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The South West Extension of the Perseus Supercluster

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Summary. We present the results of a redshift survey, almost complete to $m_{ph}=14.5$, covering 270 square degrees between R.A. 23^h20^m and 01^h00^m and DEC 21°30′ and 33°30′. This area lies at the extreme south west region of the Perseus supercluster.

New redshift determinations have been obtained for 44 galaxies. Adding the data available in the literature a total of 93 galaxies out of 99 with $m_{ph} \leqq 14.5$ have a measured radial velocity.

It is shown that the Perseus supercluster extends westward beyond the limits of previous surveys and that the general distribution of galaxies is suggestive of a "cell" structure.

Key words: supercluster of galaxies – radial velocities of galaxies

1. Introduction

The existence, in the southern galactic hemisphere, of a rich supercluster of galaxies in Perseus and Pisces was reported several times in the past, starting from Proctor (quoted by de Vaucouleurs, 1978a), and has been recently discussed by Tifft and Gregory (1978) and Joever and Einasto (1978). Gregory et al. (1981, hereafter GTT) have performed a redshift survey, complete to $m_{ph}=14.0$ in the supercluster area. They have found that most of the galaxies are actually grouped in a quite narrow redshift range.

Similar spectroscopic evidence for the existence of further large superclusters and of complementary large voids, having linear scales as large as 100 Mpc (adopting $H=100$ km s^{-1} Mpc^{-1}), has been accumulated in the last few years. Besides the systematic work by de Vaucouleurs and collaborators on the local supercluster (see de Vaucouleurs 1978b and references therein), detailed spectroscopic information has been collected in the region of Coma – A 1367 (Gregory and Tifft, 1976) and Hercules – A 2197–A 2199 (Tarenghi et al., 1979, 1980). In this last region, Chincarini et al. (1981) have recently observed a low density bridge of galaxies connecting different Abell clusters, which confirms an early suggestion by Ekers et al. (1978). Moreover, evidence for the existence of a volume of 10^6 Mpc^3 devoid of bright galaxies has been recently reported by Kirshner et al. (1981), in a random selected field at high galactic latitude.

The statistical significance of galaxy grouping and of void existence *in each single field* has been sometimes questioned because of the *a posteriori* choice of angular and redshift ranges for both groups and voids. Nevertheless the set of these works give a convincing evidence of the existence of superclusters and of the general characteristic "that galaxies located outside of superclusters are found in groups or clusters and that large volumes of space . . . are devoid of (at least) highly luminous galaxies" (GTT).

Analysing the distribution of the available radial velocities of nearby Zwicky clusters in a wide area of the south galactic polar cap, which encloses the Perseus supercluster, Einasto et al. (1980, hereafter EJS) outlined the presence of filaments and sheets surrounding a large void (the Pisces void). They suggested that such a "cell" structure is characteristic of the overall distribution of galaxies: flattened sheets populated by galaxies should surround large empty regions. Superclusters should be outstanding features located at the tips or sides of the cells.

Such a picture sets severe constraints to the process of galaxy and cluster formation from the post recombination universe and seems to definitively rule out pure gravitational instability models in favour of models assuming the growth of structures as induced by non linear gas dynamical processes (Zeldovich, 1978, and references therein).

Actually, the above mentioned results by Chincarini et al. and Kirshner et al. fit in a straightforward way into the scheme of EJS. However, several complete redshift surveys are needed in order to state the general existence of bridges and intersections between clusters and clusters chains.

In this context we present here the results of a redshift survey covering 270 square degrees and almost complete to $m_{ph}=14.5$. The surveyed area extends from the west side of the Perseus supercluster, as defined in the GTT survey, toward and beyond the suggested western limit of the chain of clusters.

