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A REDSHIFT SURVEY TOWARD A PROPOSED VOID OF GALAXIES SUGGESTED BY THE DISTRIBUTION OF ABELL CLUSTERS[1]

JEFFREY A. WILLICK,[2] JEAN P. BRODIE,[3] AND STUART BOWYER[2]
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ABSTRACT

We have carried out a program of redshift measurements in a region of the sky in which a relative underdensity of Abell clusters had been used to infer the presence of a large (diameter $\simeq 40h^{-1}$ Mpc) void in the general galaxy distribution. The purpose of this study was to investigate whether the large-scale distribution of galaxies is traced by the distribution of rich clusters. Toward this end, we present redshifts for 308 galaxies in the Zwicky Catalog in a 234 square degree region centered on R.A. $\sim 2^h$, Decl. $\sim 12°$. Two hundred twenty-nine of the 308 redshifts have been newly measured by us, while the rest come from previously reported results. Our data reveal a pattern of filamentary structure alternating with voids of characteristic diameter ~ 25–$30h^{-1}$ Mpc, throughout the volume sampled. While our redshift data reveal an underdensity in the distribution of galaxies in the general region suggested by the Abell cluster distribution, they do not support the existence there of a $40h^{-1}$ Mpc diameter void.

Subject headings: galaxies: clustering — galaxies: redshifts

I. INTRODUCTION

Galaxy redshift surveys carried out over the last decade have revealed a tremendous complexity of structure in the large-scale distribution of galaxies and clusters. Typical of the features observed are immense, coherent structures which resemble "filaments" or "sheets," as well as vast regions devoid of (or at least highly deficient in) bright galaxies (de Lapparent, Geller, and Huchra 1986; Oort 1983; Haynes and Giovanelli 1986). These empty regions, known as "voids," have become the object of intense study in recent years (Kirshner *et al.* 1981, 1987; Moody *et al.* 1987). A number of investigators have argued that a thorough study of the characteristics of voids is essential to gaining an understanding of the formation and evolution of large-scale structure in the universe (e.g., Melott 1987; Ostriker and Cowie 1981; Dekel and Silk 1986).

Several observational approaches to the problem of characterizing cosmic voids are possible. Redshift surveys which seek to cover a very large fraction of the sky down to a specified magnitude limit provide an unbiased galaxy map of the local universe and typically identify many voids in the process (Geller 1988; de Lapparent, Geller, and Huchra 1986; Haynes and Giovanelli 1986). Such surveys do not, in general, target areas of the sky which are likely *a priori* to contain voids. An alternative to carrying out such full-sky surveys is to select a particular region of the sky of intrinsic interest to the study of voids, e.g., one for which there exists independent evidence for the presence of a void. Typically, such evidence comes from previous redshift measurements taken in the region; further redshift studies can then provide quantitative estimates of the "emptiness" of the underdense volume in question, as well as information about the nature of the galaxies (if indeed any are found) which reside within the void. In this way, several studies have probed the well-known Bootes void to greater depths, selecting objects on the basis of characteristics distinct from the original selection criteria, such as the presence of emission lines in objective prism surveys (Moody *et al.* 1987) or far-infrared luminosity (Strauss and Huchra 1988).

An example of the latter approach is the recent suggestion (Batuski and Burns 1985) that voids in the distribution of field galaxies may preferentially be located within corresponding "voids," suitably defined, in the distribution of rich clusters of galaxies. By studying the Abell Catalog, according to this line of reasoning, it should be possible to develop a list of "candidate" voids suitable for intensive redshift measurement work. To the extent that the rich clusters of galaxies trace the large-scale structure of the universe, this notion may lead to an efficient strategy for the further study of voids. However, the relationship between the cluster and general galaxy distributions remains a poorly understood one (e.g., Davis 1986; Bahcall 1988), and the suggestion that the Abell Catalog can be used as an accurate map of large-scale structure remains controversial. In view of this, we considered it useful to carry out a substantial set of redshift measurements in the direction of a void tentatively identified in the manner described above.

Burns and Batuski (1987) have argued for the existence of a large ($40h^{-1}$ Mpc diameter) void in the direction of the constellations Pisces and Cetus, on the basis of an absence of Abell clusters in a large region centered on the sky at R.A. $\simeq 2^h$, Decl. $\simeq 10°$, and at a redshift of $\sim 11{,}500$ km s^{-1}. This candidate void was further explored by Burns and coworkers (Burns *et al.* 1988, hereafter BMBB) with data from a recent edition of the CfA redshift catalog (Huchra 1988), as well as a small number of redshifts acquired by the present authors at Lick Observatory. With the additional information provided by the redshift data, BMBB concluded that a substantial portion of the volume defined by the absence of Abell clusters was devoid of field galaxies as well; they found the center of this void to be R.A. = 1^h30^m, Decl. = 12°, and $cz = 11{,}500$ km s^{-1}. They noted, however, that the unknown completeness characteristics of the CfA redshift catalog required that their conclusions be considered as preliminary. This catalog (which is continuously being updated by Huchra) contains as a subset the CfA1 Redshift Survey of Huchra *et al.* (1983), which is complete to magnitude 14.5 in the northern sky, as well as numerous redshifts of fainter galaxies in many patches of the sky. In

[1] Based in part on observations made at Lick Observatory.
[2] Center for EUV Astrophysics and Department of Astronomy, University of California at Berkeley.
[3] Lick Observatory, University of California at Santa Cruz.

the area of the sky studied by BMBB and by the present authors, the version of the catalog used contains only a small fraction of Zwicky Catalog galaxies fainter than magnitude 14.5. (It should be noted, however, that more recently Huchra and collaborators have published figures resulting from the CfA redshift survey extension, which is complete to magnitude 15.5, in a portion of the sky which overlaps substantially with ours [see Huchra *et al.* 1988]. These more recent data were available neither to BMBB nor to the present authors.)

