COSMOGONY AND THE VERY NEARBY GALAXIES*

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Abstract

The sample of very nearby galaxies, at cosmological redshifts $cz \lesssim 400$ km s^{-1}, is a particularly useful testing ground for pictures of how galaxies formed, because the space distribution can be examined well into the faint end of the luminosity function, and the relative motions can be estimated with only small corrections for cosmological redshift. I argue that the systematics of the positions and motions of these very nearby galaxies pose interesting challenges for all the commonly discussed pictures for how galaxies formed.

Résumé

L'échantillonage de galaxies très proches, à déplacement cosmologique vers le rouge d'à peu près $cz \lesssim 400$ km s^{-1}, est un moyen particulièrement utile pour tester les images de formation de galaxies, parce que la distribution spatiale peut être examinée jusqu'à bien dans l'extrémité à valeurs faibles de la fonction de luminosité, et les mouvements relatifs peuvent être estimés seulement avec des corrections faibles pour le déplacement cosmologique vers le rouge. Je soutiens que la systématique des positions et des mouvements de ces galaxies très proches présentent des défis intéressants pour toutes les images que l'on discute ordinairement au sujet de la formation de galaxies.

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1. Introduction. The search for clues to how galaxies formed naturally leads us to concentrate on objects at high redshifts, because that offers the chance to observe young systems, galaxies as they were in the distant past, perhaps even galaxies in the process of forming. The evidence to be gleaned from galaxies at low redshifts is less direct, because there has been more time for evolution to erase the conditions that prevailed when galaxies formed, but that may be compensated for in part by the fact that low redshift galaxies can be observed in considerably greater detail. I consider here some properties of the very nearby galaxy sample, at cosmological redshifts $z \lesssim 0.001$, that might test our ideas of how galaxies formed.

Just two sets of observations will be discussed. As reviewed in section 2, giant and dwarf galaxies alike strongly avoid the very nearby voids, and there is nothing manifestly peculiar about the few galaxies found in the sparsely populated regions. Second, the relative peculiar velocities generally are smaller than the Hubble velocity and considerably less than the mean peculiar velocity of the sample. In

*The tenth Petrie Lecture, sponsored by the Canadian Astronomical Society, delivered at Montreal, June 28, 1989.

J. Roy. Astron. Soc. Can., Vol. 83, No. 6, 1989

section 3, I argue that these observations cause problems for all the currently popular theories for galaxy formation: biased cold dark matter, unbiased gravitational instability, cosmic strings, and explosions.

2. *Observations*. The maps in figures 1 and 2 assume redshift (with the conventional correction to the Local Group, 300 cos b sin l km s^{-1}) is directly proportional to distance. Peculiar motions distort the map, but the indication from figure 3 below is that that does not obscure the main features. The map is plotted in de Vaucouleurs supergalactic coordinates (de Vaucouleurs, de Vaucouleurs and Corwin 1977). Many of the local galaxies are on a sheet, the plane of the Local Supercluster, at supergalactic $Z \sim 0$. The maps show all galaxies in the Huchra (1989) ZCAT redshift catalogue in a cube $800 \times 800 \times 800$ km sec^{-1} centred on the Local Group and outside a 6° radius circle centred on the Virgo Cluster. (Where a conversion to usual distance units is useful, I shall write the Hubble constant as $H = 100h$ km s^{-1} Mpc^{-1}. Thus the cube width is $8h^{-1}$ Mpc.) We shall be interested in the relative distributions of giant and dwarf galaxies. As a rough way to distinguish the two, I have plotted separately galaxies with NGC names in figure 1; the rest, which are mainly less luminous galaxies, in figure 2. For another view see plate 14 of the *Nearby Galaxy Atlas* (Tully and Fisher 1987).

The central points to note (as Brent Tully has emphasized in private conversations) are that the very nearby galaxies are strongly clustered and that the distributions of giants and dwarfs are quite similar. Obscuration in our galaxy removes a wedge roughly centred on $Y = 0$. The empty regions off the plane of the Local Supercluster at $Z \sim 0$ and away from this wedge are voids, with low densities of giants and dwarfs. The similarity of the space distributions of giant and dwarf galaxies is well documented (Binggeli 1989 and references therein); the interesting feature of the very nearby galaxy sample is that the effect is seen well into the faint end of the luminosity function. Some details are discussed in Section 3a below.

