Large-Scale Structures in the Highly Obscured Orion-Taurus Region

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Abstract.

A sample of IRAS galaxy candidates were observed in HI 21 cm for galaxy identification and redshift measurements. This generated a uniform sample of IRAS galaxies in the area of $2^h < \alpha < 10^h$ and $0° < \delta < 36°$ which crosses the Zone of Avoidance (ZOA) and includes most of the heavily obscured Orion-Taurus region. The representative galaxy distribution from our resulting galaxy sample provides a view on large-scale structure in this area unbiased by Galactic reddening.

The main results are: (1) the possibility of a nearby, nearly optically hidden, very rich galaxy concentration in this region can probably be ruled out. (2) The main part of Pisces-Perseus supercluster is limited to $\alpha < 3^h$ in our *survey* region by giant voids between 3^h and 4^h. (3) There are excessive galaxies around $v \sim 5000$ and ~ 8500 km s^{-1}, respectively. The latter "wall" appears to gradually diffuse out after it enters the ZOA from the northern Galactic hemisphere.

1. Introduction

Galaxies have been identified optically in the Zone of Avoidance (ZOA) with or without using IRAS positions (e. g., Böhm-Vitense 1956, Fitzgerald 1974, Dodd & Brand *1976,* Weinberger 1980, Kraan-Korteweg 1989, Saitō *et al. 1990* & 91, Yamada *et al.* 1993, Takata *et al.* 1994, and papers in this book). While optically generated galaxy samples are quite uniform at high Galactic latitudes, they become highly nonuniform near the Galactic plane ($|b| \lesssim 30°$) and in regions of excessive and patchy reddening, making it difficult and, perhaps, ambiguous to interpret the observed galaxy distribution in the ZOA. Blind HI 21cm surveys (e.g., Kerr & Henning 1987) would produce a uniform sample, but is very time consuming.

IRAS Point Source Catalog (Version 2, 1988; hereafter PSC) is, on the other hand, fairly complete above a few degrees from the Galactic plane. A follow-up HI 21cm observation on far-infrared (FIR) selected PSC candidates allows one

TABLE 1. Infrared Selection Crteria

Parameter	Criteria
PSC flux density at 100μm:	$1.5 < f(100) < 8$ Jy
PSC flux quality at 100μm:	moderate or high
PSC flux density ratios:	$f(25)/f(100) < 0.50$
	$f(12)/f(100) < 0.17$
	$1.13 < f(100)/f(60) < 4.00$
PSC correlation coefficients (CC):	$CC(60) \geq 0.98$; $CC(100) \geq 0.98$

$f(x)$ is the PSC flux density at x μm, with x = 12, 25, 60 or 100.

to generate a galaxy sample which is free from Galactic extinction (Lu *et* al, 1990) and the resulting galaxy sample offers an unbiased view of the large-scale structure in and across the ZOA.

We have applied the above extinction-free approach to the region bounded by $2^h < \alpha < 10^h$ and $0° < \delta < 36°$. The part of the region with $b < 0°$, which contains most of the highly obscured Orion-Taurus region, is of several interests: (i) The region was always masked out by previous redshift surveys; (ii) The "local velocity anomaly" of the Local Group is pointing in (or near) this region (Faber & Burstein 1988), a possible hint for a (unknown) nearby rich galaxy concentration in this region; (iii) The main part of Pisces-Perseus (hereafter PP) supercluster is limited to $\alpha < 3^h$ in optics in this region. Despite extensive studies on the PP region (*e.g.*, Haynes & Giovanelli 1988), no specific redshift survey has been done in the current region to see if the main part of the PP supercluster extends to $\alpha > 3^h$. (iv) The "Great Wall" (Geller & Huchra 1989) optically "disappears" in the ZOA from the northern Galactic hemisphere. It is important to see if it ends there or extends to the Orion-Taurus region, in order to better determine the characteristic length of this largest known coherent structure. The part of our survey region with $b \gtrsim 10°$ which has much less obscuration, was selected for the purpose of some statistical comparison.