In this paper we report the results of a program of redshift measurements taken in the direction of the proposed Pisces-Cetus void. Our redshift sample is complete to the limit of the Zwicky Catalog ($m_{pg} = 15.7$) in 77% of the region of the sky in which we carried out redshift observations, and nearly so in the remaining 23%. This high level of completeness and the relatively faint limiting magnitude enable us to further assess the significance of the results reported by BMBB. In § II we describe the observations and data reduction; in § III we present the results in tabular and graphical form; in § IV we discuss our conclusions.

II. OBSERVATIONS AND DATA REDUCTION

Observations were made from the Lick Observatory 1 m Nickel Telescope in 1986 August–November, and at the 3 m Shane Telescope in 1986 December and 1987 September. At each telescope a lens-grism spectrograph was used in combination with a Texas Instruments CCD detector. The wavelength range covered was ~4300–7000 Å at the 3 m telescope, and either ~4400–6200 Å or ~6100–7400 Å at the 1 m telescope. The decision as to which wavelength range to observe was made in real time at the smaller telescope; the range chosen depended on whether we believed that the redshift would be most readily obtained from absorption lines in the stellar continuum at shorter wavelengths (e.g., when the galaxy appeared to have a high surface brightness core on the acquisition television), or from the Hα and [N II] emission lines in the red (usually when the galaxy appeared to have low surface brightness and to be of late morphological type). Typical exposure lengths were 5–7 minutes at the 3 m, and 10–15 minutes at the 1 m telescope.

Each two-dimensional spectrum was baseline-corrected, dark-subtracted, and flat-fielded using exposures of the dome illuminated by a continuum lamp. The resulting spectroscopic images were then visually inspected, for the purpose of determining the position of the spectrum along the slit and the presence of possible neighboring objects; during this phase cosmic-ray events and detector defects were removed. One-dimensional spectra were then obtained by means of an optimal extraction algorithm. Wavelength calibration was achieved by comparison with arc-lamp spectra taken immediately before each exposure. Spectrograph flexure during individual exposures was found to be negligible for the short integration times we used. The spectra were not in general flux-calibrated, as this was not necessary for redshift determination.

The method of redshift determination used depended upon whether the galaxy spectrum was predominantly an emission- or an absorption-line spectrum. In the former case the emission lines were interactively identified, and a line profile-fitting algorithm was used to determine an accurate central wavelength. Whenever the red portion of the spectrum was covered, the Hα line was identified in the emission-line spectra. Other lines frequently seen were [N II] λλ6549, 6583, [O I] λ6300, [O III] λλ4959, 5007, [S II] λλ6716, 6731, and Hβ. When more than one line was present, a velocity was determined for each line, and the final redshift was obtained by averaging these velocities, each weighted by the line's equivalent width. An effort was made to extract emission-line spectra from the center of the galaxies, and not from outlying H II regions, so that the velocities obtained would be as nearly representative of the systemic velocity of the galaxy as possible; only in a few cases were we forced to use lines obtained far from the galaxy nucleus. Even when the emission lines appear to arise in the center of the two-dimensional spectrum, however, they may still be offset from the galaxy's systemic velocity. In cases where a number of emission lines were identified and fitted, the scatter in velocities computed from individual lines was in the range 30–70 km s^{-1}, but external redshift errors for these galaxies are probably somewhat higher than this for the reasons just mentioned.

In the case of spectra dominated by absorption lines in the stellar continuum, redshifts were obtained from cross-correlation against high signal-to-noise template spectra. We used high-quality spectra of the nuclei of M31 and M32, obtained at Lick, as templates. The cross-correlation method used closely followed the precepts outlined by Tonry and Davis (1979). Prior to cross-correlation, the spectra were continuum-subtracted, rebinned to coordinates linear in the logarithm of the wavelength, and Fourier-filtered to remove high-frequency noise and residual low-frequency variation; the template spectra were prepared in the same fashion. An automatic routine was used to find the maximum of the correlation function, and a Gaussian curve was fitted to this peak to accurately determine its center and the corresponding velocity difference from the template. The majority of our absorption line spectra were of fairly high signal to noise, and consequently the redshift errors are small, on the order of 50 km s^{-1}. The redshifts obtained from both the emission- and absorption-line spectra were corrected for Earth's motion about the Sun in order to obtain heliocentric velocities.

Our estimate of the accuracy of our velocity determinations is supported by a comparison with a group of objects we have in common with other workers. Among those galaxies for which we measured redshifts, one has a redshift given by Huchra *et al.* (1983), and five have redshifts given in the CfA redshift catalog (Huchra 1988). For one of these six objects, our measurement disagrees substantially (by ~150 km s^{-1}) from the result given in the CfA catalog. If this object is excluded, the mean redshift difference (this paper minus previous result) is 18.4 km s^{-1}, and the rms difference is 53.2 km s^{-1}; these differences are within the quoted errors. We note that for the galaxy we have excluded from this comparison (0141+1155), we obtained a fairly high signal-to-noise emission-line spectrum in the red (containing the Hα, [N II], and [S II] lines), and we have no reason to believe that our redshift measurement is in error by more than ~50 km s^{-1}. However, as noted above, it is possible that differences in excess of the formal errors might be expected when emission lines are used to determine galaxy redshifts.