Figure 3 shows the Hubble diagram, redshift as a function of distance, for nearby galaxies. The distances are derived from the Aaronson *et al.* (1982) catalogue of 21 cm line widths Δv_c and infrared apparent magnitudes. As Tully and Fisher (1977) showed, Δv_c is a useful predictor of absolute magnitude, which with the apparent magnitude gives the distance estimate. The calibration, from Aaronson *et al.* (1986), is based on galaxies at redshifts $cz \sim 5000$ to 10000 km sec^{-1}, whose peculiar velocities are assumed to be small compared with their cosmological redshifts. The redshifts v_c have been corrected for the motion of our Galaxy relative to the mean defined by the sample at distances <900 km s^{-1}. (This is not significantly different from the standard correction to the motion of the Local Group.) It will be noted that the slope of the line, which is the Hubble relation, is not an adjustable parameter: it has been scaled from the redshifts of more distant galaxies. For more details of this figure see Peebles (1988).

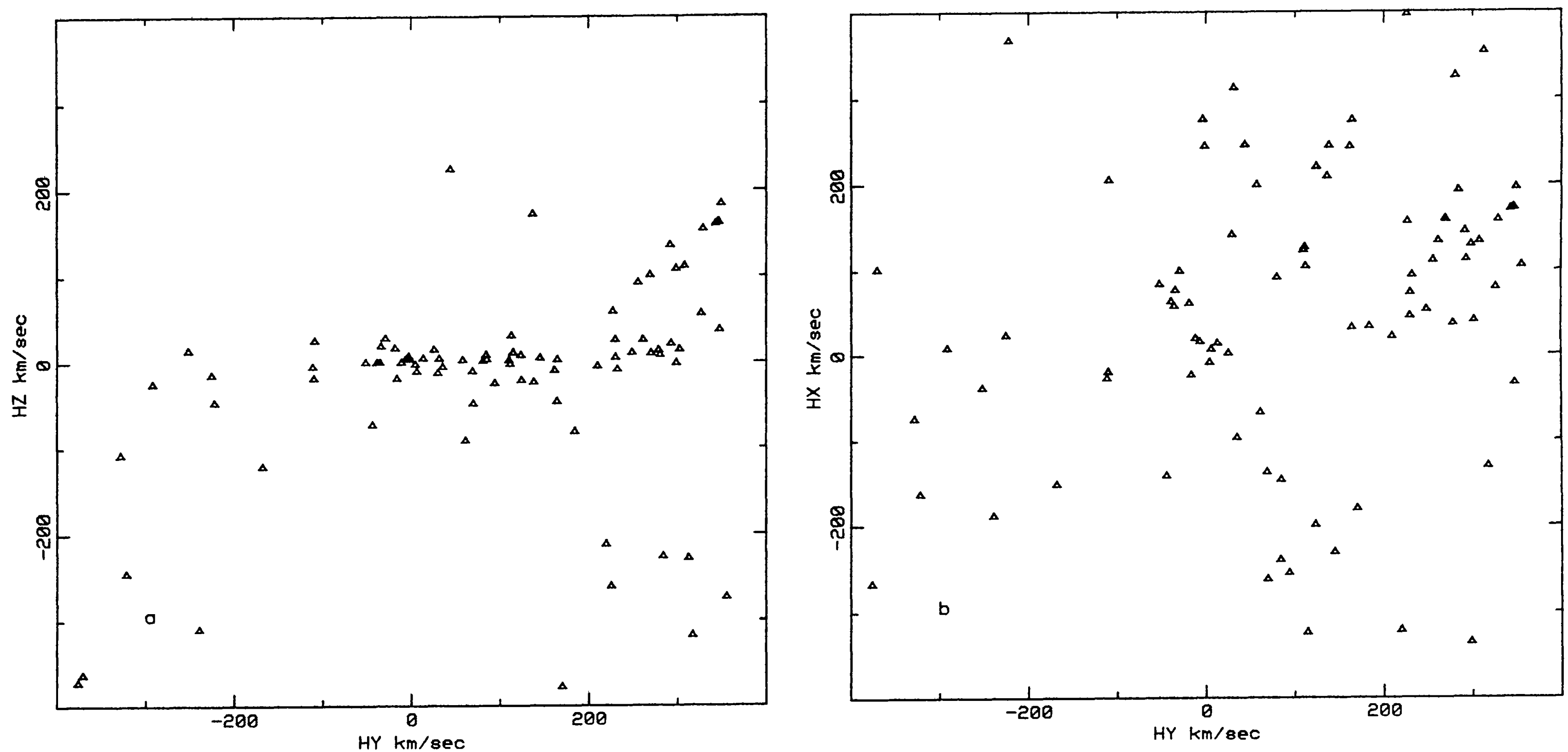

FIG. 1—The space distribution of the very nearby NGC galaxies. Galaxy distances are assumed to be proportional to redshift relative to the Local Group at the centre of the maps. The maps are plotted in de Vaucouleurs supergalactic coordinates, with the plane of the Local Supercluster at $Z \sim 0$, and the Virgo cluster toward positive Y at $X \sim Z \sim 0$. The map shows all nearby galaxies with NGC names in Huchra's (1989) ZCAT redshift catalogue and outside a 6° radius circle at the Virgo Cluster. In figure 1a the plane of the Local Supercluster is normal to the plane of the map; figure 1b shows the plane of the Local Supercluster.