2. The General Structure of the Perseus Supercluster

The main structure of the Perseus supercluster is defined by a long chain of Abell clusters and rich groups of galaxies: A 426 (the conventional Perseus cluster), NGC 1129 group, A 347, A 262, NGC 507 and NGC 383 clusters. They are aligned with P.A. of 65° and span about 40 degrees on the sky. Radial velocity measurements in each cluster (Chincarini and Rood, 1971; Tifft et al., 1975; Hintzen, 1980; Hintzen et al., 1978; Moss and Dickens, 1977) have shown they have very similar redshifts, with a mean value of 5290 ± 200 km s^{-1}. The redshift survey performed by GTT, complete to $m_{ph}=14.0$, covers 13 fields of the Zwicky Catalogue (Zwicky et al., 1961–1968) and includes the above mentioned clusters and groups. Out of 141 galaxies, 116, including most of the "field" ones, result to be members of the supercluster.

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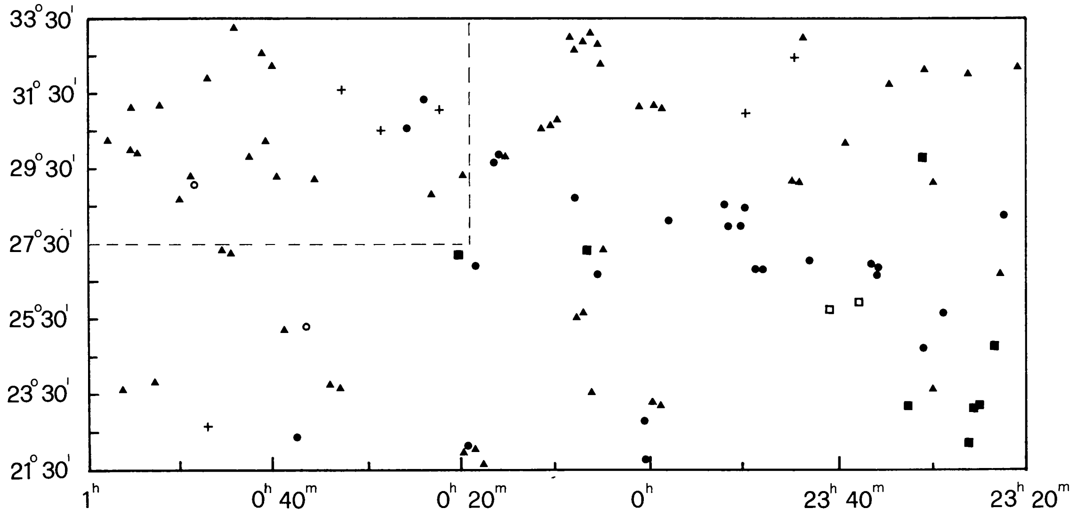

Fig. 1. Map showing the positions of the galaxies brighter than $m_{ph}=14.5$ in the surveyed area. Different symbols denote different velocity ranges: a) empty squares: $v_0<1000$ km s^{-1}; b) filled squares: $1000<v_0<4200$ km s^{-1}; c) triangles: $4200<v_0<6000$ km s^{-1}; d) filled circles: $6000<v_0<10{,}000$ km s^{-1}; e) empty circles: $v_0>10{,}000$ km s^{-1}; f) crosses: redshift unknown. Dashed lines trace the boundary of the area in common with the GTT's survey

No detailed study is possible eastward of A 426, because of the heavy galactic extinction. However, an analysis of the redshift distribution of the ScI sample of Rubin et al. (1976) suggests that the supercluster extends eastward, emerging from the galactic obscuration at R.A. $=7^h$ (Chincarini and Rood, 1979). Actually, the only direct information available in the heavily dimmed region is the presence of a cluster around 3 C 129 ($04^h45^m+45°$; $b^{II}=0.°1$) with velocity $v=6400$ km s^{-1} (Spinrad, 1975).

