THE PERSEUS SUPERCLUSTER

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1. INTRODUCTION

In analyzing the distribution of galaxies of a sample projected on the plane of the sky, the magnitude of a surface density enhancement produced by a clumpy structure depends on the size and magnitude of the volume density enhancement, and the depth of the sample. If the sample is too deep, or the line of sight size or volume overdensity of the clump too small, the surface enhancement may be too shallow to discern against the fore- and background objects. The Catalogue of Galaxies and Clusters of Galaxies (CGCG: Zwicky et al. 1960-68) provides a representative sample of the local universe (cz $\lesssim$ 15000 km s^{-1}) and, in hindsight, possibly the one available that best enhances the inhomogeneities that appear to characterize the large scale structure of the universe. Using maps of the surface density distribution of galaxies from the CGCG, of which figure 1 is an example, Martha Haynes, Guido Chincarini and I have selected a number of filamentary structures discernable and undertaken a 21 cm redshift survey of large regions enclosing them, with the telescopes of 305 m at Arecibo and 92 m at NRAO-Green Bank. Here I shall discuss our current results from a large area extending from Pegasus to Ursa Major, which engulfs the well known Perseus supercluster (Einasto et al. 1980; Gregory et al. 1981).

2. THE SAMPLE

The Arecibo sample includes all galaxies of morphology later than S0 and angular size larger than 1′, between 22^h and 4^h in RA, 3^o and 38^o in Dec. In a more restricted region, we have also included spirals smaller than 1′ and brighter than m=15.7. Our partial results include approximately 1100 21 cm redshifts which, integrated with optical data from various sources, mainly the Rood and cfA catalogs, contribute to a sample of 1435 redshifts in the region mentioned. The sky distribution of galaxies in the sample is shown in figure 2. Notice that the densest part of the Perseus filament (cf figure 1),

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located North of Dec=38°, is not yet part of our sample. The Green Bank observations discussed here refer to the region of Lynx-Ursa Major, between 6.5^h and 11.5^h in RA, 40° to 65° in Dec, and to a large section of the zone of avoidance bridging the gap between Perseus and Lynx; this sample is described in detail by Giovanelli and Haynes (1982). Our samples are incomplete in a variety of ways. Corrections for the biases introduced by the incompleteness have been applied when possible; such biases do not basically affect the conclusions that will be presented here.

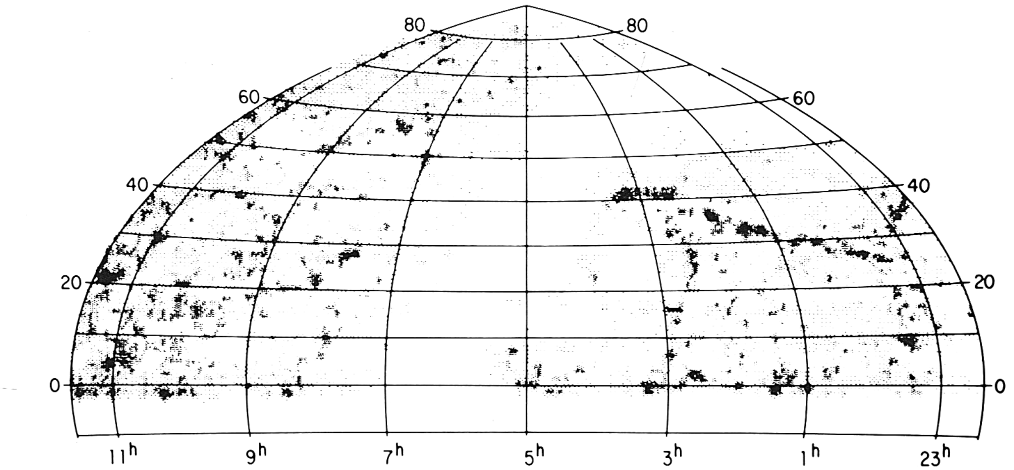

Figure 1. Surface density distribution of galaxies from the CGCG.