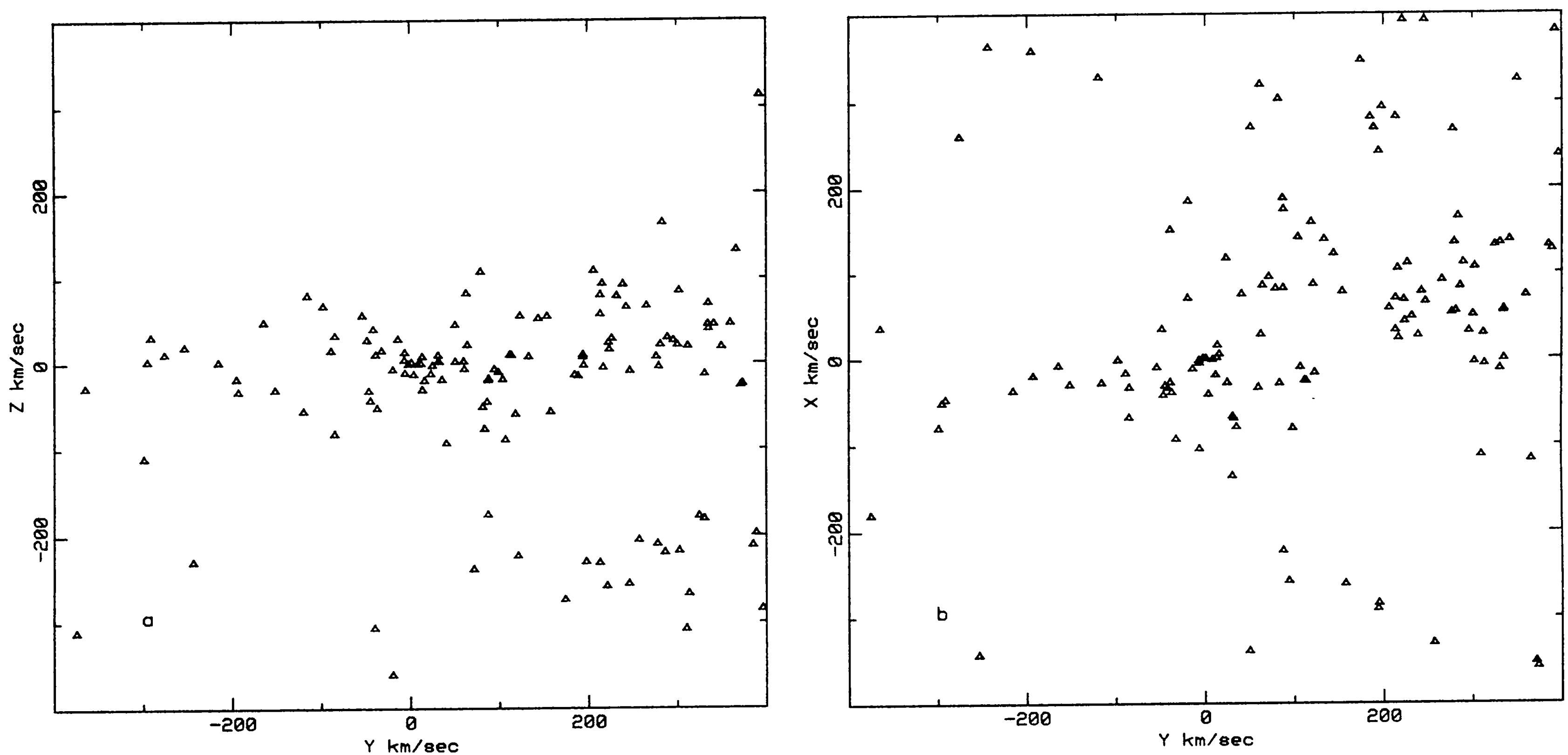

FIG. 2—The same as figure 1 for very nearby galaxies without NGC names.

