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NO HUBBLE BUBBLE IN THE LOCAL UNIVERSE

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ABSTRACT

Zehavi et al. have suggested that the Hubble flow within 70 h^{-1} Mpc may be accelerated by the existence of a void centered on the Local Group. Its underdensity would be $\sim 20\%$, which would result in a local Hubble distortion of about 6.5%. We have combined the peculiar velocity data of two samples of clusters of galaxies, SCI and SCII, to investigate the amplitude of Hubble distortions to 200 h^{-1} Mpc. Our results are not supportive of that conclusion. The amplitude of a possible distortion in the Hubble flow within 70 h^{-1} Mpc in the SCI+SCII merged data is 0.010 ± 0.022. The largest, and still quite marginal, geocentric deviation from smooth Hubble flow consistent with that data set is a shell with $\Delta H_0/H_0 = 0.027 \pm 0.023$, centered at $hd = 101$ Mpc and extending over some 30 h^{-1} Mpc. Our results are thus consistent with a Hubble flow that, on distances in excess of ~ 50 h^{-1} Mpc, is remarkably smooth.

Subject headings: cosmology: observations — galaxies: distances and redshifts — large-scale structure of universe

1. INTRODUCTION

The linearity of the Hubble law over large scales, as illustrated by the early work of Sandage & Hardy (1973), has been confirmed by more recent measurements as discussed by Postman (1997). These measurements do not however exclude the possibility of local deviations from Hubble flow with amplitudes on the order of a few percent, as would be produced by large-scale mass fluctuations. For example, an extended, underdense region centered on the Local Group would exhibit a locally accelerated Hubble flow. This could, to a point, help reconcile discrepant estimates of the value of the Hubble constant obtained by methods that sample vastly different scales and solve the still raspy conflict between some estimates of the age of the universe and that of the oldest stars. By analyzing the monopole of the peculiar velocity field as described by a sample of 44 Type Ia supernovae (SNe), Zehavi et al. (1998, hereafter Z98) have recently suggested that the Local Group may be near the center of a bubble of 70 h^{-1} Mpc radius (where $H_0 = 100h$ km s^{-1} is the Hubble constant), underdense by 20%, which may be itself surrounded by an overdense shell. The isotropic flow observed within that "bubble" would then exceed the universal rate by $\Delta H_0/H_0 = (6.5 \pm 2.1)\%$; i.e., studies that rely on distance indicators contained within that bubble would overestimate the Hubble constant by 6.5%. Z98 cautiously underscore the marginal character of their detection, as well as the need to corroborate, or refute, their suggestion by means of tests with independent sets of data. In this paper, we provide such a test.

2. THE SCI AND SCII CLUSTER SAMPLES

Based on data published earlier (Giovanelli et al. 1997a, 1997b, hereafter G97a and G97b, respectively), peculiar velocities of 24 clusters of galaxies within 90 h^{-1} Mpc, obtained from measurements for 782 galaxies in their fields (hereafter referred to as SCI) have been recently presented by Giovanelli et al. (1998b), who also used it to compute a dipole and investigate the Z98 claim. Because of the limited depth of the SCI sample, their test of the Z98 claim was inconclusive. Recently, we have completed a deeper survey of cluster peculiar velocities, which extends to 200 h^{-1} Mpc. As for the SCI sample, the new survey is based on the Tully & Fisher (1977, hereafter TF) technique. The first installments of this data set are in Dale et al. (1997, 1998); the final one is in preparation, but its results can be seen in preliminary form in Dale (1998). The new survey, which we shall refer to as SCII, includes 522 galaxies in 52 clusters. The dipole signature of the SCII, which is consistent with that of the cosmic microwave background (CMB) temperature dipole, is discussed in Dale et al. (1999a).