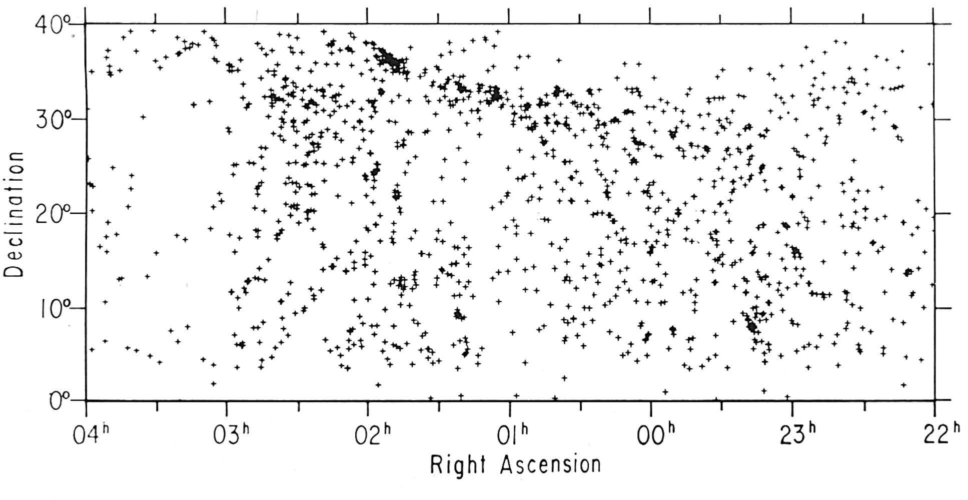

Figure 2. Distribution of redshifts of the Arecibo sample.

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3. THE REGION FROM PEGASUS TO PERSEUS

The histogram in figure 3 illustrates the redshift distribution of galaxies in the Arecibo sample, while the distribution to be expected if the volume density of galaxies were uniform along the line of sight is given by the smooth curve. While the formidable enhancement near 5000 km s^{-1} represents an average over a solid angle which exceeds 2000 square degrees, the detailed structure of the supercluster appears as a maze of thin filamentary structures, which maintain a high degree of spatial coherence; sometimes they spatially merge, sometimes they merely project across each other while remaining separate along the line of sight. Unbroken, unsplit filamentary segments can extend for several tens of Mpc along one dimension (we assume H_o=50 throughout), while they are very thin in the other two, with axial ratios usually larger than 10. The table shows the characteristic parameters of filamentary segments in the region surveyed at Arecibo, obtained from numerous such structures.

Surface density contrast	......	up to 10
Volume density contrast	......	50 to 100
Length	......	45 to 90 Mpc
Width	......	3 to 8 Mpc
	......	200 to 600 km s^{-1}
Axial ratio	......	> 10
Mass	......	10^{16-17} Ω M_o

Volume densities are estimated from the observed surface density enhancement and the assumption that they are well described by a Schechter luminosity function. Masses are estimated from the derived volume overdensity and an assumed average density of matter in the universe of Ω times the critical mass. Two examples of the velocity structure are seen in figure 4. A cone diagram of galaxies within $\pm$ 3° in Dec from

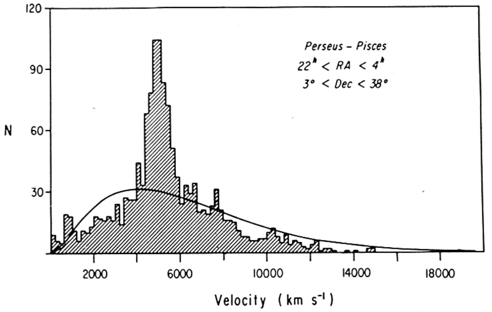

Figure 3.

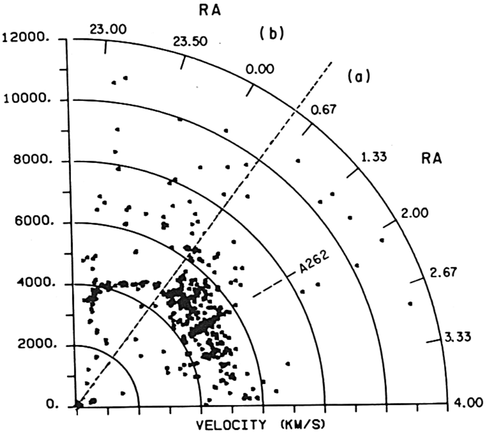

Figure 4.

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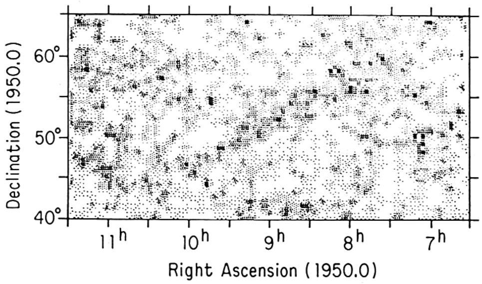
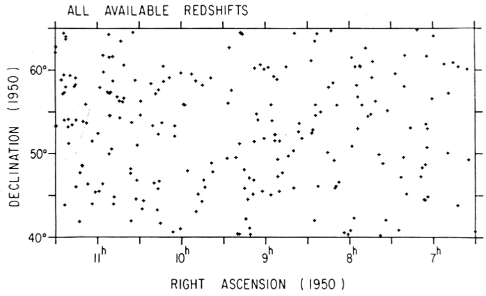
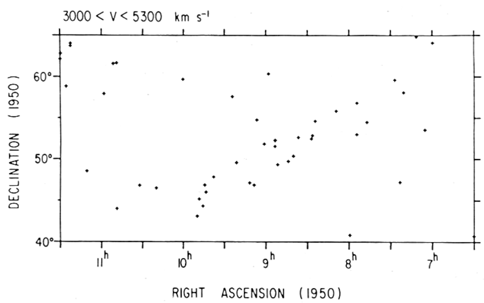
$$\text{Dec} = 27.7 + 4.14\ \text{RA} \qquad 0.46 < \text{RA} < 2.00$$
$$\text{Dec} = 27.5 + 2.50\ \text{RA} \qquad 2.00 < \text{RA} < 4.00\ ,$$