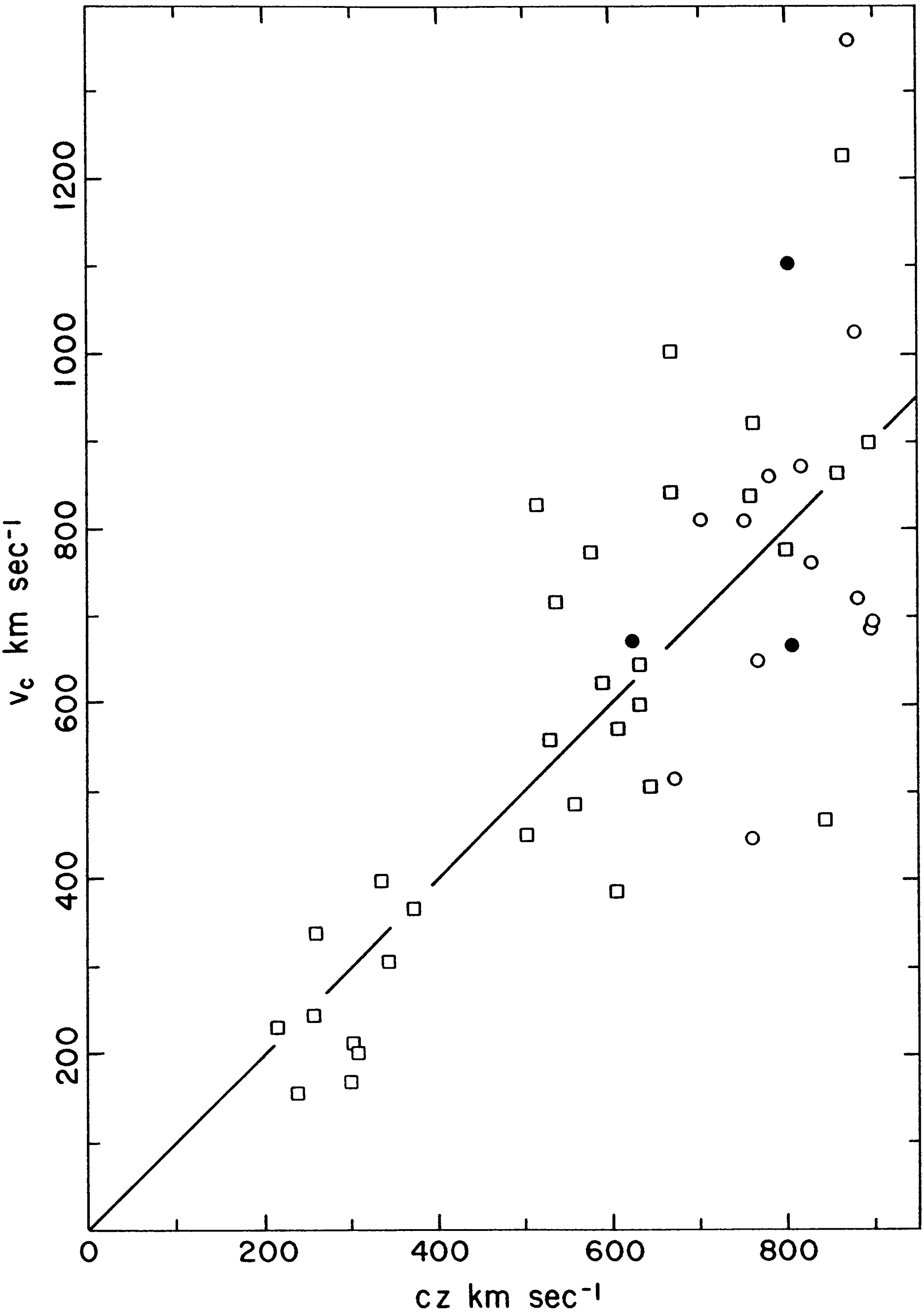

FIG. 3—The redshift-distance relation for nearby galaxies. The distance, cz/H, is estimated from the infrared Tully-Fisher relation calibrated to the redshifts of more distant galaxies. The redshift v_c is corrected to the mean motion of the galaxies at $cz < 900$ km s^{-1}. The galaxies at distances $|Z| < 2.5h^{-1}$ Mpc from the plane of the Local Supercluster are plotted as squares, the galaxies at $Z > 2.5h^{-1}$ Mpc as filled circles, and those at $Z < -2.5h^{-1}$ Mpc as open circles.

The main point of figure 3 is that the galaxies (including the ten with infrared Tully-Fisher distances <400 km s^{-1}) all are drifting away from us at close to the rate expected for pure Hubble flow, recession velocity proportional to distance. Roughly the same effect is well known to apply to all nearby galaxies: because very few galaxies outside the Virgo Cluster and Local Group have negative redshift (corrected to the Local Group), we know that outside these two regions peculiar velocities relative to the Local Group are less than the cosmological Hubble velocity. This nearly homogeneous expansion is in striking contrast to the extremely clumpy space distribution seen in figures 1 and 2.

