III

LARGE SCALE SYSTEMS

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THE LOCAL SUPERCLUSTER

G. de Vaucouleurs
The University of Texas
Austin, Texas 78712

1. INTRODUCTION

The first quantitative evidence for a large scale density excess or "metagalactic cloud" including the Local Group was obtained by Holmberg (1937) and confirmed by Reiz (1941). The present concept of the Local Supercluster (LSC) as a flattened aggregate of field galaxies, small groups and larger clouds centered at the Virgo cluster was formulated 25 years ago (de Vaucouleurs 1953) even before large-scale superclustering was recognized as a general phenomenon. See review papers in *Vistas in Astronomy* (1956), *Soviet Astronomy* (1960), *Science* (1970), *Publ. Astron. Soc. Pacific* (1971), and *IAU Symp. No. 63* (Abell 1974).

Although the concentration of the brighter galaxies ($m \lesssim 15$) toward the supergalactic plane could conceivably be fortuitous (Bahcall and Joss 1976), statistical tests demonstrate the very low probability of the random clumping hypothesis (1976a) and confirm the reality of the local supercluster as a physical association (1975a, b, c; de Vaucouleurs and Corwin 1975).

The first attempts to detect an anisotropy -- and in particular a rotational component -- in the velocity field of nearby galaxies were made by V. Rubin (1951) and Ogorodnikov (1952) with conflicting results. A specific disk model of the supercluster in differential rotation and expansion proposed by the author (1958, 1964, 1966, 1976b) predicts departures from a linear-isotropic Hubble flow in good agreement with observations. A spherical non-rotating model has been discussed by Peebles (1976) and a rotating-expanding spheroidal model by the author and Peters (1972). Both models indicate a measurable slowing down of the Hubble expansion by the local density excess, but a non-rotating model cannot reproduce details of the observed velocity field. The characteristic "double wave" first-order effects of differential supergalactic rotation have been detected in the velocity residuals of solar motion solutions for the nearer groups (Stewart and Sciama 1967) and, perhaps, even within the Local group (de Vaucouleurs *et al.* 1977a, b).

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A number of possible objections to these results (van Albada 1962; Sandage and Tammann 1975) have been examined in detail and found to be invalid or contradicted by concrete evidence (1964, 1976b). Further tests are presented in §§ 4, 5.

The effects of a local inhomogeneity imbedded in an isotropic background have been discussed by Silk (1974), Mavrides (1976, 1977) and others. More complex hierarchical relativistic cosmological models have been explored by Wesson (1975). Theoretical models for the origin and evolution of superclustering in general, and of the Local Supercluster in particular, have been discussed within the framework of the gravitational instability picture (Peebles 1974, Doroshkevich *et al.* 1974, 1976) or, alternatively, the primeval turbulence concept (Ozernoy 1969, 1974).

2. SUPERGALACTIC LATITUDE EFFECTS

A. Supergalactic concentration. The strong concentration of galaxies toward the supergalactic equator in the northern galactic hemisphere (NGH) is well documented at all magnitudes $m \leq 14$ (1960, 1975b) and is probably detectable down to $m \simeq 16$ (Carpenter 1961). In the southern galactic hemisphere the supergalactic concentration is significant only for the brighter galaxies ($m \leq 11$), an indication of the outlying location of the Local Group in the LSC.

The Local Group and nearby groups are concentrated toward the equator of a Local Cloud inclined 14° to the equatorial plane of the LSC (1975a); this local plane also controls the distribution of the nearest intergalactic H I clouds (de Vaucouleurs and Corwin 1975), including the Magellanic Stream and the presumed orbital plane of the Magellanic Clouds (Einasto *et al.* 1976; Mathewson *et al.* 1977; Davies and Wright 1977). More generally large galaxy clouds within the LSC tend to be flattened or elongated in directions inclined less than 35° to the equatorial plane of the LSC (1975c).