The area surveyed in the present work lies south west of the NGC 383 group, along the axis of the Perseus chain and extends beyond its supposed western limit (EJS). In this sky area the maps of the galaxy distribution (see, e.g., EJS, Fig. 2a and b) suggest a further extension of the chain, despite the fact that two Abell clusters on the same line, A 2666 and A 2634, have larger redshifts. A 2634 ($\alpha=23^h36^m$, $\delta=26°45'$) is a distance 1, richness 1 cluster, with mean redshift 9400 km s^{-1} and total dispersion 930 or 540 km s^{-1} (Scott et al., 1977), depending on whether some galaxies with velocity less than 7000 or larger than 10,000 km s^{-1} are considered cluster members. EJS consider A 2634 as the main member of a further supercluster, the Pegasus one. A 2666 is a quite poorly populated cluster with mean velocity 7952 km s^{-1} and total dispersion 454 km s^{-1}.

3. The Present Survey

This survey covers 270 square degrees, between R.A. 23^h20^m and 01^h00^m and between DEC 21°30′ and 33°30′ (Zwicky fields nos. 476–480 and 497–501). 99 galaxies brighter than $m_{ph}=14.5$ are present in this area. Most of them are "field" galaxies, denoting with this term any galaxy not in a rich cluster (Felten, 1977). In fact the presence of well recognizable clusters and groups affects only marginally the projected distribution: two galaxies are members of A 2634, two of A 2666, and three of a group around NGC 80. The limit in magnitude of $m_{ph}=14.5$ corresponds to $M_{ph}=-19.0$ at the supercluster distance, $M_{ph}=-20.0$ in A 2666, and $M_{ph}=-20.4$ in A 2634.

Figure 1 shows the projected distribution of the galaxies in the sample. Dashed lines trace the boundary of the area in common with GTT.

Redshifts of 36 galaxies in the sample were found in a wide compilation of the literature available until 1980 (Palumbo et al., 1982). Redshifts of further 13 galaxies were published by GTT, Tifft (1981) and Marano and Vettolani (1982). We have obtained new radial velocities for 44 galaxies. Spectra of further 4 galaxies were useless or permitted only a doubtful velocity determination. For the remaining 2 galaxies no spectrum was obtained. As a result 93 galaxies out of 99 in the complete sample have a measured redshift.

Photographic spectra were obtained with the image tube spectrograph mounted at the 152 cm telescope of the University of Bologna in Loiano. They range from 350 to 700 nm, with a typical resolution of 1.2 nm. Instrumentation and reduction procedure are the same described by Marano and Vettolani (1982). By comparison with a sample of 34 measurements from different sources, they found a typical value of 120 km s^{-1} for the velocity rms error and a zero shift of -60 km s^{-1}. The comparison sample includes 17 galaxies measured by GTT and, among them, 7 out of 8 lying in the common area.

The new data, uncorrected for the zero error and corrected for the galactic rotation by adding 300 cos b^{II} sin l^{II}, are listed in Table 1.

4. Discussion

The histogram of all the available velocities is shown in Fig. 2, where the continuous line represents the *a priori* distribution for a spatially homogeneous sample of galaxies brighter than $m_{ph}=14.5$, assuming as a mean density the value computed over the whole Zwicky catalogue. Figures 3a and 3b show the cone diagrams obtained by projection on p.a. 65° (the direction of the major axis of the Perseus supercluster) and on the normal direction (p.a. 155°), respectively. The origin is set, in accordance with GTT, at R.A. $=00^h20^m$, and DEC. 29°30′.