III. RESULTS

The earliest identification of the proposed void in Pisces-Cetus (Burns and Batuski 1987) suggested that its center was at a right ascension of $\sim 2^h$ and a declination of $\sim 12°$. Our sample included all galaxies in the Zwicky Catalog (Zwicky *et al.* 1961–68) in the fields 436–440 ($1^h05^m \leq \alpha \leq 2^h58^m$, $9°.5 \leq$

TABLE 1a

OBSERVATIONAL DATA FOR GALAXIES WITH $9^\circ.5 \leq \delta \leq 15^\circ.5$

Name (1)	RA (1950) (2)	DEC (1950) (3)	m_{pg} (4)	$V_\odot$ (5)	Code (6)	Name (1)	RA (1950) (2)	DEC (1950) (3)	m_{pg} (4)	$V_\odot$ (5)	Code (6)	
0105+1400	$01^h04^m.6$	14°00′	15.7	22616	1	0126+1430	12^h6^m0	14°30′	15.6	13571	1	
0105+1202	01 05.1	12 02	15.7	18310	1	0126+1205	01 26.1	12 05	15.7	14095	1	
0106+1046	01 05.9	10 46	15.6	10697	1	0126+1331	01 26.2	13 31	14.9	6416	1	
0107+1255	01 06.7	12 55	15.7	17821	1	N 569	01 26.5	10 53	14.7	—	4	
0107+1405	01 06.7	14 05	14.8	11553	1	0127+1053	01 26.6	10 53	15.7	—	4	
0107+1406	01 06.8	14 06	15.2	11295	1	0128+1258	01 28.0	12 58	15.6	21761	1	
0108+1455	01 08.4	14 55	15.6	11453	1	0128+1350	01 28.3	13 50	14.7	4567	1	
0110+1200	01 09.5	12 00	15.5	4857	1	0128+1323	01 28.4	13 23	15.6	5862	1	
I1645	01 09.8	15 29	15.5	11392	1	0129+0941	01 28.6	9 41	15.4	9509	1	
I1646	01 10.1	15 27	15.3	11608	1	0129+1401	01 28.8	14 01	15.1	4519	1	
0110+1518	01 10.2	15 18	15.7	13920	1	0131+1305	01 30.7	13 05	15.3	2800	1	
0110+1514	01 10.3	15 14	15.7	—	4	I1715	01 30.9	12 19	14.5	4188	2	
0111+1515	01 10.6	15 15	15.7	—	4	0132+1150	01 32.2	11 50	15.3	7861	1	
0111+1300	01 11.2	13 00	15.0	15479	1	0133+1141	01 32.9	11 41	15.0	5808	1	
0112+1224	01 11.6	12 24	15.6	5691	1	0133+1419	01 33.3	14 19	15.6	10158	1	
0113+1305	01 13.2	13 05	15.0	4196	1	0136+1448	01 36.1	14 48	15.7	8420	1	
0114+1245	01 14.3	12 45	14.9	6142	1	0136+1446	01 36.2	14 46	15.5	8380	1	
0115+1426	01 14.8	14 26	15.4	11352	1	N 658	01 39.5	12 20	13.6	2988	2	
0115+0956	01 15.1	9 56	15.7	10339	1	0140+1343	01 39.7	13 43	13.9	767	2	
0116+1107	01 15.5	11 07	14.3	5062	2	0140+1254	01 40.1	12 54	14.3	839	2	
0116+1445	01 16.1	14 45	14.2	6903	2	0140+1323	01 40.3	13 23	12.8	856	2	
0117+1211	01 16.7	12 11	15.1	—	4	0141+1139	01 40.7	11 39	15.3	8471	1	
0117+1212	01 16.7	12 12	15.2	—	4	0141+1408	01 40.8	14 08	15.5	7293	1	
N 469	01 16.8	14 36	15.0	4071	1	0141+1155	01 41.1	11 55	15.0	4968	5	
0117+0954	01 17.1	9 54	15.5	7851	1	I 152	01 41.3	12 49	15.7	7955	1	