2. The Sample Selection and Observations

2.1. The Sample Selection

In heavily obscured regions, Galactic source density in the PSC is also high. Following Lu *et al.* (1990), we use a set of selection criteria, given in Table 1, which screens out more than 75% Galactic sources, while still includes more than 50% IRAS galaxies (Lu *et* al. 1990; also see Meurs in this book). Applying our criteria to (optically) cataloged galaxies in the PSC at high Galactic latitudes, we indeed selected at least 50% at all redshifts. The adopted limiting flux density of 1.5 Jy at 100μm is equivalent to about 0.7 Jy at 60μm.

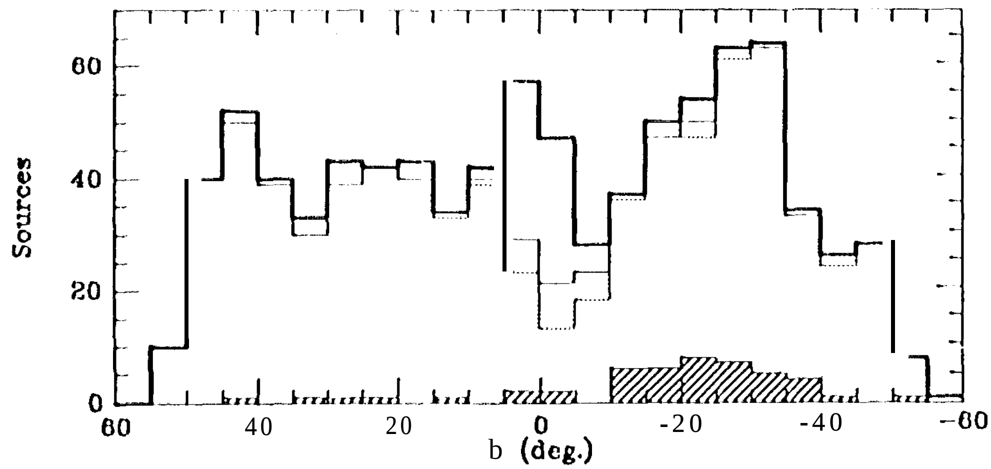


Figure 1. Plot showing our survey completeness along Galactic latitude

2.2. **Observations**

The selected sample of 876 sources can be divided into three parts: (i) 462 (53%) "cataloged galaxies", namely, those noted in PSC to be associated with one or more optical galaxy catalogs; (ii) 47 (5%) "Galactic sources" (as marked in the PSC); and (iii) 367 (42%) pure IRAS sources. Our main observational goal is to observe every source in parts (ii) and (iii), which were not known to be a galaxy to us by the time of our actual observations. To this end, we scare.hed literature for identified galaxies in our sample. Both optical and radio identifications were accepted.

The 21 cm observations were made with the 305m radio telescope of the Arecibo Observatory, A candidate source was usually first observed for the low-velocity range (-400 to 8200 km s^{-1}). If no galaxy signal was detected, another spectrum was taken for the high-velocity range (7800 to 16, 400 km s^{-1}). Each resulting spectrum has a velocity resolution of $\sim$16 km s^{-1} and a typical rms noise of 1.4 mJy (after Hanning smoothing). The HI 21 cm survey of Lu *et al.* (1990), with a velocity coverage up to 9000 km S-l, is technically very similar to the current one, but mainly limited to $|b| < 16°$, It was therefore integrated to our observations over the low-velocity range.

3. **Results**

3.1. **Survey** Completeness

Our survey completeness up to some heliocentric velocity, v_h, in our sample can be defined as the number percentage of those sample sources which are either known to be galaxies or observed (up to v_h) in one of the above mentioned HI surveys. Figure 1 shows the distribution of our sample sources along Galactic latitude (the thick solid line). The distribution of those sample sources which arc either known to be galaxies or observed over our low (low + high) velocity coverage is shown by the thin solid (dotted) line in Fig. 3. Therefore, our survey