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Table 1

UGC	NGC IC	R.A. (1950)	DEC. (1950)	CL	Mag.	v km s^{-1}	Err.	Meas. lines
12570		23 20.7	32 15	—	14.5	5480	80	2*a*, 4*e*
12594	N 7660	23 23.3	26 45	E	13.9	5910	138	3*a*
12616	N 7680	23 26.1	32 08	E–SO	13.5	5320	180	5*a*
12646		23 29.1	25 40	SBb	14.4	8340	195	3*a*, 3*e*
12655		23 30.0	23 39	SO	14.0	5340	88	4*a*
12657		23 30.2	29 11	SO	14.5	5620	170	4*a*
12666		23 31.2	32 06	Sc	14.5	5460	130	5*a*
12667		23 31.3	29 48	Sc	13.5	4043	174	2*e*
12668	N 7698	23 31.5	24 40	SO	14.5	7270	50	5*a*
12741		23 39.4	30 19	Sa	14.4	5490	133	4*a*, 3*e*
12772	N 7747	23 43.0	27 06	SBb	14.5	7780	105	3*a*
12829	N 7777	23 50.7	28 01	SO	14.5	7210	120	3*a*, 1*e*
12835		23 51.4	28 13	E	14.4	7310	99	4*a*
12840		23 52.0	28 36	SB0	14.3	7310	250	3*a*
12899		23 58.2	28 08	comp	14.4	9170	181	2*a*
12908	N 7805	23 58.8	31 09	—	14.3	5330	116	2*a*
14		00 01.0	22 56	Sc	14.0	7450	50	2*a*, 1*e*
60	I 1530	00 04.7	32 20	Sb	13.4	5270	130	3*a*, 2*e*
68		00 05.6	26 44	SB	14.4	9100	80	4*e*
77	N 13	00 06.2	33 10	Sb	14.2	4990	100	3*a*
78	N 9	00 06.3	23 33	Pec	14.5	4800	96	5*e*
84	N 20	00 06.9	33 03	E–SO	14.5	5300	171	4*a*
96	N 27	00 07.9	28 44	S	14.5	8130	73	2*a*
98	N 21	00 08.0	32 43	SBb	13.9	5100	215	2*a*
100	N 29	00 08.1	33 05	Sb–c	13.5	4830		1*e*
114	N 39	00 09.7	30 47	Sc	14.4	5050		1*e*
120	N 43	00 10.4	30 39	SBO	13.9	5000	90	5*a*
130		00 11.3	30 37	—	14.2	5340	160	2*a*
198	I 1543	00 18.3	21 36	S	14.2	5960	100	2*a*
202		00 18.5	26 57	SBO	14.5	9570	219	3*a*
221		00 20.6	27 10	—	14.5	4070	50	2*e*
255	N 112	00 24.2	31 25	S...	14.5	6550	200	4*a*[a]
411		00 36.8	25 22	comp	14.5	10560	108	2*a*
425		00 37.5	22 26	SBpec	14.5	6280	168	2*e*
459	N 226	00 40.2	32 18	—	14.4	4800	162	2*e*
465		00 41.1	32 35	SBa	14.5	4980	77	4*a*
478		00 43.7	29 58	Sa	14.5	5250	81	2*a*
491	N 252	00 45.3	27 21	SO	13.4	5410	200	2*a*
524		00 48.9	29 08	SBb	14.5	11090	166	3*e*
529		00 49.4	29 24	SO–a	14.3	5820	195	3*a*
540		00 50.2	28 45	—	14.1	5280	154	3*e*
573	N 304	00 53.4	23 51	—	14.0	5110	136	5*a*
598		00 55.1	31 13	SO–a	14.4	5410	86	2*a*
612		00 56.3	23 35	—	14.5	5270	50	3*a*

[a] Mean of two spectra

From Figs. 2 and 3a and b a relevant concentration of galaxies with $v_0 \simeq 5000$ km s^{-1} is apparent. After the exclusion of galaxies lying in the area in common with GTT, the concentration is still apparent (Fig. 2, hatched area). This proves the extension of the Perseus supercluster well far from the main cluster chain. Only in the extreme south west side of the surveyed area one gets the impression of a fading of the 5000 km s^{-1} "belt" of galaxies.

In the foreground the following features emerge: a) two nearby galaxies: NGC 7741, $v_0=958$ km s^{-1}, and UGC 12732, $v_0=985$ km s^{-1}. A third possible member of the same group, DD 0220 ($v_0=1036$ km s^{-1}) is fainter than the limiting magnitude of our sample. b) a well defined group of galaxies (NGC 7664, 7673, 7677, 7678, 7712, UGC 12667), centered at about 23^h25^m, $+26°$. It has $\bar{v}_0=3754$ km s^{-1} and $\sigma=297$ km s^{-1}. Two further galaxies with radial velocities in the same range, NGC 16 and UGC 221, lie at a projected distance of 8 and 11 Mpc, respectively from the center of the group. It is, therefore, likely that they are isolated galaxies, at least within the magnitude limit of the present survey. UGC 221, with $v_0=4070$ km s^{-1}, could well belong to the low velocity tail of the supercluster.