0117+1205	01 17.3	12 05	15.7	14487	1	0142+1200	01 41.6	12 00	15.5	10210	1	
0117+1222	01 17.3	12 22	15.7	14497	1	0142+1210	01 41.8	12 10	15.2	8096	1	
0117+1240	01 17.3	12 40	15.6	5796	1	N 665	01 42.3	10 10	13.5	5494	3	(5420)
N 471	01 17.3	14 31	14.0	4138	2	0143+1006	01 42.6	10 06	15.5	5520	1	
0117+1406	01 17.4	14 06	14.9	9378	1	I 154	01 42.6	10 24	14.8	5613	1	
0118+1138	01 18.2	11 38	15.4	12973	1	I 156	01 42.8	10 18	15.0	5339	1	
0118+1526	01 18.4	15 26	15.6	5117	1	0143+0934	01 43.3	9 34	15.5	5306	1	
0119+1209	01 18.6	12 09	15.7	567	5	0144+1426	01 43.9	14 26	15.7	7373	1	
0119+1415	01 18.8	14 15	15.0	4206	1	0144+1110	01 44.2	11 10	15.0	5205	1	
0119+1128	01 19.1	11 28	15.1	14153	1	0144+1210	01 44.3	12 10	15.1	834	5	
0121+1457	01 20.7	14 57	15.5	10246	1	N 671	01 44.3	12 52	14.3	5460	2	
N 511	01 20.8	11 02	15.4	11218	1	0145+1152	01 44.8	11 52	15.5	6624	1	
N 514	01 21.4	12 39	12.8	2477	2	0145+1106	01 45.0	11 06	15.7	5257	1	
I 101	01 21.5	9 40	15.1	—	4	N 673	01 45.7	11 17	13.3	5173	2	
I 102	01 21.8	9 38	15.6	—	4	0146+1221	01 45.8	12 21	14.0	5474	2	
0122+1530	01 21.8	15 30	15.7	5038	1	0146+1310	01 45.8	13 10	15.5	5022	1	
0122+0930	01 22.1	9 30	15.7	—	4	I 162	01 46.1	10 15	14.2	5354	2	
N 522	01 22.1	9 44	14.2	2806	2	0146+1016	01 46.2	10 16	14.8	—	4	
I 107	01 22.5	14 37	15.4	6402	1	0146+1020	01 46.2	10 20	15.3	—	4	
I1698	01 22.6	14 35	14.9	—	4	0146+1257	01 46.3	12 57	14.6	5054	1	
0123+1416	01 22.7	14 16	15.2	11147	1	N 675	01 46.4	12 48	15.5	5317	1	
I1700	01 22.7	14 36	14.3	6356	2	0147+1236	01 46.5	12 36	15.2	7887	1	
0123+0952	01 22.9	9 52	15.5	14177	1	N 677	01 46.5	12 48	14.3	5100	2	
I 112	01 23.4	11 11	14.2	5810	2	0147+1228	01 46.6	12 28	15.7	10040	1	
I 114	01 23.7	9 40	15.7	2275	1	0147+1307	01 46.7	13 07	15.3	4633	1	
0124+1146	01 24.2	11 46	15.7	9504	1	0147+1215	01 46.8	12 15	14.2	5221	2	
0124+1247	01 24.2	12 47	15.6	10306	1	N 683	01 47.1	11 27	14.8	5257	1	
0125+1022	01 24.5	10 22	15.5	14309	1	0147+1134	01 47.3	11 34	15.1	13618	1	
I1706	01 24.5	14 31	14.2	6319	2	0148+1228	01 47.5	12 28	15.7	5151	1	
0125+1144	01 24.6	11 44	15.7	9498	1	0148+1218	01 48.2	12 18	15.2	8014	1	
0125+1348	01 24.7	13 48	15.6	7121	1	0148+1303	01 48.3	13 03	15.1	5271	1	
0125+1435	01 24.8	14 35	15.4	6502	1	0149+1253	01 48.7	12 53	15.5	4862	5	
0125+1158	01 25.0	11 58	15.6	16844	1	I1743	01 50.2	12 28	14.0	4611	2	
0126+1033	01 25.8	10 33	15.7	14712	1	0152+1317	01 51.6	13 17	15.6	6080	1	

