxies indicated in Figure 1.

The distribution of redshifts is due to a nonhomogeneous distribution of galaxies. A homogeneous distribution in the Hubble flow would be characterized, in a sample with limiting magnitude $m_0 = 15.7$, by a smooth distribution of redshifts with a maximum at $V_0 \approx 7261$ km s^{-1} (Chincarini 1978). Most of our redshifts are in the range between 9000 and 11,000 km s^{-1}.

III. DISCUSSION

Since the redshift of a nearby galaxy is proportional to its distance (to within the uncertainty caused by peculiar motions), Figure 2 combined with Figure 1 yields the three-dimensional configuration of the galaxies in the survey regions. The most prominent feature within this volume is a supercluster bridge containing 33 (or 32 if the galaxy with a redshift of 13,435 km s^{-1} and a declination of 26°.1 is omitted) of the 44 sample galaxies which link the Hercules group and the A2199/A2197 group. Two quantitative factors provide the basis for our claim that these galaxies constitute a supercluster bridge. First, by analyzing the plot of redshift versus declination, we find a gradient in redshift significant at the 3 σ level. Second, the extrapolation of the redshift versus declination relationship to the known declinations of A2151 and A2199 predicts the observed redshifts of these clusters on the $\leq 2\ \sigma$ level.

Details of our calculations are presented in Table 1. The redshift for the A2151 cluster is from Tarenghi *et al.* (1980), and that for A2199 is from Noonan (1981). Quantities listed in Table 1 are derived for the "pure bridge" containing the 33 (or 32) galaxies of the region we surveyed and the "bridge + A2151" which adds the 17 randomly selected galaxies with bridge redshifts from the study by Tarenghi *et al.* (1979, 1980).

Although the detailed structural properties of the Hercules/A2199 bridge will become apparent only when more galaxy redshifts have been obtained, the following general characteristics have been determined on the basis of our small data sample:

1. The rms line-of-sight velocity dispersion of the bridge is ~ 1000 km s^{-1}. If the Hubble flow dominates the dynamics of the bridge, its thickness is ~ 40 h^{-1} Mpc^{-1} (4 σ front-to-back).

2. The bridge covers a large part of the surveyed solid angle, but its overall width is indeterminate because the data sample is small.

3. By applying the law of cosines to the angular separation and Hubble distances of A2151 and A2199, we find that the bridge between these two clusters spans 44 h^{-1} Mpc^{-1} and that the tilt of the bridge off the plane of the sky is 27°.

4. The plot of RC2 redshift versus declination for the strip of the sky passing through A2151 and A2199 (Fig. 3 of Tarenghi *et al.* 1980) suggests that the bridge extends at least ~ 25 h^{-1} Mpc^{-1} farther to the north of A2199.

In front of the bridge is a void which contains no galaxies and which stretches not only across the entire solid angle (0.08 sr) of the surveyed region, but also over a range in redshifts from 7000 km s^{-1} to 8500 km s^{-1}. From these values, the limiting magnitude $m_p = 15.7$ mag, and the fraction of surveyed galaxies (44/350), we find (following the procedure of Chincarini 1978), that if the surveyed galaxies were distributed uniformly, there should be 8 galaxies in the hole, but it actually contains none. If the upper redshift limit is increased to 9000 km s^{-1}, we would expect to find 11 galaxies in the 7000–9000 km s^{-1} interval, whereas we observe just one.