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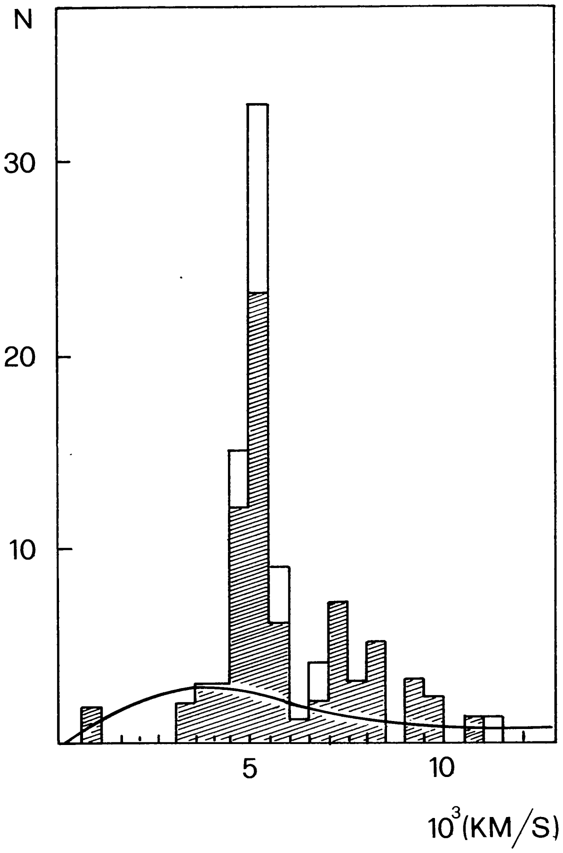

Fig. 2. Histogram of the observed redshifts. The solid line shows the expected distribution for a spatially homogeneous sample of galaxies. The hatched part of the histogram represents the redshift distribution after exclusion of galaxies lying in the area in common with the GTT's survey

A relevant percentage of galaxies populate the high velocity side ($v_0 > 6000$ km s^{-1}) of the diagrams. This could be due to the presence of a uniform distribution of galaxies in the background. However such a tail is not present in nearby areas of the supercluster, where about 80% of the galaxies brighter than $m_{ph} = 14.5$ have published redshift (Palumbo et al., 1982). GTT also conclude that a deficiency of high velocity galaxies is present in the area surveyed by them. Moreover in our survey most of the galaxies with $v_0 > 6000$ km s^{-1} are aligned along p.a. 65° (Figs. 3a and 3b), looking as if they are part of part of a structure "pointing toward" A 2666 and A 2634. We conclude that galaxies in the higher velocity range are not part of an amorphous component, but form a diffuse structure associated with rich clusters and filling interspaces among them. Of course, due to the magnitude limit, the sampling of such a structure is quite poor and the study of redshifts of a deeper sample is necessary in order to confirm this conclusion.

On the basis of the velocity distribution (Figs. 2 and 3) and according to the previous discussion we shall adopt the convention that all the galaxies with $v_0 < 4200$ and $v_0 > 6000$ km s^{-1} are not