The combination of SCI and SCII provides a peculiar velocity data set of slightly smaller depth but higher sampling density than the SN sample of Z98. The peculiar velocity errors of the SCI set vary between 3% and 6% of the distance, for each individual cluster. In the case of the SCII set, peculiar velocity errors are somewhat higher, because of the smaller number of galaxies observed per cluster: they hover between 4% and 9%, except in a few cases that will be discussed later. On the average, the accuracy of each cluster peculiar velocity compares favorably with the quoted uncertainty of 5%–8% (for the internal errors alone) of the distance of individual SNe in the Z98 sample. Since the 76 clusters in the SCI+SCII merged sample straddle quite comfortably the boundaries of the Z98 bubble, they can provide tighter constraints than the SN sample on the amplitude of the proposed, locally underdense region.

Table 1 lists the clusters in the SCI+SCII merged sample, identified either by their Abell number (Abell, Corwin, & Olowin 1989) or by their common name, the adopted center coordinates, as well as the radial velocity

TABLE 1

CLUSTER POSITIONS AND VELOCITIES

Cluster	R.A. (1950)	decl. (1950)	cz_{cmb}	V_{pec}	n
		SCI			
N383	01 04 30.0	+32 12 00	4865 ± 32	−6 ± 170	21
N507	01 20 00.0	+33 04 00	4808 ± 99	94 ± 204	14
A262	01 49 50.0	+35 54 40	4664 ± 80	70 ± 133	31
A400	02 55 00.0	+05 50 00	6934 ± 75	−126 ± 227	25
Eridanus	03 30 00.0	−21 30 00	1534 ± 30	−304 ± 74	34
Fornax	03 36 34.0	−35 36 42	1321 ± 45	−109 ± 60	39
Cancer	08 17 30.0	+21 14 00	4939 ± 80	61 ± 172	26
Antlia	10 27 45.0	−35 04 11	3120 ± 100	185 ± 109	27
Hydra	10 34 27.7	−27 16 26	4075 ± 50	−320 ± 142	25
N3557	11 07 35.0	−37 16 00	3318 ± 57	199 ± 155	11
A1367	11 41 54.0	+20 07 00	6735 ± 88	62 ± 191	35
Ursa Major	11 54 00.0	+48 53 00	1101 ± 40	−425 ± 56	30
Cen 30	12 46 06.0	−41 02 00	3322 ± 150	310 ± 98	38
A1656	12 57 24.0	+28 15 00	7185 ± 68	212 ± 210	41
ESO 508	13 09 54.0	−23 08 54	3210 ± 100	417 ± 128	17
A3574	13 46 06.0	−30 09 00	4817 ± 30	−26 ± 174	20
A2197[a]	16 26 30.0	+41 01 00	9162 ± 100	−204 ± 384	25
Pavo II	18 42 00.0	−63 20 00	4444 ± 70	137 ± 163	18
Pavo	20 13 00.0	−71 00 00	4055 ± 100	80 ± 219	10
MDL59	22 00 18.0	−32 14 00	2317 ± 75	−503 ± 120	23
Pegasus	23 17 42.6	+07 55 57	3519 ± 80	−186 ± 180	17
A2634	23 35 54.9	+26 44 19	8895 ± 79	−136 ± 270	26
A2666	23 48 24.0	+26 48 24	7776 ± 84	−156 ± 459	9
		SCII			
A2806	00 37 54	−56 26 00	7867 ± 80	464 ± 382	10
A114	00 51 12	−21 58 00	17144 ± 143	−578 ± 1111	9
A119	00 53 48	−01 32 00	13141 ± 85	−275 ± 988	6
A2877	01 07 36	−46 10 00	6974 ± 58	−104 ± 489	7
A2877b	01 07 36	−46 10 00	9040 ± 48	307 ± 634	5
A160	01 10 12	+15 15 00	12072 ± 141	280 ± 977	6
A168	01 12 36	−00 01 00	13049 ± 58	679 ± 725	9
A194	01 23 00	−01 46 00	5037 ± 37	−216 ± 302	13
A260	01 49 00	+32 55 00	10664 ± 111	−1175 ± 835	9
A397	02 54 12	+15 45 00	9594 ± 78	553 ± 630	14
A3193	03 56 54	−52 29 00	10522 ± 112	450 ± 668	6
A3266[b]	04 30 30	−61 35 00	17782 ± 61	−2700 ± 2345	2
A496	04 31 18	−13 21 00	9809 ± 59	566 ± 513	9
A3381[b]	06 08 06	−33 35 00	11510 ± 48	798 ± 868	4
A3407	07 03 42	−49 00 00	12861 ± 136	−179 ± 1235	8
A569	07 05 24	+48 42 00	6011 ± 43	−157 ± 280	13
A634	08 10 30	+58 12 00	7922 ± 42	−222 ± 469	8
A671	08 25 24	+30 35 00	15307 ± 194	−120 ± 838	9
A754[b]	09 06 24	−09 26 00	16599 ± 82	−92 ± 3294	3
A779	09 16 48	+33 59 00	7211 ± 101	−100 ± 320	14
A957	10 11 24	−00 40 00	13819 ± 120	−866 ± 974	6
A1139	10 55 30	+01 46 00	12216 ± 71	694 ± 629	11
A1177	11 06 48	+21 58 00	10079 ± 81	51 ± 689	6
A1213	11 13 48	+29 32 00	14304 ± 90	744 ± 899	6
A1228	11 18 48	+34 36 00	10794 ± 34	−603 ± 517	13
A1314	11 32 06	+49 19 00	9970 ± 154	−134 ± 582	8
A3528[b]	12 51 36	−28 45 00	16770 ± 139	−1441 ± 1703	3
A1736	13 24 06	−26 51 00	10690 ± 50	−49 ± 887	6
A1736b[b]	13 24 06	−26 51 00	14017 ± 84	186 ± 1121	4
A3558	13 25 06	−31 14 00	14626 ± 44	678 ± 981	8
A3566	13 36 06	−35 18 00	15636 ± 87	236 ± 837	9
A3581[b]	14 04 36	−26 47 00	7122 ± 126	−139 ± 659	4
A1983b	14 47 24	+17 06 00	11524 ± 62	1291 ± 589	8
A1983	14 50 24	+16 57 00	13715 ± 45	429 ± 1165	7
A2022	15 02 12	+28 37 00	17412 ± 72	−1134 ± 1067	8
A2040	15 10 18	+07 37 00	13616 ± 61	212 ± 839	10
A2063	15 20 36	+08 49 00	10605 ± 53	680 ± 398	18