TABLE 1

STRUCTURE OF HERCULES/A2199 BRIDGE

V_0 (km s^{-1}) = $(A_0 \pm S_0) + (A_1 \pm S_1)\delta(0)$

Parameter[a]	Units	Sample 1	Sample 2
N	...	33	32
A_0	km s^{-1}	12932	12596
$\pm S_0$	km s^{-1}	±946	±814
A_1	km s^{-1}	−90	−81
$\pm S_1$	km s^{-1}	±33	±28
S_{xy}	km s^{-1}	962	822
S_{xy}	Mpc	10 h^{-1}	8.2 h^{-1}
$S_{xy} \cos\theta$	Mpc	8.6 h^{-1}	7.3 h^{-1}
V_0 (at A2151)	km s^{-1}	11319	11137
rms error	km s^{-1}	±168	±145
$\langle V_0 \rangle$ (A2151)	km s^{-1}	11142	11142
rms error	km s^{-1}	±145	±145
$(V_0 - \langle V_0 \rangle)/\sigma_{\Delta V}$ (at A2151)	...	0.8	0.02
V_0 (at A2199)	km s^{-1}	9366	9371
rms error	km s^{-1}	±168	±145
$\langle V_0 \rangle$ (A2199)	km s^{-1}	9084	9084
rms error	km s^{-1}	±155	±155
$(V_0 - \langle V_0 \rangle)/\sigma_{\Delta V}$ (at A2199)	...	1.2	1.4
A2151–A2199 Bridge Span	Mpc	44 h^{-1}	...

[a] N = number of galaxies in the bridge with observed redshifts. The galaxy with V_0 = 13,435 km s^{-1} was included when deriving the results of Sample 1 and deleted when deriving the results of Sample 2.

A_0 and A_1 are the coefficients of the regression line of V_0 on δ; S_0 and S_1 are the rms errors of the regression coefficients.

S_{xy} = standard error of estimate of V_0 for a galaxy; it is derived by applying the observed δ to the regression relation.

θ = tilt of the bridge relative to the plane of the sky = 27°.

V_0 (at A2151) = the velocity of the bridge at the position of A2151 as predicted by the extrapolation of the V_0 regression line. V_0 (at A2199) has the corresponding definition for A2199.

$\langle V_0 \rangle$ (A2151) = unweighted average velocity of the observed galaxies in A2151. The quantity V_0 (A2199) has the corresponding definition for A2199.

$(V_0 - \langle V_0 \rangle)/\sigma_{\Delta V}$ (A2151) = the difference between the velocity predicted for A2151 by the regression line and the observed average velocity of A2151, in units of the quadrature sum of the rms error of these quantities.

A2151–A2199 Bridge Span = length of a straight line terminated on either end by the centers of A2151 and A2199.

We wish to thank J. Barnes at KPNO for instructing us on the IIDS data reduction software. Part of this study was done during a visit by H. J. R. at the Institute for Advanced Study. The hospitality of the IAS faculty and members is gratefully acknowledged. Ioanna Manousoyannaki helped in selecting the sample of galaxies to be observed. This research was supported in part by the U.S. National Science Foundation grant AST 77-17958 and by the University of Oklahoma Research Council.

REFERENCES

Abell, G. O. 1961, *A.J.*, **66**, 607.
Burns, J. O., and Owen, F. N. 1979, *A.J.*, **84**, 1478.
Chincarini, G. 1978, Nature, **272**, 515.
Chincarini, G., and Rood, H. J. 1979, *Ap. J.*, **230**, 648.
de Vaucouleurs, G., de Vaucouleurs, A., and Corwin, H. G. 1976, *Second Reference Catalogue of Bright Galaxies* (Austin: University of Texas Press) (RC2).
Noonan, T. W. 1981, *A.J.*, submitted.
Tarenghi, M., Chincarini, G., Rood, H. J., and Thompson, L. A. 1980, *Ap. J.*, **235**, 724.
Tarenghi, M., Tifft, W. G., Chincarini, G., Rood, H. J., and Thompson, L. A. 1979, *Ap. J.*, **234**, 793.
Thompson, L. A., and Gregory, S. A. 1981, in preparation.
Tifft, W. G., and Gregory, S. A. 1979, *Ap. J.*, **231**, 23.
Zwicky, F., Herzog, E., Karpowicz, M., Kowal, C. T., and Wild, P. 1960–1968, *Catalogue of Galaxies and of Clusters of Galaxies*, Vol. **1–6** (Pasadena: California Institute of Technology).

GUIDO CHINCARINI: Department of Physics and Astronomy, University of Oklahoma, 440 West Brooks, Norman, OK 73019

HERBERT J. ROOD: School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540

LAIRD A. THOMPSON: Institute for Astronomy, 2680 Woodlawn Drive, Honolulu, HI 96822