the main filament, is shown in figure 4a. Notice the enhaced velocity dispersion around the dense clusters in the filament. Figure 4b presents the velocity structure of a filament running from the Pegasus cluster, near 23.3^h, 8^o, to the main filament at 0.5^h, 30^o. The Pegasus cluster is identified by the large velocity dispersion







a b
c

Figure 5

The Lynx-Ursa Major filament

structure near 3500 km s^{-1}; a very narrow filament joins the cluster and the main filament shown in figure 4a. Figure 4b includes galaxies within a 4^o wide band.

4. THE REGION FROM PERSEUS TO LYNX-URSA MAJOR

Inspection of figure 1 shows the main filament of the supercluster merging into the zone of avoidance near the Perseus cluster. A filamentary structure is discernible on the other side of the galactic plane, and is shown in better detail in figure 5a, as a shade plot similar to figure 1. Giovanelli and Haynes (1982) have shown the filamentary structure to be associated with a density enhancement located between 3500 and 5300 km s^{-1}, as illustrated in figures 5b and 5c. The question naturally arises of whether the Perseus and Lynx regions are connected across the zone of avoidance. Figure 6 shows the distribution of velocities in the region between the two filaments, as a histogram on which the expected redshift for a homogeneously distributed sample is superimposed as a smooth line (similarly to figure 3). A significant excess is present near 5000 km s^{-1}, confirming the suspicion of a connection, which corroborates previous suggestions put forth by Burns and Owen (1979).

5. APPLICATION TO THE DETERMINATION OF H_o

A 21 cm survey provides important additional information besides redshifts. A prominent one is the collection of line-widths which can be used, as first proposed by Tully and Fisher (1977), to determine the Hubble constant. In most application of this method, calibrators of the relationship between line width and luminosity are nearby galaxies, usually inhabitants of low density regions, while H_o has been preferentially determined using samples belonging to clusters of galaxies. The application of the method relies on the assumption that the ratio between line width (related to total mass) and luminosity is an environment independent quantity. We have investigated this question using subsamples of supercluster galaxies ($4000 < cz < 6000$ km s^{-1}) of various morphological types (in order to single out the effects of morphological segregation in the supercluster), analyzing the dependence of the total mass luminosity ratio as a function of local galaxian density. The total mass was determined from the velocity width and the customary assumption for the shape of the rotation curve (assumed flat) using a Brandt formula (cf Roberts 1975); the luminosities are from the CGCG, corrected for reddening and for the irregularities discussed by Bothun and Schommer (1982). The Local galaxian density is defined as

$$\rho = \Sigma_i L_i \exp(-0.5(r_i/\sigma)^2)$$

where L_i, r_i are the luminosity and projected distance (on the plane of the sky) of the i-th neighbor found in the CGCG, assumed at the same redshift as the sample galaxy, and $\sigma = 0.5$ Mpc. The summation is carried on over all neighbors within 4 Mpc. Figure 7 shows the behavior of the total mass to luminosity ratio as a function of

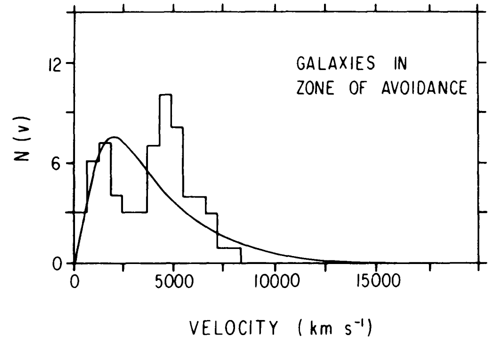


Figure 6

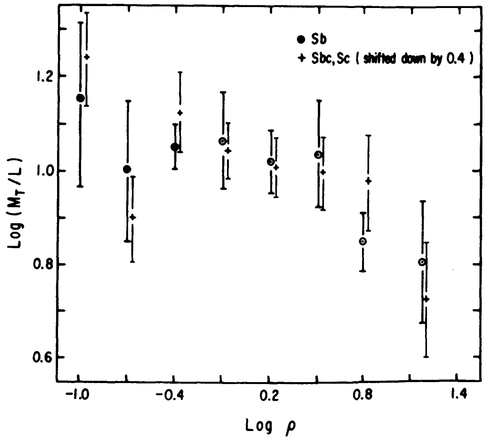


Figure 7

ρ separately for two samples of Sb and Sbc, Sc galaxies. In both cases a trend is discernible for galaxies in higher density environments to have lower mass to luminosity ratios than those in low density environments. The difference, on the order of a factor of two, could produce an overestimate of the value of H_o derived from cluster galaxies by about $\sqrt{2}$, unless it results from a bias in Zwicky magnitudes or UGC morphological types which differentially affect regions of different density.