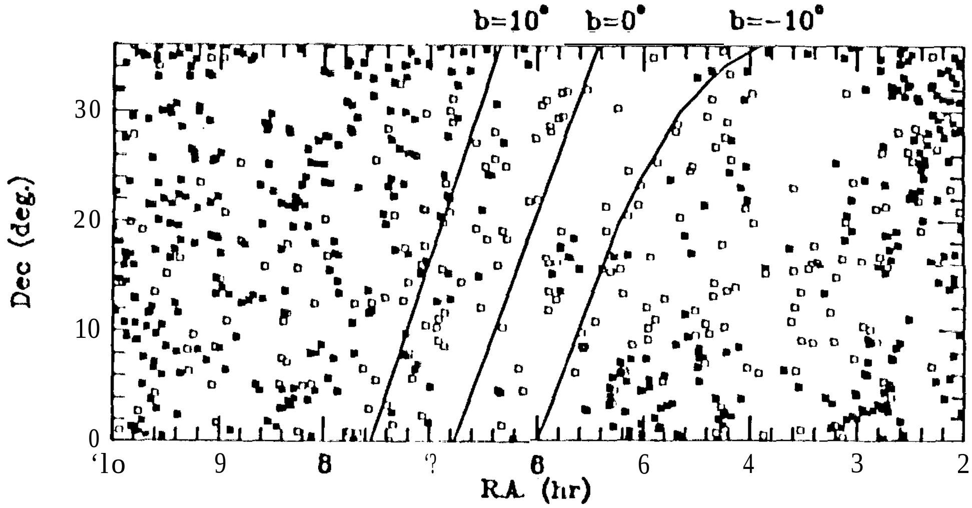


Figure 2. Distribution of Sample Galaxies in Equatorial Coordinates

is nearly complete up to ~ 16,000 km s^{-1} for $|b| > 10°$. For $|b| < 10°$, the completeness is somewhat lower, but up to 8000 km s^{-1}, we are more than 80% complete down to $|b| = 5°$. The hatched histogram is the distributions of known "non-galaxies" up to our limiting velocity of 16,000 km s^{-1}, which comprise less than 15% percent of our sample at $b <-10°$ and less than 6% at $b > 10°$.

Our 111 detections should be quite complete up to $v_h \approx$ 8000 km s^{-1} (Lu *et al.* 1990), At higher velocities, we may lose some galaxies with low HI flux density in face-on position.

4. Results

4.1. Overall Galaxy Distribution

The sky distribution of all 717 known galaxies is shown in Figure 2, where we have symbolically differentiate the cataloged galaxies (filled squares) from the pure IRAS galaxies (open squares). The percentages of pure IRAS galaxies in four equal-area bins along R.A. arc, respectively, 33% (for 2^h - 4^h), 53%, 43%, and 20%. The variation of this ratio should mainly reflect the pattern of the variation of Galactic extinction A_v. A_v is quite small for the last bin of $8^h < \alpha < 10^h$ (Burstein & Heiles 1982), the difference between pure and cataloged IRAS galaxies there reflects largely the true selection effect. As we shall see in Figure 4, the majority of pure IRAS galaxies (27 out of 29) in this R.A. bin are at velocities higher than 8000 km s^{-1}, while most of the cataloged galaxies are below 10,000 km s^{-1}, These results show: (i) existing all-sky optical galaxy catalogs could be 33% (= 53% - 20%) incomplete in Orion-Taurus region, (ii) in regions of small Galactic extinction, our selection dots not select many optically unknown galaxies below 8000 km s^{-1}.

83% (594) of the identified galaxies have heliocentric velocities v_h available to us. We reduced v_h to v_c, the velocity with respect to the centroid of the Local Group, using $v_c = v_h + 300 \sin(l)\cos(b)$ (km s^{-1}) where l and b are Galactic