TABLE 1*a*—*Continued*

Name (1)	RA (1950) (2)	DEC (1950) (3)	m_{pg} (4)	$V_{\odot}$ (5)	Code (6)
0152+1314	$01^{h}52^{m}2$	13°14′	15.7	6314	1
0153+0946	01 52.5	9 46	15.5	--	4
0153+1442	01 53.1	14 42	15.2	13263	1
0154+1033	01 53.5	10 33	15.0	6088	1
0154+1255	01 53.6	12 55	15.7	7720	1
0154+1446	01 54.0	14 46	14.9	4708	1
0154+1438	01 54.2	14 38	15.6	13200	1
0155+1117	01 54.5	11 17	15.7	3509	1
I1755	01 54.5	14 19	14.8	7920	1
0155+1430	01 54.5	14 30	15.7	7769	1
0156+1403	01 55.6	14 03	15.6	7886	1
N 774	01 56.9	13 46	14.4	4595	2
N 781	01 57.5	12 24	14.0	3483	2
0158+1456	01 58.2	14 56	14.6	4610	2
N 786	01 58.6	15 24	14.3	4465	2
N 792	01 59.5	15 28	14.6	—	4
I1771	01 59.6	9 43	15.4	4788	1
I1770	01 59.6	9 44	15.4	4569	1
I 193	01 59.8	10 51	14.7	—	4
0201+1530	02 00.9	15 30	15.7	8010	1
I 195	02 01.0	14 28	14.3	3648	2
I 196	02 01.1	14 30	14.2	3640	2
I1774	02 01.2	15 04	15.2	3619	1
0202+1111	02 02.2	11 11	15.5	7822	1
0203+0941	02 02.6	9 41	15.2	7750	1
N 810	02 02.7	13 00	15.4	7755	1
0203+1441	02 03.2	14 41	15.6	12562	1
0203+1302	02 03.4	13 02	15.6	7301	1
I1777	02 03.4	14 58	15.7	12748	1
0204+1459	02 03.9	14 59	15.3	12953	1
I1780	02 04.1	14 29	15.5	10334	1
0205+1507	02 04.9	15 07	15.7	12833	1
N 820	02 05.6	14 06	13.7	4426	2
0206+1444	02 05.6	14 44	14.3	4405	2
N 821	02 05.7	10 45	12.6	1716	2
0207+1044	02 07.2	10 44	15.4	4632	1
0207+1107	02 07.2	11 07	15.7	10995	1
0207+1032	02 07.3	10 32	15.3	6779	1
0209+1353	02 08.5	13 53	14.8	7662	1
0209+1136	02 08.8	11 36	15.7	13430	1
0209+1404	02 08.8	14 04	15.6	8061	1
0209+1340	02 08.9	13 40	15.0	—	4
0209+1404	02 09.0	14 04	15.3	7698	1
0209+1521	02 09.3	15 21	15.2	7811	1
0210+1408	02 09.9	14 08	15.2	7882	1
0213+1338	02 12.8	13 38	15.6	6400	1
0213+1510	02 13.0	15 10	15.7	6893	1
N 871	02 14.4	14 19	13.6	3740	2
0215+0935	02 14.6	9 35	15.4	8150	1
0215+0938	02 14.7	9 38	15.4	8360	1
0215+1002	02 14.7	10 02	15.7	18674	1
I1790	02 14.9	12 17	15.7	3641	1
I1791	02 15.0	12 15	14.6	3638	1
N 877	02 15.2	14 19	12.5	3910	2
0216+1258	02 15.5	12 58	15.3	3612	1
0216+1456	02 16.1	14 56	15.7	3751	1
0216+1502	02 16.3	15 02	15.7	3812	1
0219+1359	02 18.8	13 59	14.8	3813	2
0220+1149	02 19.6	11 49	15.3	3856	1
I 222	02 20.1	11 25	15.2	13186	1
0220+1415	02 20.2	14 15	15.7	12123	1
0223+1450	02 22.5	14 50	15.6	8040	1
0223+1052	02 22.7	10 52	15.6	6243	1
0223+1115	$02^{h}22^{m}8$	11°15′	15.7	3796	5
0224+1011	02 23.6	10 11	15.5	11955	1
N 927	02 23.9	11 56	14.5	8258	2
0226+1010	02 25.7	10 10	15.1	8653	1
0227+0957	02 26.7	9 57	14.9	8421	1
0227+0959	02 27.1	9 59	15.5	8505	1
0227+0938	02 27.2	9 38	15.7	8458	1
0229+0931	02 29.2	9 31	15.4	8440	1
0230+0930	02 29.5	9 30	15.3	8503	1
I1817	02 31.2	11 00	14.9	7452	1
0232+1020	02 31.6	10 20	15.4	7390	1
I 238	02 32.6	12 36	14.1	6008	2
N 990	02 33.6	11 26	13.9	3508	2
I1821	02 33.7	13 33	15.4	12082	1
0236+1005	02 36.2	10 05	15.5	8012	1
N1024	02 36.5	10 38	13.8	3472	2
0237+1228	02 36.7	12 28	15.7	0	0
N1029	02 36.9	10 35	14.1	3635	2
N1028	02 36.9	10 38	15.3	8644	1
0238+1405	02 37.8	14 05	15.7	13200	1
I1835	02 41.1	14 41	15.7	13907	1
I1839	02 42.0	15 02	15.3	7549	1
I1842	02 42.7	11 15	15.7	6358	1
0244+1253	02 43.6	12 53	15.2	6478	1
0244+1053	02 43.7	10 53	15.4	7513	1
0244+1513	02 44.2	15 13	14.8	8037	1
0245+1511	02 44.5	15 11	15.6	7214	1
I1846	02 45.0	13 03	15.4	8778	1
0245+1520	02 45.0	15 20	15.6	7421	1
I1847	02 45.1	14 18	15.7	6396	1
0246+1148	02 45.8	11 48	15.5	10518	1
0246+1403	02 45.8	14 03	15.5	7587	1
0246+1406	02 45.9	14 06	14.8	7329	1
0246+1519	02 45.9	15 19	15.7	7648	1
I1852	02 46.3	13 01	14.9	8473	1
I1857	02 46.9	14 25	15.1	9096	1
0247+1412	02 47.1	14 12	15.7	8721	1
0247+1238	02 47.4	12 38	15.4	10380	1
0247+1240	02 47.4	12 40	15.2	10377	1
N1115	02 47.7	13 03	15.6	8579	1
N1116	02 47.8	13 07	15.4	7722	1
0249+1259	02 48.5	12 59	14.9	7571	1
0249+1347	02 49.4	13 47	15.2	10069	1
N1127	02 50.1	13 03	15.7	9822	1
0250+1250	02 50.4	12 50	15.5	3721	1
0251+1145	02 50.6	11 45	15.7	7652	1
N1134	02 50.9	12 48	13.2	3595	2
I 267	02 51.1	12 38	14.1	3577	2
0251+1324	02 51.2	13 24	15.7	10172	1
0251+1446	02 51.2	14 46	14.6	—	4
0251+1137	02 51.3	11 37	15.7	7676	1
0252+1357	02 51.7	13 57	15.5	12570	1
0252+1523	02 52.0	15 23	15.7	9930	1
0252+1527	02 52.0	15 27	15.7	10302	1
0253+1201	02 52.5	12 01	15.7	7805	1
0255+1516	02 54.6	15 16	15.6	10067	1
0255+1017	02 54.7	10 17	15.3	7778	1
0255+1059	02 55.2	10 59	15.4	3404	1
0256+1055	02 55.5	10 55	15.4	7793	1
0257+1505	02 57.0	15 05	15.6	6507	1
N1166	02 57.8	11 39	15.4	—	4
N1166	02 58.0	11 35	15.4	—	4