It is also curious that the very nearby galaxies have a mean peculiar velocity of about 600 km s^{-1}, well above the scatter in their relative velocities. This is based on the dipole anisotropy of the 2.8 K cosmic background radiation (CBR) (Wilkinson 1988). Two pieces of evidence argue that the dipole is correctly interpreted as the result of our motion rather than an intrinsic anisotropy of the universe. First, under the velocity interpretation, distant galaxies ought to define a rest frame consistent with that of the CBR. Aaronson *et al.* (1986) find that the rest frame defined by clusters of galaxies at redshifts 4000 to 10000 km s^{-1} agrees with the CBR frame to one standard deviation ~200 km s^{-1}. This indicates that the motion of the Local Group relative to a universal reference frame has been detected, at ~3 standard deviations. Second, if galaxies trace the large-scale mass distribution, we ought to be able to identify the mass fluctuations that generated our motion. Again, this is observed: if the mass density is high where the number density of galaxies is high, then the peculiar gravitational acceleration at the Local Group that originates in mass fluctuations within distances $Hr \sim 4000$ km s^{-1} produces a local peculiar motion with roughly the right direction (Yahil 1988 and references therein). The derived velocity has about the right magnitude if the mean mass density is somewhere between that indicated by local dynamical estimates and the Einstein-de Sitter value (density parameter Ω between ~0.1 and 1). I conclude that these two sets of observations make a strong case for the velocity interpretation of the CBR dipole anisotropy.

3. *Theoretical Concepts.*

a) Cold Dark Matter and Biased Galaxy Formation. The simplest cosmology, and hence arguably the one to prefer, is the Einstein-de Sitter model, with negligibly small space curvature and cosmological constant. Dynamical estimates of the mean mass density, based on the assumption that the mass distribution is traced by galaxies, are ~10 to 30 per cent of the Einstein-de Sitter value (Peebles 1986). The biasing concept invented to account for this assumes the bulk of the mass is outside groups and clusters and so not detected in the studies of the dynamics of these systems.

The astrophysical biasing picture developed along with the study of galaxy formation out of cold dark matter (hypothetical mass that does not interact with ordinary matter and radiation, so it moves under gravitational forces alone, and with negligible primaeval pressure). For early discussions see Kaiser (1986), Bardeen (1986), and Davis *et al.* (1985). In the astrophysical biasing picture, galaxies are strongly clustered because they formed in islands, the voids between the islands containing considerable mass not incorporated in the massive halos of bright galaxies. Because galaxies are assumed to have grown by gravitational instability out of gaussian random initial mass density fluctuations, one must imagine that the voids also contained seeds of galaxies, with number densities comparable to the number densities of galaxies in the islands. Galaxy formation in the voids must have been suppressed; perhaps seeds in the voids ripened at a later epoch than in the islands, when conditions for star formation were less propitious.

This picture offers an elegant explanation for the smooth relative velocity field in figure 3: velocities are not strongly perturbed, because the mass distribution is nearly smooth, the galaxies being just a clumpy distribution of highlights. There is however a problem, arising from the similar space distributions of bright and faint galaxies.

In the unobscured parts of the projected distributions in figures 1 and 2, perhaps a third of the volume is occupied at fairly high number density, by a total of 216 galaxies. Thus under the astrophysical biasing picture there would some 500 seeds of unborn galaxies in the observed voids in this map. (Another way to get this number is to note that dynamical estimates reveal ~10 to 30 per cent of the Einstein-de Sitter mass density, so one wants to suppress galaxy formation in ~70 to 90 per cent of the mass). What became of these seeds in the voids? Whatever inhibited their development into observable galaxies could not have been completely efficient, and indeed there are galaxies outside the dense islands. But we surely would expect that a galaxy in a void bears signs of what must have been a traumatic youth: stunted growth, deformed and irregular parts. Thus Rees (1986) and Bond *et al.* (1988) propose that the dark potential wells of unborn galaxies could trap the hydrogen clouds that produce the forest of Lyα lines in the spectra of high redshift quasars. The potential wells would have to be still present in the voids. Might the nearby ones be visible? Dekel and Silk (1986) note that these potential wells might reasonably be expected to produce a generation of dwarf galaxies.

White *et al.* (1988) find evidence that galaxies with lower circular velocities do prefer regions with fewer neighbours within distances $\sim 1h^{-1}$ Mpc, consistent with results of numerical simulations of the biased cold dark matter theory (*e.g.* Melott and Fry 1986, and White *et al.* 1987). A similar effect might be seen in figures 1a and 2a: the NGC galaxies define a somewhat tighter plane at $Z \sim 0$. However, the more direct and striking point was emphasized by Binggeli (1989): the voids defined by giants contain few dwarfs. The very nearby galaxy sample allows us to add some interesting details.