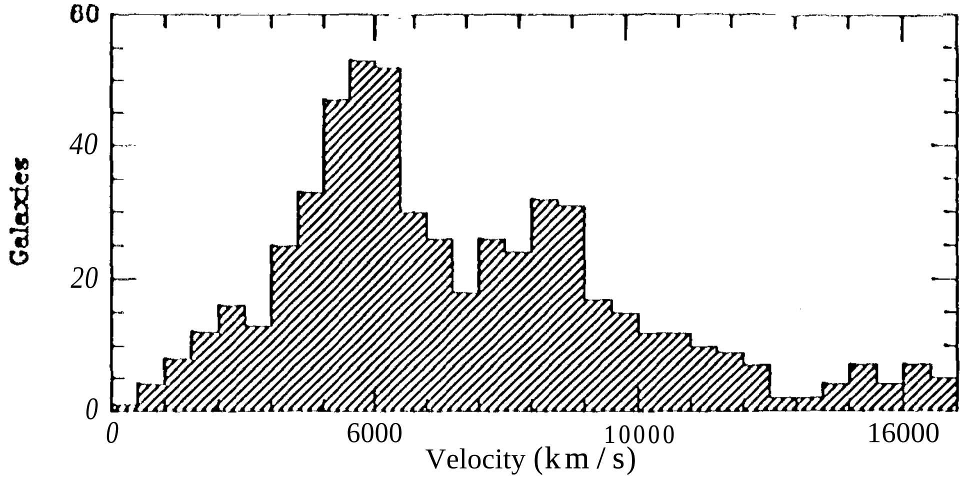


Figure 3. Redshift distribution of our sample galaxies.

longitude and latitudes, respectively. Figure 3 shows *the* overall distributions of v_c up to 16,000 km s^{-1} for sample galaxies. For a comparison, a sample selected with $f(60) > 0.7$ Jy (see § 2.1.) from a uniformly distributed galaxy population characterized by one of the available 60μm luminosity functions (e. g., Yahil *et* al. 1991) would have a redshift distribution which peaks around 4000 km S-l. The overall pattern in Figure 3 can be characterized by two "valleys" (or voids) and two '(peaks" , superposed on the underlying smooth distribution. The two apparent voids are one below $\sim$ 4000 km s^{-1} and one around $\sim$ 7000 km s--'. The first peak has a factor of $\sim$ 2 overdensity at $\sim$ 5000 km s^{-1}. Galaxy concentrations around this velocity were also observed in various directions in and around our survey region (e.g., Focardi, Marano, & Vettolani 1984; Hayschildt 1987; Dow *et al.* 1988; Haynes & Giovanelli 1988; Maurogordato 1991; Giovanelli & Haynes 1993; Takata *et al.* 1994; Seeberger, Huchtmeier & Weinberger 1 994). As shown below, this "wall" of galaxies around 5000 km s^{-1} is due to a number of superclusters between 4000 aud 6000 km s^{-1} and relative deficiencies of galaxies off the wall in the two voids, The secondary peak centers at about 8500 km s^{-1}], a velocity corresponding to that of the Great Wall (Geller & Huchra 1989). As wc shall see below, our data suggests that the Great Wall difl'uses out in the 7,0A .

4.2. Galaxy Distribution Over Smaller Scales

Galaxy distributions over scales much smaller than our survey scale can be visually illustrated by the cone diagrams in Figure 4, where wc plot v_c versus R.A. for the whole survey area (panel [a]) ant] for threw declination zones of 12 degrees each (panels [a] to [c]). We only show galaxies with $v_c < 12,000$ km S-l above whit.]1 our data appear sparse in such cone diagrams. The area between the two dashed lines in each diagram indicates $|b| < 5°$, where our observations are not quite complete yet.

A few known supm-clusters can be easily identified in Figure *4: the* "head" of PP supercluster (Haynes & Giovanelli 1988) in Figure 4d ($v_c \sim$ 5000 km s^{-1},