NOTES.—The redshift source codes are as follows: (0) Redshift not obtained; (1) our measurement; (2) velocity from the published CfA1 redshift survey (Huchra *et al.* 1983); (3) our measurement, velocity also published by CfA1 (in parentheses); (4) velocity obtained from the recent version of the CfA redshift catalog (Huchra 1988), used in figures; (5) our measurement, velocity also in CfA redshift catalog.

TABLE 1*b*

OBSERVATIONAL DATA FOR GALAXIES WITH 6°5 ≤ δ ≤ 9°5

Name (1)	RA (1950) (2)	DEC (1950) (3)	m_{pg} (4)	$V_\odot$ (5)	Code (6)	Name (1)	RA (1950) (2)	DEC (1950) (3)	m_{pg} (4)	$V_\odot$ (5)	Code (6)
0135+640	$01^h35^m.1$	6°40′	15.6	18152	1	0207+705	$02^h07^m.1$	7°05′	15.6	7356	1
0136+716	01 35.8	7 16	14.8	—	4	0207+725	02 07.4	7 25	15.1	3484	1
N 638	01 37.0	6 58	14.4	3178	2	N 840	02 07.6	7 36	14.7	—	4
N 652	01 38.1	7 43	14.7	5250	1	0208+810	02 07.8	8 10	15.7	14993	1
I1721	01 38.8	8 15	14.3	4299	2	0208+726	02 08.4	7 26	15.4	7403	1
0139+652	01 39.3	6 52	15.5	5489	1	0210+823	02 09.7	8 23	15.3	0	0
0140+755	01 40.1	7 55	15.6	9409	1	0210+915	02 10.4	9 15	15.2	8175	1
0140+750	01 40.2	7 50	15.5	—	4	0210+916	02 10.4	9 16	15.6	8240	1
I1723	01 40.6	8 38	14.2	5498	2	0212+737	02 11.7	7 37	15.7	18056	1
0147+707	01 47.2	7 07	15.7	19597	1	0218+758	02 17.6	7 58	15.6	8870	1
0149+800	01 48.9	8 00	14.2	5538	2	0218+748	02 17.7	7 48	15.7	7111	1
0149+803	01 49.0	8 03	15.0	—	4	0218+635	02 17.9	6 35	15.1	0	0
0149+811	01 49.2	8 11	15.7	5557	1	0227+638	02 26.5	6 38	15.6	9201	1
0151+809	01 50.9	8 09	15.5	5236	1	0229+915	02 29.2	9 15	15.7	13923	1
0152+737	01 51.5	7 37	15.0	8151	1	0231+928	02 30.5	9 28	15.5	18228	1
0153+826	01 52.7	8 26	15.3	5657	1	N 975	02 30.6	9 23	14.2	6111	2
I1749	01 53.6	6 30	14.8	5050	1	0231+925	02 31.2	9 25	15.3	0	0
0155+845	01 55.1	8 45	15.6	17548	1	0234+719	02 33.7	7 19	15.4	6555	1
N 766	01 56.1	8 06	14.4	8104	2	0234+705	02 33.8	7 05	15.6	6085	1
I1827	01 57.2	7 10	14.6	4825	1	N 997	02 34.6	7 05	14.6	6460	1
0157+643	01 57.4	6 43	15.7	—	4	N 998	02 34.6	7 13	15.6	5932	1
0158+804	01 58.3	8 04	14.4	4756	2	0236+747	02 35.7	7 47	15.4	—	4
0159+814	01 59.0	8 14	15.7	0	0	I1825	02 36.2	8 53	14.9	—	4
N 791	01 59.1	8 15	14.8	8018	1	0236+829	02 36.3	8 29	15.7	6159	1
0159+814	01 59.2	8 14	15.7	7465	1	0238+838	02 37.9	8 38	15.5	6005	1
0160+812	01 59.5	8 12	15.2	8045	1	0238+823	02 38.2	8 23	15.1	5396	1
0200+717	02 00.3	7 17	15.4	7623	1	0238+832	02 38.3	8 32	15.7	6190	1
0202+818	02 02.1	8 18	14.3	3508	2	0238+800	02 38.4	8 00	15.5	0	0
0203+817	02 02.7	8 17	15.6	5746	1	N1044	02 38.4	8 31	14.8	6358	1
0203+632	02 03.0	6 32	14.6	—	4	N1046	02 38.5	8 30	14.9	5906	1
I 198	02 03.4	9 03	14.8	—	4	0239+658	02 38.9	6 58	15.0	—	4
I 199	02 03.6	8 59	15.4	9214	1	0240+800	02 39.7	8 00	15.4	0	0
0207+924	02 03.6	9 24	15.4	9251	1	0240+723	02 40.2	7 23	15.0	—	4
0204+754	02 04.4	7 54	15.4	3465	1	0240+755	02 40.3	7 55	15.7	11386	1
I 202	02 04.8	8 56	15.3	9231	1	0241+729	02 41.0	7 29	15.4	6351	1
N 827	02 06.2	7 44	14.0	3458	2	0241+736	02 41.3	7 36	15.6	11692	1

NOTES.—See notes to Table 1*a*.

$\delta \leq 15°.5$), and the northern half of fields 412–414 ($1^h35^m \leq \alpha \leq 2^h41^m$, $6°.5 \leq \delta \leq 9°.5$). In the 9°5 to 15°5 declination range, the Zwicky Catalog contains 243 galaxies. We measured 184 galaxy redshifts in this strip, and we used 58 measurements from other sources (obtained from a recent version of the CfA redshift catalog made available to us by J. Huchra.) We were unable to obtain a redshift for the one remaining galaxy in this region (galaxy 0237+1228 in field 439), which we discovered to have a star superposed on it and which is most likely fainter than the nominal Zwicky limit of 15.7. In the 6°5–9°5 range, there are 72 Zwicky galaxies. We obtained new redshifts for 47 of these galaxies, while 19 have previously reported redshifts. For five galaxies in this strip, our spectra were of very poor quality, and we were unable to determine a reliable redshift, while for another (galaxy 0240+0800 in field 414), we could not acquire a spectrum because of a bright superposed star.

In Table 1*a* we present our results for the 9°5–15°5 strip, and in Table 1*b* for the 6°5–9°5 strip. The tables provide the following information: Col. (1) name of the object, either the NGC or IC number or the IAU positional designation. Col. (2) R.A. (1950) in hours, minutes. Col. (3) Decl. (1950) in degrees, arcminutes. Col. (4) Photographic magnitude as given in the Zwicky Catalog. Col. (5) Heliocentric redshift *cz* given in km s^{-1} (a "0" in this column indicates that we do not have a redshift for the object.) Col. (6) a redshift "source code" (see footnotes to the tables.)

In Figure 1 we present "pie" diagrams (polar plots with redshift as the radial coordinate and R.A. as the azimuthal coordinate) of our data. Figure 1*a* represents the 9°5–15°5 strip, Figure 1*b* the 6°5–9°5 strip, and Figure 1*c* the two strips together. The figures all reveal the characteristic pattern of alternating elongated filamentary structures and relatively empty regions, similar to the results which have emerged from other redshift surveys.

A number of regions that could plausibly be called voids are evident in Figures 1*a*–1*c*. The first is in the immediate foreground, for velocities less than ~3500 km s^{-1}. Another empty region occurs in the velocity interval ~3500–6000 km s^{-1}, for values of R.A. greater than ~2^h. This region is bounded on the west by a rather dense filament that stretches roughly, but not precisely, along the line of sight. Our survey region does not extend far enough to detect the eastern boundary of this void. Both of these voids are evident in the redshift maps of the same area of the sky obtained from the 21 cm redshift survey of Haynes and Giovanelli (1986); they comprise part of the very large underdense volume in the foreground of the massive Perseus-Pisces supercluster at ~5000 km s^{-1}.