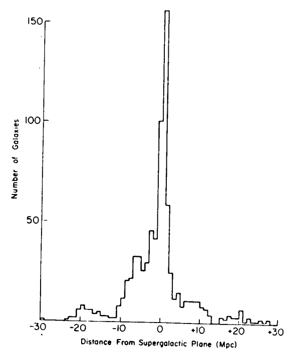

Figure 1

The nearby dwarf elliptical galaxies of the Sculptor type are also strongly concentrated toward the supergalactic equator especially in the NGH (Karachentseva 1969), as are the DDO dwarfs, and more generally the low-velocity galaxies of all types (1965, 1975a; Tully and Fisher 1977a, b). (Figure 1).

B. Orientation of galactic planes. An unpublished search by the author in 1953-54 did not detect any strong tendency of the planes of galaxies toward parallelism to the supergalactic plane either in the position angles of the major axes of galaxies close to the SG equator in the Reinmuth catalogue (1926) nor in the distribution of the poles of 202

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large spirals in the Danver catalogue (1942).

However, according to Reinhardt and Roberts (1972), the ellipticity of galaxies in the (first) *Reference Catalogue* (RC1) is greater in low galactic latitudes. An unpublished analysis of the mean ellipticity of lenticular and spiral galaxies in the *Second Reference Catalogue* (RC2) by type and SG latitude confirms this finding: galaxies of a given type tend to have greater than average ellipticity near the SG equator; however, the effect is indicated in both galactic hemispheres which detracts from its significance.

C. Color excess. A tendency for galaxies of a given type to appear redder than average in low supergalactic latitudes was detected by Takase (1972) from an analysis of the corrected colors C_0 of 510 galaxies in RC1. This result was confirmed by an independent analysis of color residuals of 262 galaxies from new McDonald data (de Vaucouleurs *et al.* 1972). This effect was interpreted as evidence for intergalactic extinction and reddening (see also Schmidt 1975), or, alternatively, as an effect of local density on the composition and intrinsic colors of galaxies (Abadi and Edmunds 1976).

However, because the galactic and supergalactic equators are nearly orthogonal, there is a loose negative correlation between galactic and supergalactic latitudes; as Gula *et al.* (1975) have noted this makes the results sensitive to errors in the galactic extinction correction. A new, detailed analysis of the fully corrected total colors $(U - V)_T^o$ of 468 galaxies in RC2 fails to detect any significant color excess near the supergalactic plane in either hemisphere. It is not clear why the two previous studies showed a positive effect, but the nil result from the new data which are far superior in quality and quantity has greater weight.

D. Intergalactic extinction. There is some evidence for an anti-correlation between counts of faint galaxies and clusters and supergalactic latitude B. An unpublished study by the author in 1954 indicated a negative correlation between the apparent surface density of bright galaxies ($m < 13$, Shapley-Ames) and faint galaxies ($m < 21$, Hubble counts). Zwicky (1962) has commented on the marked deficiencies of VD and ED clusters in the areas covered by the Virgo cluster and Ursa Major Cloud along the SG equator. This conclusion is confirmed by Holmberg's (1974) analysis of the distribution of Zwicky's D, VD and ED clusters; the observed deficiency in the Virgo area could be explained by an intra-cluster extinction of 0.25 mag. This needs to be confirmed by a study of colors.

3. SUPERGALACTIC LONGITUDE EFFECTS

The apparent distribution as a function of SG longitude L of galaxies in the equatorial belt ($|B| < 30°$) is an important indicator of the structure of the LSC; in particular the direction of the SG center is consistently determined to be that of the Virgo cluster ($L = 104°$) whether

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low latitudes ($|B| < 10°$) are included or not. This result holds at all magnitudes $11 < m < 14$ (1975b) within statistical fluctuations caused by the cloud structure of the LSC. Only the nearest galaxies and groups ($\Delta < 10$ Mpc) show pronounced departures; in particular, several nearby groups and clouds are concentrated in the UMa-CVn area ($L < 90°$) (1965, Figure 3).