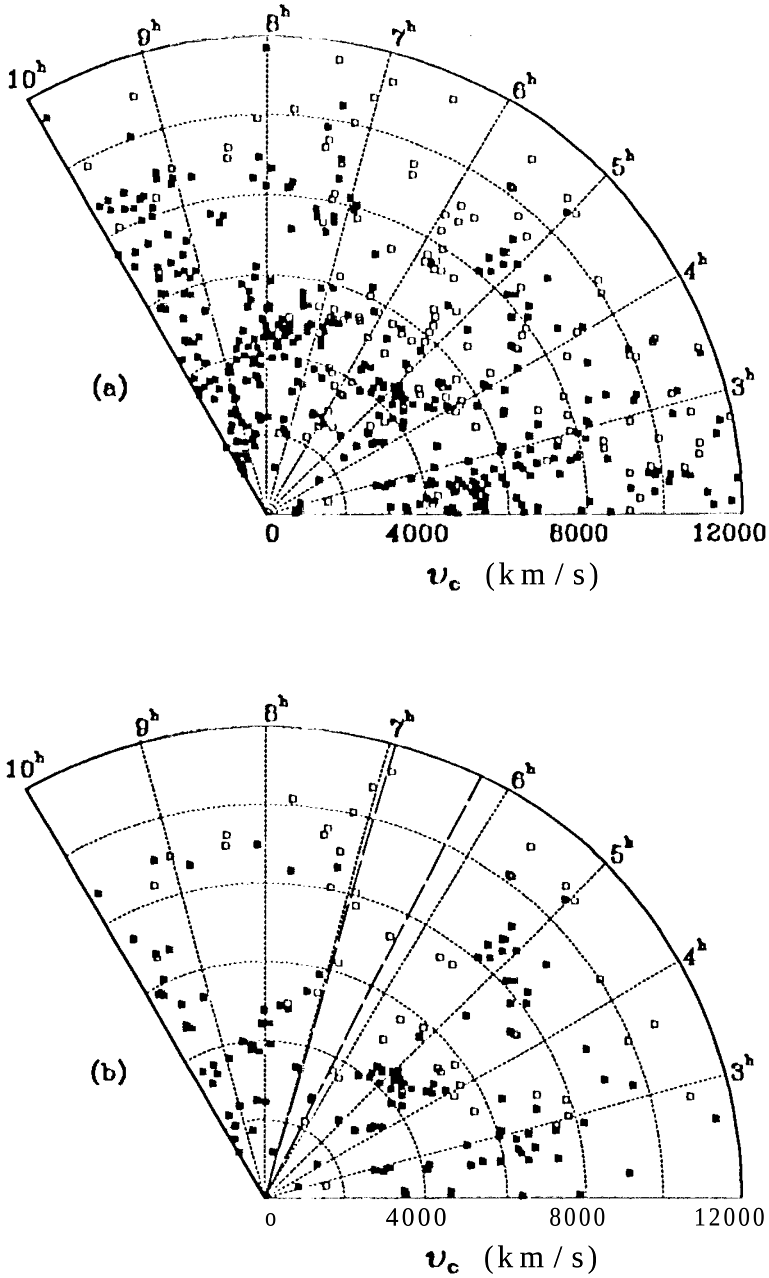
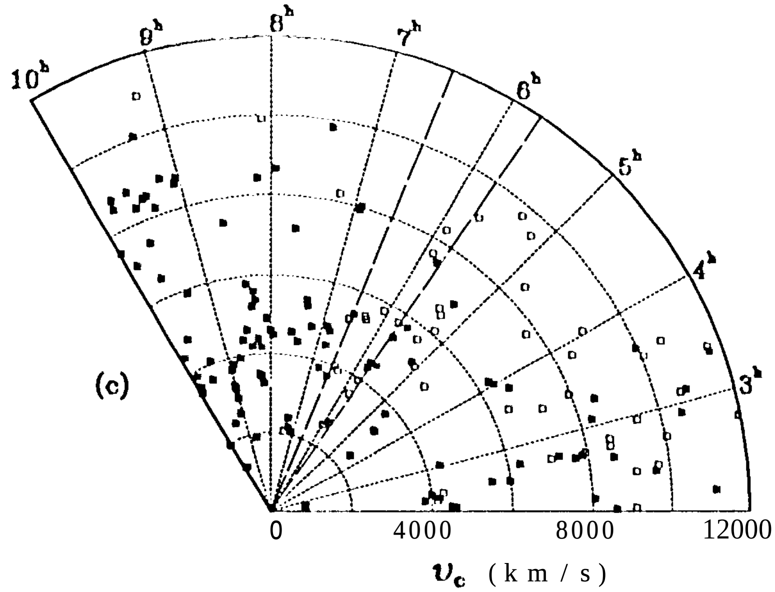


Figure 4. Cone diagrams of velocity versus R.A. for various zones of declinations δ: (a) the whole survey area, and (b) $0° < \delta <$ 1 ‘2° on this page; (c) $12° < \delta < 24°$, and (d) $24° < \delta <$ 36°011 the next page. The symbols are the same as in Figure 3.