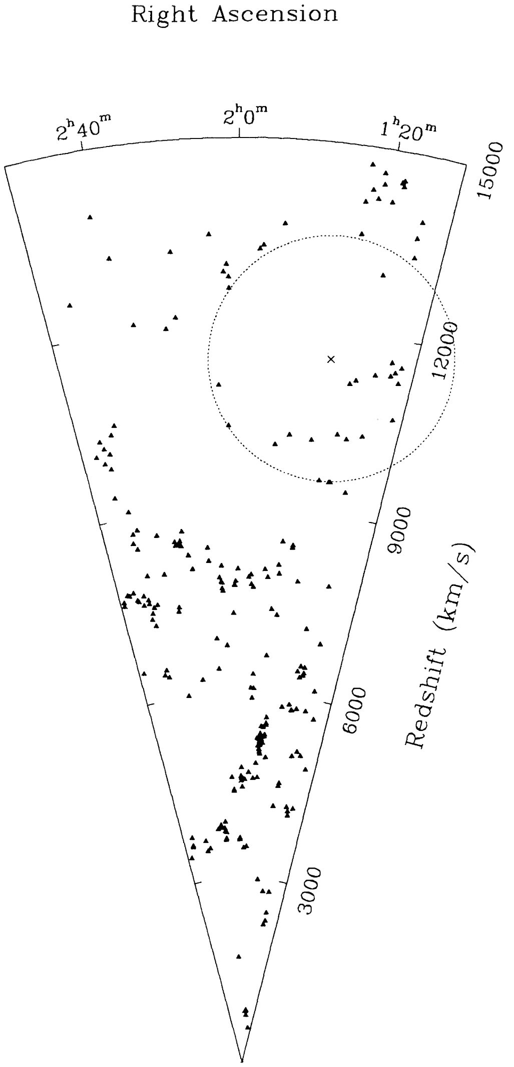

FIG. 1a

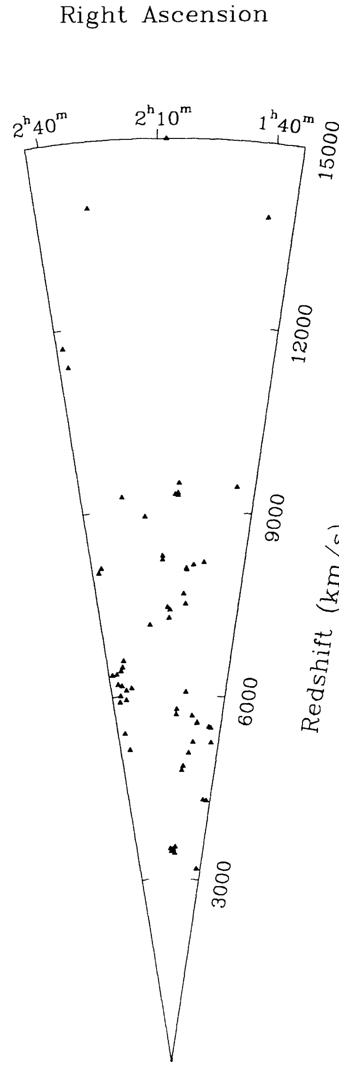

FIG. 1b

FIG. 1.—Plots of galaxy position in redshift and R.A. for (*a*) the 9°5–15°5 declination strip, (*b*) the 6°5–9°5 declination strip, and (*c*) the two strips combined. In (*a*), the circle shows the extent of the void postulated by Burns *et al.* (1988 *see text.*)

Perhaps the most remarkable feature seen in the pie-diagram for the northern strip (Fig. 1*a*) is the narrow filament which stretches from $\sim 1^h25^m$ to 2^h40^m at a redshift of ~ 8000 km s^{-1}. The far edge of this ridge is extremely sharp, and gives way to a large empty region whose size is not well constrained by our data. There seem, in fact, to be two voids at higher redshifts, one centered at $cz \sim 9500$ km s^{-1}, R.A. $\sim 2^h20^m$, and a second at $cz \sim 12{,}000$ km s^{-1}, R.A. $\sim 1^h50^m$, with several galaxies forming a thin boundary between them. The rather sparse sampling at this distance precludes our making a definitive statement about the "connectedness" of these two volumes; however, the contention of BMBB, that a $40h^{-1}$ void is present here, is not substantiated by our data. To underscore this point, we have plotted in Figure 1*a* the center (*marked by a cross*) and the boundary of the void postulated by BMBB. The region interior to this boundary is seen not to be devoid of galaxies. A smaller region, slightly displaced to the east and to higher redshift, is seen to be empty to the faintness limit considered here.

In the southern strip (Fig. 1*b*), a region ~ 4000 km s^{-1} deep, from ~ 9500 km s^{-1} to 13,500 km s^{-1} redshift, is empty within the confines of our survey. However, it must be remembered that there is only $\sim 90\%$ completeness in the southern region, which is also only 3° thick in declination. This region is significantly underdense, but it does not represent a very large volume. Moreover, it is well to the south of the center of the proposed Pisces-Cetus void.

It should also be noted that the larger voids which have appeared in recent redshift surveys seem to occur preferentially at relatively great distances; the Pisces-Cetus void described by BMBB, as well as the Bootes void, for example, are at redshifts well in excess of 10,000 km s^{-1}. In larger redshift surveys, such as the CfA redshift survey extension, a similar effect obtains: one gets a visual impression of larger voids at higher redshifts in all such samples. This may well be due to signal-to-noise considerations: when the sometimes tenuous connections between adjacent voids are sampled very dilutely, as they are at distances $\gtrsim 10{,}000$ km s^{-1} in surveys which sample to the limit