TABLE 1—*Continued*

Cluster	R.A. (1950)	decl. (1950)	cz_{cmb}	V_{pec}	n
A2147	16 00 00	+16 02 00	10588 ± 85	303 ± 427	19
A2151	16 03 00	+17 53 00	11093 ± 59	312 ± 424	22
A2256	17 06 36	+78 47 00	17401 ± 132	56 ± 998	8
A2295b[b]	17 59 00	+69 16 00	18633 ± 82	−408 ± 1587	4
A2295	18 00 18	+69 13 00	24554 ± 199	−1145 ± 1448	10
A3656	19 57 12	−38 40 00	5586 ± 64	−72 ± 375	6
A3667[b]	20 08 30	−56 58 00	16477 ± 94	−3034 ± 1582	4
A3716	20 47 54	−52 54 00	13618 ± 64	359 ± 581	14
A3744	21 04 18	−25 41 00	11123 ± 89	−150 ± 578	11
A2457	22 33 12	+01 13 00	17280 ± 110	−144 ± 946	9
A2572	23 15 54	+18 28 00	11495 ± 100	436 ± 803	5
A2589	23 21 30	+16 33 00	11925 ± 95	−194 ± 804	6
A2593	23 22 00	+14 22 00	12049 ± 86	−761 ± 605	12
A2657	23 42 18	+08 52 00	11662 ± 137	32 ± 844	5
A4038	23 45 06	−28 25 00	8713 ± 63	68 ± 534	7

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[a] Includes A2197 and A2199.