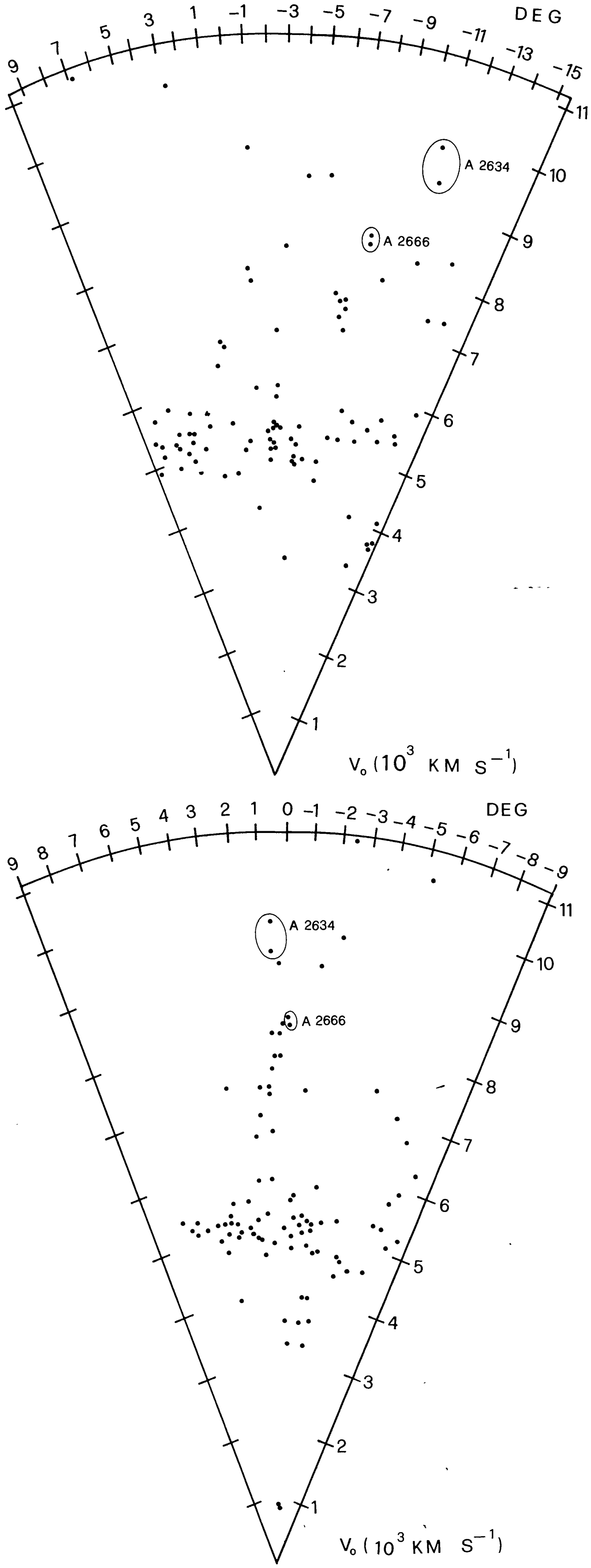

Fig. 3. **a** Cone diagram obtained by projection on a line in p.a. 65° NE at left. **b** Cone diagram obtained by projection on p.a. 155° NW at left

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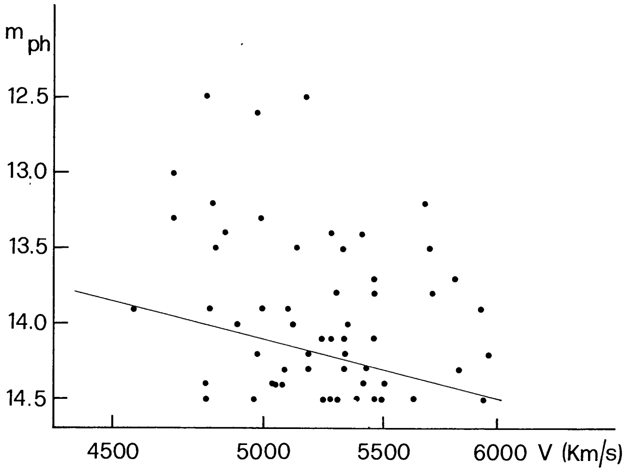

Fig. 4. Redshift magnitude diagram for galaxies in the 4200–6000 km s^{-1} interval. The solid line shows the locus of points with $M_{ph} = -19.4$, assuming that radial velocity represents cosmic distance

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supercluster members. On the remaining 57 supercluster galaxies we find $\bar{v}_0 = 5240 \pm 335$ km s^{-1}. No excluded galaxy has radial velocity within a 3σ interval from the mean. The definition of the velocity range is therefore self-consistent. After correction for observational errors, assumed to be $\sigma_{obs} = 120$ km s^{-1}, the intrinsic radial dispersion results $\sigma_r = 312$ km s^{-1}.