4. SUPERGALACTIC KINEMATICAL EFFECTS

Systematic departures from the ideal linear-isotropic Hubble expansion are an important corollary of the supergalactic hypothesis. A rotating-expanding model of the LSC accounts for the observed departures with a minimum number of free parameters (1958, 1964, 1966, 1972, 1976b). Several possible objections or alternative interpretations have been examined and tested as follows:

(a) The velocity anisotropy does not exist or is not significant (Bahýl 1974; Sandage and Tammann 1975 = ST V). The data on Sc I and nearby groups presented in ST V have been examined in detail (1976b). They show the same typical velocity anisotropy with the same phase and amplitude (at given modulus μ_0) as had been previously derived from the totality of available (m,z) data (*loc. cit.*, Figs. 5-7). Tully and Fisher (1977a, b) have confirmed the center-anticenter anisotropy in their extensive sample of nearby spirals and irregulars.

(b) The anisotropy of the (m,z) relation could conceivably be produced by an anisotropy of the distribution of absolute magnitudes at given m (van Albada 1962), but detailed examination of the supergalactic distribution of luminosity classes shows that no such effect is present (1964).

(c) Another possible cause of anisotropy is the dependence on space density of the effective mean distance of a magnitude-limited sample in the presence of a significant dispersion σ_M of absolute magnitudes (Teerikorpi 1975). While this bias can account for apparent departures from linearity in z(m) in some directions and in some data, it does not follow that the anisotropy of the relation is in fact and quantitatively the result of the supergalactic anisotropy of the space density of galaxies. Two tests are possible:

(I) Compare the amplitudes of the velocity anisotropy derived from several magnitude-limited samples having different dispersions

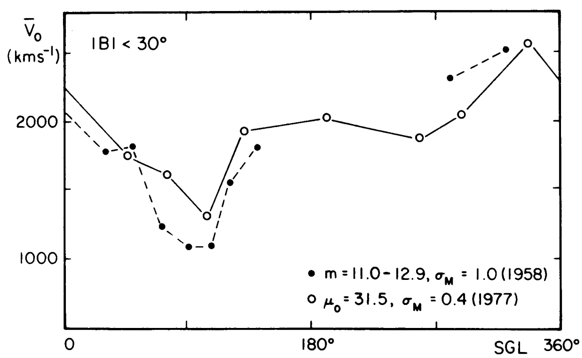

Figure 2

TABLE 1. NORTH-SOUTH MODULUS ANISOTROPY AT z = constant †

Data	log V_o	$\Delta\mu_o$(B − E)	N_B, N_E	$\sigma(\mu_o)$
ST V, Sc I	2.8–3.3	+0.82 ± 0.22	19, 9	0.51, 0.63
T > 2, $0.5 \leq \Lambda \leq 1.4$	2.8–3.2	+0.46 ± 0.10	92, 27	0.43, 0.60

† area B (60° < L < 120°), area E (240° < L < 300°), both $|B| < 30°$.

σ_M; since any statistical bias is proportional to σ_M^2 the anisotropy should decrease as σ_M^{-2} if it is a statistical artifact, but should be independent of σ_M if it is a real property of the velocity field. Fig. 2 shows the dependence of $< V_o >$ on SGL for 2 corresponding samples, one of old data having a large dispersion $\sigma_M \simeq 1.0$ mag (m = 11.0–12.9, de Vaucouleurs 1958, Table 1) and one of the latest data for which $\sigma_M \simeq 0.4$ mag ($< \mu_o > = 31.5$, see § 5). The amplitude is only slightly less in the new data.

(II) Compare the absolute magnitudes (or distance moduli μ_o) derived from the m(z) relations in a bias-free range of z. Table 1 shows two recent estimates for the north and south galactic polar caps (60° x 60° areas B and E in de Vaucouleurs 1976b, Fig. 1); the first is from 28 Sc I galaxies with μ_o derived from H II regions (Sandage and Tammann 1975; de Vaucouleurs 1976b, Tables 4 and 7); the second is from 119 spirals (T > 2, Sb or later) having a luminosity index Λ = (L+T)/10 in the range $0.5 \leq \Lambda \leq 1.4$. Both sets indicate that at the mean redshift $< \log V_o > \simeq 3.0$ where the statistical bias is negligible (Sandage and Tammann 1975; Teerikorpi 1975), galaxies are about 0.6 mag (or 30 percent) more distant in area B. Conversely, at a given mean distance $< \log \Delta > \simeq 10$ Mpc, redshifts are greater by about 30 percent in area E as all previous studies had indicated (1976b, Table 6).