[b] Excluded from statistical analysis.

cz_{cmb} and the peculiar velocity V_{pec} in the CMB reference frame (after Giovanelli et al. 1998b; Dale 1998) and the number N of galaxies in each cluster with TF measurements. We compute a distance $hd = (cz_{cmb} - V_{pec})/100$ and a deviation from Hubble flow $\Delta H_0/H_0 = V_{pec}/(cz_{cmb} - V_{pec})$.

The total error on the peculiar velocity of each cluster, as listed in Table 1, includes several components, arising from (1) photometric and spectroscopic observational errors; (2) uncertainties in the corrections applied to observed parameters; (3) uncertainties in the cluster redshifts; (4) the scatter in the TF relation; (5) uncertainties in the TF template relation slope and zero point, especially that deriving from the assumed standard of rest. We discuss point 5 in greater detail in the next section. The other sources of error are extensively discussed in the data papers mentioned above.

3. TEMPLATE RELATION ACCURACY AND ITS EFFECT ON THE MONOPOLE MOMENT

TF peculiar velocities are derived as offsets from a template relation, which in its simplest form is defined by two parameters: a slope and a zero point. Errors on both the zero point and on the slope translate into spurious, geocentric peculiar velocity fields. For example, an error of 0.05 mag in the zero point would simulate a slowing down or speeding up of the Hubble expansion by 2.3%. As for the effect of an error on the TF slope, if the template relation is, for example, too steep—i.e., for a given velocity width that is broader than some fiducial value the template predicts too bright a magnitude—then high-width galaxies will preferentially yield positive magnitude offsets. The opposite will be true for low-width galaxies. Since low-width galaxies are intrinsically faint, they are more likely to be present in nearby samples than in more distant ones; thus nearby samples fitted with too steep a TF template relation exhibit a net negative magnitude offset, which translates into a spurious outflow. The effect of unrecognized TF calibration errors can then be misconstrued as a monopole perturbation, and thus as a geocentric Hubble flow distortion.

The TF template relation is determined internally for a cluster sample. In the case of SCI, it was obtained by assuming that the subset of clusters farther than 40 h^{-1} Mpc has a globally null monopole (G97b). Dale (1998) obtained an SCII template by assuming that the set of clusters has a globally null monopole and adopting the same TF slope as for the SCI sample. As discussed in G97b, given a number N of clusters the uncertainty on the TF zero point of the resulting template cannot be depressed indefinitely by increasing the average number $\bar{n}$ of galaxies observed per cluster and taking advantage of the $\bar{n}^{-1/2}$ statistical reduction of noise on the mean. That is because a "kinematical" or "thermal" component of the uncertainty depends on the number N, the distribution in the sky, and the peculiar velocity distribution function of the clusters used. In SCI, for example, the statistical uncertainty deriving from the total number of galaxies observed ($\bar{n} \times N$) is exceeded by the kinematic uncertainty, which is quantified as follows. For a sample of N clusters of average redshift $\langle cz \rangle$, the most probable systematic error on the template relation zero point is $|\Delta m| \simeq 2.17\langle V_{pec}^2\rangle^{1/2}\langle cz\rangle^{-1}N^{-1/2}$, where $\langle V_{pec}^2\rangle^{1/2}$ (expressed in the same units as cz) is the line-of-sight rms cluster peculiar velocity, about 300 km s^{-1} (G97b; Giovanelli et al. 1998b; Dale 1998). This quantity is about 0.04 mag for SCI, while it is only 0.01 mag for SCII because of the larger mean distance and number of clusters of the latter. Since the total number of galaxies involved in the two samples is comparable, the zero point of the SCII template is thus more accurate than that of SCI. On the other hand, the peculiar velocities of individual clusters in SCII are less accurate than those in SCI. We note that the kinematical (or thermal) component of the uncertainty is larger for SN peculiar velocities than for our cluster ones. That is because the amplitude of the distribution function of peculiar velocities among individual galaxies—the hosts of SNe—is larger than that of clusters, as the former is amplified by the variance associated with fluctuations on small scales.