6. CONCLUSIONS

The distribution of galaxies between Pegasus and Ursa Major, analyzed mainly on the basis of 21 cm redshifts, resembles a network pattern of thin filamentary segments. The segments, typically extending several tens of Mpc, represent density enhancements of 30 to 100 times the average volume density, and have masses of $10^{16-17}\,\Omega\,M_o$. The network pattern can be followed uninterruptedly for at least several hundreds of Mpc, as indicated by the suggestive connection between the Perseus and Lynx regions across the zone of avoidance. The large 21 cm sample of supercluster galaxies enables us to analyze the environmental dependence of integral properties of galaxies, suggesting that the Hubble constant as derived previously via the Tully-Fisher method may have been overestimated, if the difference in the mass to luminosity ratio between high and low density regions is not the effect of so far unknown observational biases.

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Discussion

Szalay: What was the method by which the masses were determined of the objects plotted on Figure 7?

Giovanelli: They were determined in the traditional way from the 21-cm line width, corrected for inclination, and assuming that the rotation curve is flat and that the maximum rotational velocity is reached at a fixed fraction of the optical diameter.

Szalay: As far as I know, there are no data on whether spiral galaxies in rich environments also have flat rotational curves. Is that true?

Giovanelli: I would agree. I am not aware of any systematic mapping of rotation curves in the denser parts of clusters.

Thompson: If Dr. Dekel is correct and filamentary structures are stabilized by streaming motions along the filaments, then any filament oriented with its major axis out of the plane of the sky should show evidence for such streaming motions. For the filaments which appear in your study, can you test Dr. Dekel's hypothesis?

Giovanelli: The clearly discernible filament with the largest angle to the plane of the sky is located between 10 and 30 degrees declination, 2.4 and 3 hours right ascension. It exhibits a gradual velocity change of about 3000 km s^{-1} from one extreme to the other, or an inclination of about 45 degrees to the plane of the sky. It could provide an ideal case to test Dr. Dekel's hypothesis. At present, however, the sampling of that filament is rather coarse, and it is premature to say whether the relatively large redshift width is an effect of streaming or just of poor sampling associated with the large velocity gradient due to differential Hubble flow. Fifty more redshifts in the filament could help to answer less ambiguously.

Aaronson: I just wanted to repeat a comment I made in Patras regarding your last transparency (Figure 7). We do not see any evidence for environmental effects on the IR Tully-Fisher method. In particular, we now have a sample of ten distant clusters ranging from high-density, spiral-poor objects like Coma to low-density, spiral-rich objects like Pisces. All these yield a similar Hubble ratio. Furthermore, we also have a sample of distant field Sc galaxies drawn from the studies of Sandage-Tammann and Rubin et al. These yield a Hubble ratio which agrees with the cluster data. We generally use a circle of only 3° radius for the clusters to that a large range in density contrast does exist between the cluster and field samples.

Giovanelli: I wish to underscore again the caution with which I am mentioning the result. It is possible that the effect is milder or disappears if one uses infrared magnitudes; we don't have them for our sample, yet. As for the difference in local density between galaxies in clusters like Coma and Pisces, I think that the detected galaxies at 21 cm may be less representative of the difference in density among clusters than you imply. As you know, spirals in cores of clusters are usually very gas-poor and not chosen for Tully-Fisher samples because of the difficulty in measuring a 21-cm line width. It is likely that the Coma spirals used for FT studies are in lower density regions than cluster cores, even if projected onto them; similarly in other dense clusters. Hence, detected cluster spirals used in your samples are likely to inhabit regions that bridge a very narrow dynamic range in local densities; thus, the similarity of the inferred results is not inconsistent with the point made in this paper. The results for your field Sc sample, on the other hand, appear to indicate disagreement.

Scott: Can you give some details as to how your filaments were determined? As seen by me sitting here, the dog had a lot more legs.

Giovanelli: The redshift information helps to disentangle surface density features.

Tarenghi: How was your sample chosen, what is your detection rate and what is the velocity range of search for unknown redshifts?

Giovanelli: We observed all spirals of type Sa or later, with optical sizes greater than one arcminute (UGC objects), except in a few fields where we have observed smaller Zwicky galaxies. Our overall detection rate is of about 80 percent. Our range of search is between zero and about 14,000 km s^{-1}.

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