If, however, the spread in velocity is mainly due to Hubble flow, we have to compute the mean velocity and dispersion after correction for the Malmquist bias. Assuming a pure Hubble flow this can be done restricting the sample to the galaxies brighter than $M_{ph} = -19.4$, corresponding to $m_{ph} = 14.5$ at $v_0 = 6000$ km s^{-1}. In this way we obtain a sample of 34 galaxies and find $\bar{v}_0 = 5272$ km s^{-1}. The corrected radial dispersion is $\sigma_c = 341$ km s^{-1}.

These results are directly comparable with GTT's ones. Actually GTT consider all the galaxies in the broader range 4200–7000 km s^{-1} but, being the interval 6–7000 km s^{-1} populated by only a few galaxies, the induced inhomogeneity is not relevant. They obtain $\bar{v}_0 = 5165$ km s^{-1} and $\sigma_r = 442$ km s^{-1} for the total sample and $\bar{v}_0 = 5375$ km s^{-1} and $\sigma_c = 471$ km s^{-1} after correction for the Malmquist bias. The difference in dispersion between our sample and GTT's one is significant at the 1 % level for σ_r and at the 5 % level for σ_c.

The surface density of supercluster galaxies is considerably lower in the area covered by this survey than in the GTT one: they find 104 supercluster galaxies brighter than $m_{ph} = 14.0$ on about 500 square degrees, whilst we find only 27 on 270 square degrees.

The observed velocity distribution can, in principle, be the result of any situation between the two extreme ones: a) the supercluster has a considerable level of virialisation also in this peripheral area, the lower dispersion reflecting the lower density; b) in this region the supercluster is expanding with an Hubble like flow and the dispersion reflects the depth in space of the populated volume.

In the latter hypothesis a shift of about 0.5 mag between the luminosity function of the high and low velocity tails should in principle be present. The plot of magnitudes versus velocities (Fig. 4) shows a trend of this kind. The hypothesis that galaxies with $m_{ph} = 13.0$ represent a subsample with randomly distributed velocities can be rejected at a level of significance of 0.01 by the Mann-Whitney test (see, e.g., Siegel, 1956); the same hypothesis applied to the subsample of galaxies with $m_{ph} \leq 13.5$ is rejected at a level of significance of 0.02; these results imply that the magnitudes of the brightest galaxies significantly increase with increasing radial velocity. This favours the hypothesis that the supercluster, in this region, is experiencing cosmic expansion.

5. Conclusions

By studying the velocity distribution of 93 galaxies out of 99, which constitute a complete sample in a peripheral zone of the Perseus supercluster, we obtain that: a) the presence of a well defined population of galaxies with $\bar{v}_0 = 5240$ km s^{-1} and $\sigma_r = 312$ km s^{-1} proves the further extension of the Perseus supercluster; b) as found in different fields by other authors, foreground galaxies are mainly grouped: only a few, if any, isolated galaxies are found; c) background galaxies with $v_0 < 10{,}000$ km s^{-1}, extremely rare in the area eastward of our field (the "Pisces void"), are very common in our sample and are mostly organized in a structure connected with Abell clusters having similar velocity; d) apparent magnitudes of the brightest galaxies show a trend to increase with velocity; this is an argument in favour of the hypothesis that at least a fraction of the velocity dispersion is determined by a Hubble flow within the supercluster.

The picture we obtained of this part of the Perseus supercluster differs in many details from the description given by EJS on the basis of galaxy positions and of redshifts of bright members of clusters and groups. Nevertheless our results fit in an excellent way into the "cell" model.

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