In the case of both SCI and SCII, a direct TF template relation was obtained, using the approach described in G97b. The data for each cluster offset was corrected for the effect of an incompleteness bias. The zero points of the two templates were found to agree to within 0.015 mag (SCII being fainter by that amount).

In this paper, we combine the SCI and SCII samples, and use them to investigate the presence of large-scale variations in the monopole of the Hubble flow. Note that such combined sample cannot be used for the detection of a geocentric deviation from smooth Hubble flow *which would extend over the full volume sampled by the total cluster set, as it would be null by design.* The merged cluster data set can, however, be used to detect changes in $\Delta H_0/H_0$ that would take place well within the volume spanned by the data. The amplitude of the change (say a step in $\Delta H_0/H_0$) that can be detected depends on the location of the presumed step and on the accuracy with which the match in the TF zero point between the SCI and SCII samples is established.

1. For our cluster sample, a step would be ideally situated between 70 h^{-1} and 110 h^{-1} Mpc, in order to maximize the chance of detection, because it would split the cluster sample into two roughly equal parts. The SCI + SCII sample is thus well suited to test the Z98 result.

2. The internal accuracy of the zero point for the SCI sample is 0.025 mag; however, since it is based on a subset of 14 clusters farther than 40 h^{-1} Mpc, the kinematical uncertainty of 0.04 mag, as mentioned above, increases the total uncertainty to 0.045 mag. The total uncertainty on the zero point of SCII, because it involves a larger number of more distant clusters, is only 0.025 mag; the kinematical component in this case is only 0.01 mag. Note for comparison that a 6.5% step in $\Delta H_0/H_0$ would translate in a 0.13 mag differential TF offset between clusters on each side of the step. It is also useful to point out that each of the two samples was completed over many observing runs, both in their photometric and spectroscopic parts, and a number of objects were observed in more than one run. Mismatches in the cross-run and cross-cluster calibrations thus have been minimized and their impact on the final error budget is included in the statistical estimate given above.

3. The small overlap in distance between SCI and SCII occurs near 70 h^{-1} Mpc, which is the edge of the Hubble bubble suggested by Z98 (four clusters in SCI are farther than $cz = 7000$ km s^{-1}, while four in SCII are within that redshift). We thus need to establish the impact of the accuracy of the match between the two samples' zero points, on the estimation of the likelihood of a Hubble bubble. We return to this point in § 4.1.

4. GEOCENTRIC HUBBLE DEVIATIONS

Using the data in Table 1, and forcing the template TF zero point to be the same for SCI and SCII, we obtain Figure 1, a plot of the Hubble deviation versus the distance. In the upper panel of Figure 1, we display the individual data points, while in the lower one we show the errors associated with each measurement. Stars refer to the SCI sample, while circles refer to SCII. Eight clusters, footnoted in Table 1, are plotted in Figure 1 as unfilled symbols: their peculiar velocities have been obtained from fewer than five TF measurements and are thus very unreliable. The latter are not used in the following statistical analyses.

The plot presented in Figure 1 is similar to that in Figure 1 of Z98. For comparison, we have included the outline of the Z98 step as a dashed line, which extends from 0 to 70 h^{-1} Mpc distance, at the level of $\Delta H_0/H_0 = 0.065$. We note immediately that the Z98 proposal of a Hubble bubble is not corroborated by the cluster data. We also note that at distances nearer than ~ 30 h^{-1} Mpc even modest peculiar velocities constitute a sizable fraction of cz, thus amplifying and distorting the values of $\Delta H_0/H_0$. The implied deviation from Hubble flow they reveal is of scarce interest, as they apply to too small, too sparsely sampled a volume.