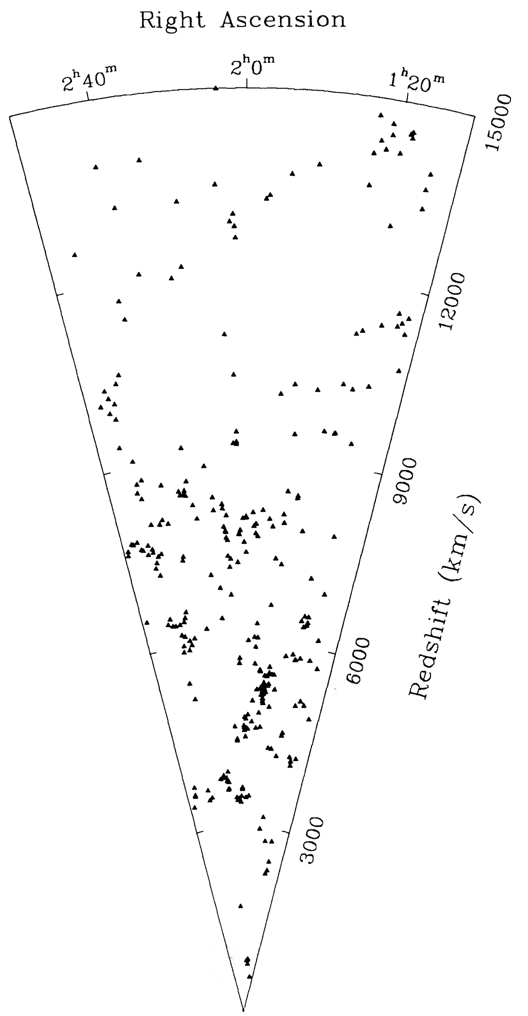

FIG. 1c

of the Zwicky Catalog, the visual impression of connectedness tends to disappear and smaller voids appear to merge into single, apparently large empty regions.

In Figure 2 we show a histogram of object number (in 500 km s^{-1} bins) versus redshift for the entire sample. We have superposed on the histogram a smooth curve representing the expected number of objects for a homogeneous universe, for a magnitude limit of 15.7 and a Schechter luminosity function (Schechter 1976) with parameters $n_0 = 0.014$ Mpc^{-3}, $M_* = -19.4$, and $\alpha = 1.3$. In this figure, in which we relinquish angular resolution for the sake of better statistical weight at a given velocity, the foreground void is still apparent, as is the overdense "ridge" at $\sim$8000 km s^{-1}; an underdensity at radial velocities 8500 km s^{-1} $\lesssim cz \lesssim$ 13,000 km s^{-1} is in evidence, but it is not so dramatic.

IV. SUMMARY

We have made a test of the suggestion that large voids in the distribution of galaxies may be identified from empty regions in the distribution of Abell clusters. By carrying out a redshift survey complete to the limit of the Zwicky Catalog in a 180 square degree area, and more than 90% complete in an adjacent 54 square degree region, we have been able to test for the presence of a $40h^{-1}$ Mpc diameter void whose existence was inferred by Burns *et al.* (1988) from the absence of Abell clusters. While our redshift data reveal a number of smaller voids, generally with diameter of order 25–30h^{-1} Mpc, they do not confirm the presence of a larger region as suggested by BMBB. The results of our redshift survey are consistent with those of other surveys in that they show that an alternating pattern of voids and filaments is characteristic of the large-scale distribution of galaxies. The typical scale of both voids and filaments in our data is $\sim 30h^{-1}$ Mpc (length of the filaments, diameter of the voids).

A definitive conclusion regarding the utility of the Abell cluster technique for locating candidate voids cannot be reached on the basis of the survey described here. However, we

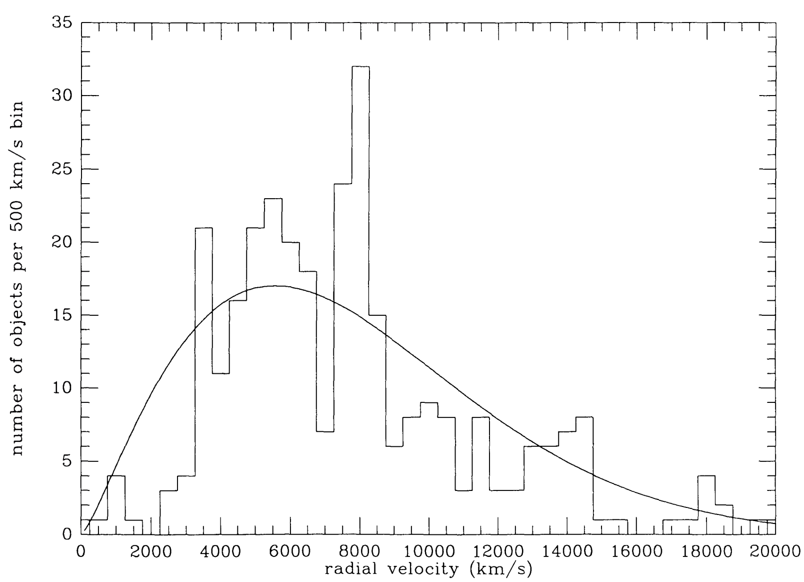

FIG. 2.—Histogram of number of galaxies observed, in 500 km s^{-1} bins, as a function of redshift, for the entire data set described in the text. The smooth curve represents the expected number of objects per 500 km s^{-1} bin, in a homogeneous universe characterized by a Schechter luminosity function with parameters $n_0 = 0.014$ Mpc^{-3}, $M_* = -19.4$, and $\alpha = 1.3$, for a survey covering the same solid angle (234 square degrees) and having the same magnitude limit (15.7) as that represented by the histogram.

do believe that the technique is not well suited to the purpose of identifying the most common voids, those of diameter ~ 25–$30h^{-1}$ Mpc. In view of the fact that the typical intercluster separation for the Abell clusters is $\sim 50h^{-1}$ Mpc, as well as the fact that the smaller voids are quite common, voids will almost invariably be found in the spaces between Abell clusters. The correlation properties of the rich clusters (see, e.g., Bahcall and Soneira 1983) ensure that there will be occasional very large ($\gtrsim 100h^{-1}$ Mpc) volumes devoid of such clusters; however, we will have to await the completion of redshift surveys considerably deeper than those carried out to date before we can assess the reality of comparably sized voids in the general galaxy distribution.

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J. P. Brodie: Lick Observatory, University of California, Santa Cruz, CA 95064

J. A. Willick and S. Bowyer: Center for EUV Astrophysics, University of California, Berkeley, CA 94720