5. MOTION OF LOCAL GROUP AND HUBBLE CONSTANT

New solutions from RC2 data are presented in Table 2 for the motion of the Local Group with respect to some 300 galaxies having distance moduli $27 \lesssim \mu_o \lesssim 33$. The distance moduli were derived from fully corrected

TABLE 2. LOCAL GROUP MOTION IN SUPERGALACTIC COORDINATES

	$< \mu_o >$	N	$< \Delta >$	$< z >$	V	L	B	$< H >$
(A)	29.70	94	8.71	0.0030	343 ± 65	64° ± 10	− 2° ±19	103 ± 5
(B)	31.20	98	17.38	0.0052	348 ± 80	102 ± 23	− 9 ±20	90 ± 3
(C)	32.17	96	27.26	0.0083	727 ±135	100 ± 18	+27 ±13	92 ± 3

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total magnitudes B_T and, independently, from isophotal diameters D_o as a function of luminosity index Λ through the formulae

$$M_T^\circ = -19.25 - 1.4(\Lambda^2 - 1), \; \log D_o = 4.23 - 0.25(\Lambda^2 - 1).$$

The zero points are fixed by 19 Local Group and nearby galaxies having revised distances $\Delta < 4$ Mpc derived from primary and secondary indicators (1977a, b). Only galaxies of revised types Sb and later ($T > 2$) and $0.45 \leq \Lambda \leq 1.55$ were considered. The standard error of the mean distance moduli derived from both B_T° and D_o is $\sigma(\overline{\mu}_o) \simeq 0.4$ mag (exclusive of zero point $\sigma_o \simeq 0.15$ mag). The solar motion relative to the extended Local Group ($V_S = 336$ km s^{-1} toward $\ell_S = 107°$, $b_S = -16°$, solution B from de Vaucouleurs *et al.* 1977, Table 1) was subtracted to calculate the Local Group apices A, B, C. The main conclusions are

(a) H is substantially constant (outside Local Group) and independent of Δ with $\langle H \rangle = 95 \pm 3$ (internal m.e., exclusive of zero points); the luminosity selection bias which results in an apparent increase of V/Δ with V or Δ (Teerikorpi 1975) is not in evidence;

(b) redshifts at μ_o = const. are systematically larger in the SGH and, if this anisotropy is attributed only to a motion of the Local Group, it implies a velocity $V_c \simeq 350 \pm 50$ km s^{-1} toward SGL $\simeq 80° \pm 10°$, SGB $\simeq -5° \pm 15°$ relative to an all-sky sample of some 200 galaxies in the distance range $5 < \Delta < 20$ Mpc (A, B shells);

(c) the Local Group apex (Fig. 3) is still in the same general direction indicated by previous studies (de Vaucouleurs and Peters 1968) and in good agreement with directions calculated from a kinematical model of the Local Supercluster (1972);

(d) at greater redshifts (C shell) the effect of solar motion is less well determined and may include a component of the systemic motion of the LSC relative to more distant galaxies. The C shell overlaps with the inner shell ($1600 < V_o < 3500$, N = 22) of the Rubin *et al.* (1976a, b) sample of distant Sc I galaxies (LG velocity $V_c = 406 \pm 164$ toward SGL = 25°, SGB = −24°, D in Fig. 3); the velocity vectors V_c agree in amplitude, but differ by ~ 90° in apex directions.