Next, we test for the presence of a step at 70 h^{-1} Mpc distance, of the kind suggested by Z98, and we search for the signature of other possible, geocentric large-scale fluctuations in the Hubble flow.

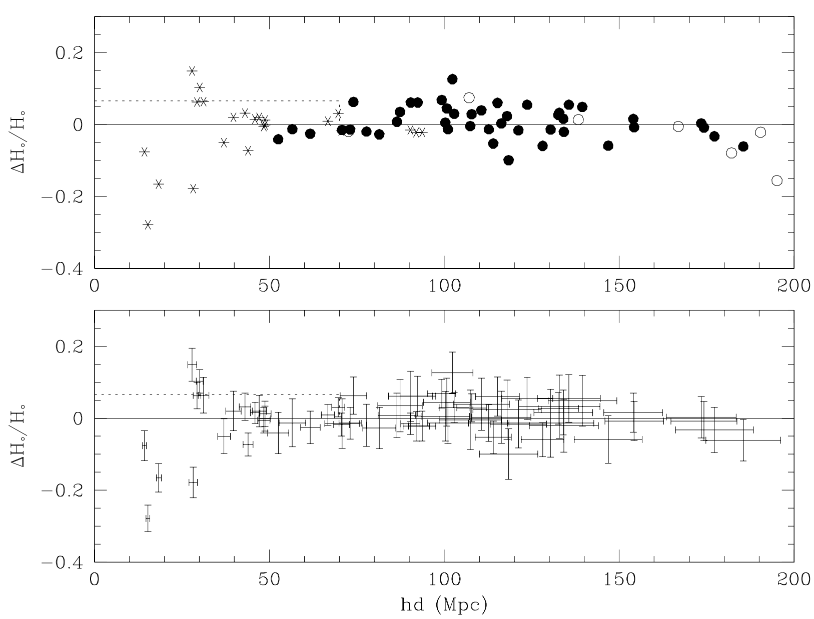

FIG. 1.—Deviations from Hubble flow plotted vs. TF distance for the clusters listed in Table 1. *Upper panel:* Clusters in SCI (*stars*) and SCII (*circles*). Among the latter, filled symbols identify clusters with distance determinations based on $n > 4$ individual galaxy TF distances, while unfilled ones refer to clusters with $n \leq 4$, the peculiar velocities of which are deemed least trustworthy and are not used in the statistical analysis; their names are footnoted in Table 1. The horizontal dashed line identifies the acceleration of 6.5% in the Hubble flow within $hd = 70$ Mpc claimed by Z98. *Lower panel:* Error bars associated with each starred or filled data point.

4.1. *Test for a Hubble Bubble*

We consider whether a step is present in $\Delta H_0/H_0$ at 70 h^{-1} Mpc, by taking the difference in the average of $\Delta H_0/H_0$ between 30 h^{-1} and 70 h^{-1} Mpc, and the corresponding average at distances higher than 70 h^{-1} Mpc. That difference is 0.010 ± 0.012, if individual clusters are weighed by their errors in $\Delta H_0/H_0$, and 0.007 ± 0.012 if equal weight averages are computed. The uncertainty of this result can however be affected by a number of systematic errors, which exceed the statistical estimate given above; in the following we discuss them one by one.

Kinematic zero point mismatch.—First, we consider the impact of the systematic mismatch between the TF template zero points of the two samples, as discussed in part (3) of § 3. We can evaluate the impact of that uncertainty on the determination of the amplitude of a possible step at 70 h^{-1} Mpc by offsetting by $\pm(0.04^2 + 0.01^2)^{1/2} = \pm 0.04$ mag the SCI and SCII samples with respect to each other, computing in each case the amplitude of the step (note that there are SCI and SCII clusters on both sides of the step). The results are respectively 0.022 and -0.004 mag. It can thus be inferred that the impact on the uncertainty of the step, produced by a possible systematic error in the match between zero points for the two samples, is about 0.03 mag or 1.5%.