The two galaxies in figure 1 at $HZ \sim 200$ km s^{-1} and $HY \sim 0$ to 150 km s^{-1} are at

$HX \sim 200$ km s^{-1}; the pair might be classified as a loose group with an unusually low ratio of faint to bright galaxies. The galaxy at smaller Y is NGC6946. It is an Arp (1966) peculiar galaxy, because a supernova was seen in it. Sandage and Bedke (1988) show a magnificent image of this galaxy; it looks like an ordinary large face-on spiral galaxy. The other, NGC6503, appears to be an edge-on spiral galaxy, classified as Scd in the *Nearby Galaxies Catalog* (Tully 1988).

Independent of any particular theory of galaxy formation, it would be fascinating to know whether NGC6946 and NGC6503 have any features that might correlate with their unusual isolation. Did the lack of competition allow these two spiral galaxies to accumulate unusual envelopes of atomic hydrogen, or unusual optical spheroids or dark halos, or unusual distributions of globular star clusters? (NGC6503 is edge-on, perhaps suitable for such studies.) For the astrophysical biasing picture, the situation as we already know it is strange enough: of perhaps 500 galaxy seeds that the picture says are present in the very nearby voids, only a handful managed to develop into recognizable galaxies, yet one, NGC6946, turned into a classic spiral galaxy, showing no manifest peculiarities apart from the unusual shortage of less luminous companions.

Among the very nearby dwarf galaxies, DDO 154 and 155 (van den Bergh 1960) are worth special mention. The latter is discussed by Carignan (1989); he points out that at $M \sim -12$ it is among the faintest known galaxies, yet it has an H I envelope that shows a rotation curve to 3 optical Holmberg radii. Carignan and Freeman (1988) trace the H I rotation curve of DDO 154 to 5 Holmberg radii, and demonstrate that the optically bright component is a small fraction of the total mass. Carignan and Freeman call DDO 154 a *Dark Galaxy*: if it were a little fainter, or a little farther away, it would be an optically invisible massive object. This galaxy, along with DDO 155, is just the sort of thing we might expect to find in the dark mass, and, under the astrophysical biasing picture, just the thing we would expect to be present in great numbers in the voids. However, DDO 154 and 155 are in the main concentration of galaxies in the the plane of the Local Supercluster (at $|Z| < 0.5h^{-1}$ Mpc, and redshifts $v_c = 380$ and 165 km s^{-1} for DDO 154 and 155). These objects are usefully placed to contribute to the dark mass revealed by dynamics of systems of galaxies, but they are in the wrong place for the mass to close the universe. Could Dark Galaxies like DDO 154 be present in the local voids? We see from figure 1 that there are not many candidates.

To summarize, the astrophysical biasing picture would suggest that the voids contain galaxies that are stunted and irregular. However, there is ample evidence that dwarfs cluster with giants. In the very nearby galaxy sample, we see ordinary-looking spirals in the voids and the best candidates for Dark Galaxies clustered with the bright galaxies. This is not what a reasonable interpretation of the astrophysical biasing picture would have led us to expect.

b) The Unbiased Gravitational Instability Picture. The direct interpretation of the above observations is that the voids do not contain many dwarf galaxies because they do not contain much mass. This is consistent with the unbiased gravitational instability model, in which one assumes that galaxies grew out of small primaeval mass density fluctuations, as in the picture just discussed. However, one imagines that galaxy masses were assembled at high redshifts, and that groups and clusters of galaxies formed later, by the gravitational growth of mass fluctuations on larger scales. Gravity would pull both giants and dwarfs out of the voids, along with any exotic dark matter that does not have high pressure. This would make dwarfs cluster with giants, as observed, but it would also suppress any biasing present at galaxy formation, so we would have to learn to live in a low density universe.

There is the observational constraint (often emphasized in private discussions by J.P. Ostriker) that galaxies would have to move so as to develop strong clustering without violating the bounds on peculiar velocities. This does seem to be a problem in the very nearby sample: in a planar mass distribution model, the concentration to the Local Supercluster can develop by gravitational collapse consistent with observed bounds on peculiar velocities if the density parameter is $\Omega \lesssim 0.2$ (Peebles, 1988). The small value of Ω is consistent with what is indicated by other dynamical tests.