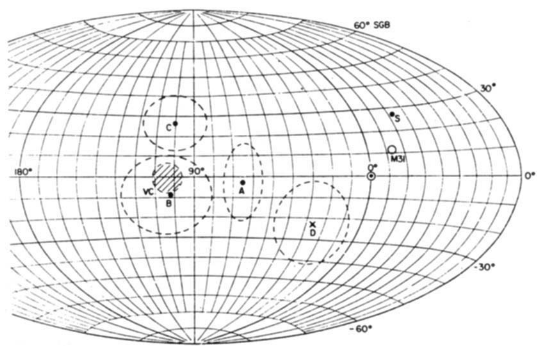

Figure 3

6. VELOCITY ANISOTROPY AT μ_o = const.

Classical cos A-term solutions have limited significance when higher-order harmonics are present, *i.e.*, when the velocity field is not merely a reflection of solar motion. Solutions of the form $\log V_o - \langle \log V_o \rangle = S(\mu_o - \overline{\mu}_o)$ were made for 262 galaxies of type $T > 2$ and in the range

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TABLE 3. VELOCITY-DISTANCE RATIOS AT μ_0 = const.

Areas L	|B|	$<\mu_0>$ from	29.0 B_T^o	log D_o	30.5 B_T^o	log D_o	31.5 B_T^o	log D_o	$<H_r>$
A,B,C		V_r	675	631	1028	1054	1720	1455	
< 180°	< 30°	H_r	107	100	82	87	87	73	89
		n	16	16	55	44	61	57	
D,E,F		V_r	853	793	1267	1408	2378	1959	
> 180°	< 30°	H_r	135	126	101	112	119	98	115
		n	7	7	18	7	16	26	
G, J		V_r	380	419	1348	1075	1752	1668	
< 180°	> 30°	H_r	60	66	107	85	88	84	82
		n	5	4	6	6	14	12	
H, K		V_r	635	685	1349	1428	2069	1777	
> 180°	> 30°	H_r	101	108	107	113	104	89	104
		n	5	5	9	7	18	13	
		$<H_r>$	101	100	99	99	99	86	97

$0.5 \leq \Lambda \leq 1.5$ for different sectors of the SG equatorial belt. The characteristic SG anisotropy is still in evidence in both $<H>$ and S even when $<\mu_0> \simeq$ const.

Another approach consists in applying differential corrections $\Delta\log V_o = +0.2(\mu_0 - \bar{\mu}_0)$ to the corrected velocities V_o in small intervals of μ_0 and calculate $<\log V_o(\bar{\mu}_0)>$ at $\bar{\mu}_0$ = const. The corresponding mean reduced velocities V_r and $V_r/\Delta = H_r$ are given by Table 3 for 4 large sectors. The mean Hubble ratio is systematically higher by ~ 30 percent in the SGH (L > 180°) at both low and high SG latitudes; further, the all sky average $<H> \simeq$ const., independent of Δ or V_o, which confirms that this sample is substantially free of statistical bias.

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DISCUSSION

Zeldovich: What is the effective flattening of the supercluster in terms of the ratio of axes of distribution of galaxies?

de Vaucouleurs: About 0.4 to 0.5 for the outer regions, see *Vistas in Astronomy*, vol. 2 (1956).

Zeldovich: Is it due to rotation?

de Vaucouleurs: No, not in the sense of a Newtonian spheroid in centrifugal equilibrium.

Zeldovich: The cosmological Hubble constant should be measured at distances where density uniformity is established - not in superclusters.

de Vaucouleurs: Of course, but we can measure directly only small distances, say < 50 Mpc, so a compromise must be accepted. Except in the heavily populated supergalactic equatorial belt in the north galactic hemisphere, H is approximately constant and independent of directions (see Table 3). $H_o \simeq 100$ km s^{-1} Mpc^{-1} should be a good enough approximation to the asymptotic, low-density value of the Hubble constant.

van der Laan: Referring to Figure 1, can you say what this diagram means? Have the space densities of galaxies been corrected for the $\cos^2\theta$ factor at high latitudes?

de Vaucouleurs: All the effect occurs very close to the supergalactic equator, $\theta = 0$, and hence these correction factors are very small in comparison with the rapid fall-off in the number density of galaxies.

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