Differential Malmquist bias.—Malmquist bias corrections have not been applied to the cluster peculiar velocities. If such a correction were the same for all the clusters, it would have no impact on the detectability of a Hubble bubble step. However, since the more distant clusters of SCII each include a smaller number of galaxies with TF measurements, the impact of a possible differential Malmquist bias between SCI and SCII needs to be explored. As discussed in Giovanelli et al. (1998b), the Malmquist bias can be estimated with adequate accuracy in the "homogeneous" assumption, i.e., that the clusters' distribution in space is Poissonian and shown to be quite small. The Malmquist bias correction in that case is $e^{3.5\Delta^2} - 1$, where $\Delta =$ dex $(0.2\epsilon/n^{1/2}) - 1$, with ϵ the scatter in magnitudes about the TF relation (about 0.35 mag) and n the number of galaxies with TF measurements per cluster. For example, for a cluster with 10 galaxies with TF measurements, the average for SCII, the Malmquist bias correction is 1.0% on the distance. In the case of SCI, the average number of galaxies with TF measurements per cluster is about 16. In that case the Malmquist bias correction is 0.7% on the distance. Neglecting to apply a Malmquist bias correction thus introduces a possible bias with an amplitude of 0.003 in $\Delta H_0/H_0$.

Template relation slope.—The same template relation slope has been used for both SCI and SCII, as discussed in Dale (1998). The error on the determination of that slope is given in G97b, as 0.12 on a slope of -7.68, or 1.6%. If there were a significant difference in the distribution of galaxies as a function of velocity width, between nearby and more distant clusters, the uncertainty on the slope would introduce a systematic bias in the distances. To estimate the amplitude of that bias, we binned galaxies as a function of width, separately for the clusters within and beyond 70 h^{-1} Mpc, and for each group estimated the average magnitude offset introduced by an error in the slope of 1.6%; in doing so, we assumed that the zero point, i.e., the value of the template relation at $\log W = 2.5$, is correct. The resulting TF offset uncertainty between the two groups is 0.0055 mag, or 0.0025 on the distance.

Evolution.—Some authors (Rix et al. 1997; Simard & Pritchet 1998) have claimed substantial evolution in the mass-to-light ratio of spiral galaxies between $z = 0$ and relatively modest redshifts $s \sim 0.4$, while others (Vogt et al. 1997; Bershady 1996; Dale, Usón, & Giovanelli 1999b) find no such effect. Evolution would translate into a shift of the TF relation zero point. While this issue is still quite uncertain, we can estimate the possible impact of evolution, assuming a (rather generous) shift of 1 mag between $z = 1$ and $z = 0$. The difference in z between the clusters within 70 h^{-1} Mpc and those farther away is $\simeq 0.02$; thus, a possible shift of 0.02 mag or 0.01 in distance would be possible. The direction of this relative shift would be that of a gradual brightening of the higher redshift galaxies and therefore increasing their average $\Delta H_0/H_0$. Probably overestimating it, we conclude that the uncertainty associated with this effect is 0.01 in the distance.

In Table 2, we give a summary of the components of uncertainty with which the SCI+SCII merged sample can be used to identify a possible step in the Hubble flow at 70 h^{-1} Mpc.

Thus our estimate of the amplitude and significance of a step in the Hubble flow at 70 h^{-1} Mpc is

$$\frac{\Delta H_0}{H_0} = 0.010 \pm 0.022 \ . \tag{1}$$

For a two-zone model, which includes an inner void out to 70^{-1} Mpc and an outer region expanding at the Hubble rate, Z98 report an amplitude of 0.065 ± 0.021; such a void is not apparent in our data, in which a 6.5% step would be a 3 σ event. We remark however that, compounding our estimated error with that reported in Z98, the difference between the two results is 0.055 ± 0.030.