Would the distinctive sheet-like character of the local galaxy distribution naturally develop out of gravitational collapse? It has been suggested that we have an example of this effect in the 'pancake' collapse that develops out of the gravitational growth of initially small mass density fluctuations. The idea is appealing, but caution is in order. In classical pancake collapse, the first generation of non-linear objects is pancakes at sites of orbit intersections (Shandarin and Zel'dovich 1989 and references therein). Because the velocity field in the initial mass distribution is continuous, having a coherence length, the locus of intersections of orbits at a fixed time defines a two-dimensional surface, the pancake. In the next stage of evolution, mass drains along the pancakes into mass lumps that typically grow at intersections of pancakes. (This is beautifully illustrated in the numerical solutions of Melott and Shandarin 1989.) Can we imagine that these mass lumps then become organized in a second generation of pancakes? There is no consensus on the answer. My impression is that in general there is not a second generation of pancakes, because the velocity coherence length now is fixed by the sizes of the individual lumps, so we are missing the essential ingredient for the development of pancakes, the continuous velocity field. Instead, evolution is likely to proceed by the usual hierarchical agglomeration of lumps into superlumps. Dekel (1983) points to one way out of this argument: suppose the primaeval mass fluctuation spectrum has two prominent bulges, one to make galaxies by gravitational collapse at reasonably high redshifts, the other to cause a second generation pancake collapse of the galaxies moving as a nearly smooth fluid.

Could the plane of the Local Supercluster be a first generation pancake? The problem with this idea is that the concentration of galaxies in the Local Supercluster seems to be younger than the galaxies it contains. The youth of the plane is suggested by its low density and low peculiar velocities. In particular, the motions of the galaxies in the Local Group are at least roughly consistent with a model in which the group is collapsing now for the first time (Peebles *et al.* 1989). The alternative is a second generation pancake. As I have argued, my impression is that Dekel's (1983) picture is the only way to save the phenomena (by which one means, save the theory); it requires special but by no means impossible initial conditions.

In summary, the challenge for an unbiased gravitational collapse picture, which must describe both the development of galaxies and of the clustering of galaxies, is to reconcile the local galaxy space distribution, which has the character of a recent collapse from a mass distribution with a broad coherence length, with the dense, well isolated and old mass concentrations seen in individual galaxies.

c) Cosmic strings. In this picture (Vilenkin 1985, Turok 1985, and references therein) a phase transition in the early universe leaves a tangled network of cosmic string that moves so its coherence length expands with the Hubble length, in the process breaking off loops. The motions of long strings and the mass concentrations in loops perturb the distribution of matter, and the perturbations grow by gravity into galaxies and groups and clusters of galaxies. Biasing can be the result of clustered initial positions of the perturbations: where there were few bits of string there is a good deal of mass not incorporated in galaxies.

In the original version of this picture, a galaxy is seeded by a single loop, the loops being placed in a highly clustered fashion. Since a galaxy would grow by gravitational accretion around a loop, the mass of the galaxy would be correlated with the size of the loop. Since the typical loop size increases with increasing time of formation of the loop, one would predict that the loop seeds of dwarfs tended to form earlier than the seeds of giants. But in this case, how can one understand the correlation of positions of giants and dwarfs seen for example in figures 1 and 2? Since loops are produced by long strings that are moving at close to the speed of light, why would the long strings that produced the seeds of dwarfs and those that produced the seeds of giants place the seeds along the same sheet-like concentrations?

In a more recent version of the picture, as discussed in Stebbins *et al.* (1987) and Bennett and Bouchet (1989), the dominant perturbation to the mass distribution is caused by the motions of long strings rather than the gravitational attraction of loops. The motion of a long string piles matter into a sheet along the string wake. This has the advantage that the seeds of galaxies, which would be the fluctuations in mass per unit area in the wakes, would naturally be arranged on sheet-like structures. However, there is still the problem with the lack of segregation of giants and dwarfs. Wakes produced at different epochs would tend to have different values of the mean mass per unit area, and it is natural to expect that that would be translated into systematic differences in masses of the galaxies produced along different wakes.

To summarize, it seems to be salient features of the string concept that galaxy seeds are produced in a significant range of redshifts, and that seeds produced at different epochs have uncorrelated positions and produce systematically different galaxies. As discussed in the last section, that is not easily reconciled with the observed tendency of giant and dwarf galaxies to cluster together.

d) Explosions. In the explosion picture (reviewed recently by Weinberg *et al.* 1989 and West *et al.* 1989), a blast wave in the early universe piles matter into a shell that expands and eventually cools and fragments into galaxies. The hole within the shell acts as a region of negative mass density relative to the mean, so it tends to push the shell, eventually leading to a gravitationally driven expanding shell that accumulates the material it encounters.

The explosion picture has the great advantage that galaxies naturally are produced on sheets, as observed. If the mass of the universe were dominated by exotic dark matter, galaxy formation could be biased, because the blast wave would only sweep up the baryonic part, leaving a smoother background of dark matter. Some dark matter could be accreted as the dark halos of galaxies, the rest left to close the universe. As discussed in Section 2, the Local Supercluster is moving at ~600 km s^{-1}. This could be the expansion of the shell. And the small relative velocities within the shell would reflect the fact that the shell is coherently expanding.