10h
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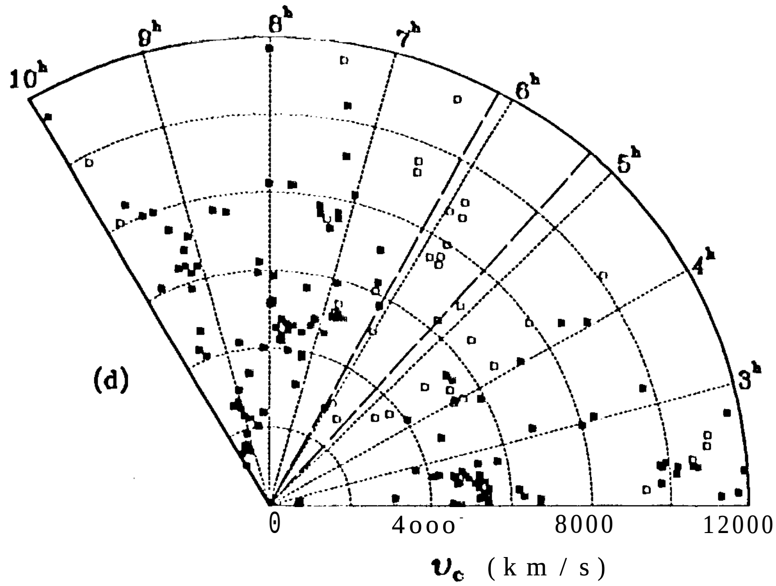
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'2}' $< \alpha <$ 3"), the N1600 supercluster (Saunders *et al.* 1991) in Figure 4c ($v_c \sim$ 4400,&w 5^h), the Gemini filament (Focardi, Marano, & Vettolani 1984) in Figures 4c and 4d ($4000 < v_c < 6000$, $6^h < \alpha < 8^h$, part of the Great Wall (Geller & Huchra 1989) in Figures 4b and 4c ($8000 < v_c < 10{,}000$, $\alpha > 7^h$). Our statistical analysis also shows that the concentration around $\alpha \sim 2.4^h$ *and* $v_c \sim$ *9100* km s^{-1} in Figure 4d is probably fairly high in galaxy density and that there exists a significant supercluster at $\alpha \sim 6^h$, $\delta \sim 18°$, and $v_c \sim$ **5800** km s^{-1}.

A few large voids were unambiguously identified and arc visible in these cone diagrams. A void up to $v_c \sim 6000$ km s^{-1}, bounded by $3^h < \alpha$ <41', fills our declination range. At its lower velocity end, this void connects to a "local void'' lying below ~ 4000 km s^{-1} at $3^h \lesssim \alpha \lesssim 8^h$; while at the high velocity end, it connects to another large void at $\delta \gtrsim 18°$ with a velocity stretching out to at least 10,000 km s^{-1}. The existence of these voids clearly shows that the 1'1' supercluster does not extend to $\alpha > 3^h$ within our survey declination range.

There is another giant void with $6000 \lesssim v_c \lesssim 8000$ km s land $\alpha \lesssim$ 9}'. This void is located just in front of the Great Wall and appears to extend well into the ZOA. But the galaxy density in this void apparently increases as R.A. decreases, so is the contrast between the Great Wall and its neighboring region.

5. Conclsuions

Our main results, based on the cxtillction-free galaxy distribution of a uniform sample of IRAS galaxies in the area of 2}' $< \alpha < 10^h$ and $0° < \delta < 36°$, can be summa arized as follows: (1) Our data extended some otically known concentrations and revealed some new ones, but the possibility of a nearby, very rich supercluster can probably be ruled out in this region. (2) Several voids are unambiguously identified. In particular, a large void between $\alpha \approx$ 3}' and 4^h, up to $v_h \sim 6000$ km/s, separates the Pisces-Perseus supercluster at $\alpha <$ 3}' from structures at $\alpha > 4^h$. (3) There are excessive galaxies around v $\sim$ 5000 and $\sim$ 8500 km s^{-1}, respectively. The latter '(wall" appears to gradually diffuse out after it enters the Zone of Avoid ance from tile northern Galactic. hemisphere.

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