The Hubble distortion reported by Z98 reduces to 0.053 ± 0.022 in a three-zone model, where an inner underdense sphere of 70 h^{-1} Mpc is surrounded by an overdense shell between 70 and 105 h^{-1} Mpc; for the outer shell, Z98 report an inflow of $\Delta H_0/H_0 = -0.059 \pm 0.027$. For the latter region, between 70 and 105 h^{-1} Mpc, our data yields $\Delta H_0/H_0 = +0.020 \pm 0.018$. The difference between our

TABLE 2

STEP UNCERTAINTY BUDGET

Parameter	Value (%)
Statistical distance error	1.2
Kinematic zero point mismatch between SCI and SCII	1.5
Malmquist bias	0.3
Template slope uncertainty	0.3
Evolution	1.0
Total	2.2

and the Z98 results, compounding the reported errors, is 0.079 ± 0.032.

4.2. *Other Geocentric Deviations*

We search for the signature of other possible large-scale fluctuations in the Hubble flow, adopting a similar χ^2 minimization analysis to that carried out by Z98. We minimize

$$\chi^2 = \sum_i \{\log [1 + (\Delta H_0/H_0)_i] - \log [1 + (\Delta H_0/H_0)_{\rm model}]\}^2/\sigma_i \,, \quad (2)$$

where $(\Delta H_0/H_0)_i$ are the values plotted in Figure 1 and $(\Delta H_0/H_0)_{\rm model}$ is a model with a constant departure from zero in $\Delta H_0/H_0$ between two arbitrary distances hd_1 and hd_2, is equivalent to that expressed in equation (2) of Z98. σ_i is the estimated error on log $[1 + (\Delta H_0/H_0)_i]$. The strongest signature for a departure from Hubble flow consistent with the SCI + SCII cluster data is a (very marginal) step of amplitude $\Delta H_0/H_0 = 0.027 \pm 0.023$ centered at $hd = 101$ Mpc and 33 Mpc wide. The boundaries of the region are very "soft." In the calculations, we impose that the width of the perturbed region should be no less than 20 Mpc, including only 61 clusters with hd between 30 and 200 Mpc and excluding the eight clusters with poor sampling ($n < 5$) plotted as open symbols in Figure 1 and footnoted in Table 1.

5. CONCLUSIONS

Z98 have cogently argued that a region of 70^{-1} Mpc radius could be underdense by $\sim$20%—which is the amount necessary to produce a suggested local acceleration of 6.5% of the Hubble flow—without unreasonably stretching the plausible amplitude range of cosmological density fluctuations. One would be left, of course, with the nagging coincidence of the nearly central location of the Local Group in the void (a circumstance that would also be at some odds with the fairly large peculiar velocity of the Local Group of some 620 km s^{-1}, as indicated by the CMB dipole). Our data give an amplitude for a possible Hubble flow distortion within 70 h^{-1} Mpc of $\Delta H_0/H_0 = 0.010 \pm 0.022$.

In a three-zone model, Z98 suggest that an overdense shell between 70^{-1} and 105 h^{-1} Mpc may be affected by an inflow of $\Delta H_0/H_0 = -0.059 \pm 0.027$. For that region, our data yields $\Delta H_0/H_0 = 0.020 \pm 0.018$.

The distortion of largest amplitude, consistent with our data, is $\Delta H_0/H_0 = 0.027 \pm 0.023$ centered at $hd = 101$ Mpc and extending over a shell some 30 h^{-1} Mpc thick.

The results of this paper are consistent with those on the peculiar velocity field as traced by the SFI sample of field spirals: its dipole converges to that of the CMB dipole, both in amplitude and apex direction, within about 50 h^{-1} Mpc (Giovanelli et al. 1998a). We conclude that, at distances in excess of $\sim$50 h^{-1} Mpc, the cluster peculiar velocity data are consistent with a picture in which the average Hubble flow is remarkably smooth.

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