These are attractive features, but yet again the details of the very nearby galaxy sample suggest a problem. Figures 1 and 2 show that the bulk of the very nearby galaxies are on the sheet of the Local Supercluster, but that there are appreciable numbers off the sheet, particularly at negative Z. The same is true of somewhat more distant galaxies, at distances $\lesssim 10h^{-1}$ Mpc. It could be significant that the mean motion of the sheet is toward these galaxies at $Z < 0$. (The Z component of the mean peculiar velocity of the galaxies on the sheet is (-440 ± 150) km s^{-1}; Peebles 1988.) If the shell has become gravitationally dominated, it will tend to incorporate galaxies as it encounters them, emptying the region of positive Z. The problem is with the galaxies at negative Z, which presumably originated in other explosions. These galaxies would be expected to have the peculiar velocities of other shells, and we would predict therefore that they have high peculiar velocities relative to us. The open circles in figure 3 represent galaxies at $Z < -2.5h^{-1}$ Mpc; we see that they are about as close to the Hubble line as are the squares for galaxies on the sheet. And we know that roughly the same applies to distances $Z \lesssim 10h^{-1}$ Mpc, because galaxies outside the Virgo Cluster do not have negative redshifts.

In the conventional gravitational instability picture, it is easy to make the velocity field in the very nearby galaxy sample nearly smooth, as observed:

imagine that the velocity is dominated by the gravitational field of primaeval mass fluctuations with a large coherence length, which originated in the early universe. (For an example where this happens see Peebles 1987.) If on the other hand the large-scale mass fluctuations were produced by rearrangements by explosions, one would have to suppose that, after the galaxies in our neighbourhood had formed, a blast wave pushed a considerable amount of material past us. A radius $R \sim 30h^{-1}$ Mpc for this secondary blast wave would give about the wanted scale. But then the mass per unit area in this blast wave would amount to about 10^{19} protons cm^{-2}, comparable to the H I mass per unit area seen in the outer parts of galaxies such as DDO 154 (Carignan and Freeman 1988). How could the gas rich dwarfs in our neighbourhood have survived this blast wave?

The key point here is that the explosion picture does not naturally produce the smooth velocity field that, I have argued in section 2, is well established in our neighbourhood.

4. Concluding Remarks. It should be understood that I am not claiming that the very nearby galaxy sample is representative. Though the luminosity per unit volume in the box in figures 1 and 2 is close to the large-scale mean, one could place a cube this size in a large void, where the number of galaxies contained might be an order of magnitude smaller, or on a cluster, where the number would be an order of magnitude larger and the relative galaxy velocity dispersion much higher. But despite these differences among different samples the very nearby galaxies are part of the universe and an acceptable theory of galaxy formation has to account for them.

A good part of the theoretical problems with the very nearby galaxy sample arises from the assumption of an Einstein-de Sitter universe. Should we give special weight to this particular cosmological model? One often sees the argument that this model is required by inflation, but in fact the standard inflation scenario applies equally well in a low density universe with an effective cosmological constant. I also disagree with the contrary view, that the Einstein-de Sitter model should be assigned little weight because the observational evidence for it is so weak. The aesthetic arguments favouring Einstein-de Sitter are attractive and have worked in other applications, and I would be glad to see them work here. But it is undeniably true that we would find it a good deal easier to understand the observations if the mean mass density were $\sim$10 per cent of Einstein-de Sitter!

The main message from this discussion is that the very nearby galaxies are a promising sample for future study. Because peculiar velocities are small, galaxies in the nearby low density regions must have spent most of their lives there. That surely has had some effect on their morphologies: perhaps the lack of competition allowed the void galaxies to accumulate larger dark halos or more globular clusters for a given central mass; perhaps the lack of perturbations by neighbours allowed the void galaxies to store more interstellar gas. Under the biasing conjecture, voids have not been emptied by gravity, so the voids must contain remnants of primaeval matter, including the remnants of the Lyman α forest and perhaps also the seeds of unborn galaxies. The very nearby voids offer the best chance to check on this because one can look well into the faint end of the luminosity function. Are there Carignan-Freeman Dark Galaxies in the very nearby voids? And what is the origin of the distinctive planar character of the Local Supercluster? If reliable distances for more of the very nearby galaxies were known, we might hope to piece together the pattern of peculiar motions and the process of development of the plane.

I would emphasize finally that, although I have argued that all the popular pictures for galaxy formation have problems with the very nearby sample, I do not consider this a crisis for cosmology; the arguments are based on tentative theoretical interpretations of observations that are not always well established. The confusion more likely is a healthy sign of an active if immature science.

I am grateful to Dave Bennett, Ruth Daly and Adrian Melott for stimulating discussions. This research was supported in part by the U.S. National Science Foundation.

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