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The local supercluster of galaxies

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Abstract. The history of the discovery of the Local Supercluster or "Supergalaxy" is traced. Recent studies of its influence on the distribution and velocities of nearby galaxies are reviewed.

Key words : galaxies — supercluster

1. Hierarchical clustering

The notion of superclustering, or clustering of the second order, can be traced back to the eighteenth century cosmological speculations of Lambert (1761) who envisioned a universe built up of a hierarchy of systems of ever-increasing content and size, all controlled by gravitation. The concept was revived by Charlier (1908, 1922) as a mathematical device to resolve, within the framework of a static, Euclidean universe, the so-called "Olbers paradox" (1826) or dark night sky problem (Harrison 1965, 1977) and its analogue for gravitation (von Seeliger 1895). Charlier showed "how an infinite universe may be built up" if it possesses a hierarchical structure that satisfies the inequality $R_{i+1}/R_i > \sqrt{N_{i+1}}$ relating the radii R and population N of systems of order i and $i + 1$. He concluded that if the "white nebulae" were island universes (i.e. galaxies), these nebulae should be part of a "nebula of the second order" which he attempted to discover in plots of the number density of nebulae listed in Dreyer's NGC (1888) as a function of galactic latitude (Figure 1). Charlier noted the large density excess in the general direction of the north galactic pole which he interpreted as evidence for the existence—and an indication of the shape—of the nebula of the second order. Although much distorted by averaging in galactic coordinates and confused by galactic extinction, Charlier's diagram was the first indication of the Local Supercluster of galaxies

Interest in hierarchical clustering nearly vanished after Charlier, mainly for two reasons: (i) the belief that the universal redshift by reducing the energy of photons received from distant sources resolves the Olbers paradox; and (ii) the working hypothesis of an isotropic and statistically homogeneous universe, introduced as a simplifying assumption by theoretical cosmologists, was soon accepted as fact and elevated to the status of dogma. Although Hubble's (1934) galaxy

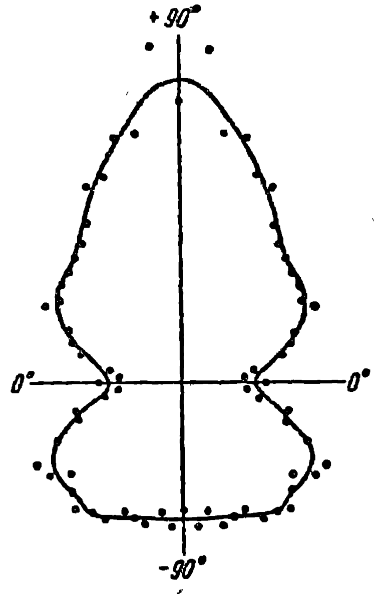

Figure 1. This diagram prepared by Charlier in 1921 of the "nebula of the second order", a plot of the surface density of NGC nebulae as a function of galactic latitude, was the first hint of a local supercluster.

counts were initially misinterpreted as evidence for random distribution, this error was quickly pointed out by Bok (1934), Bourgeois & Cox (1937, 1938) and Mowbray (1938).

Nevertheless, the search for a local or perhaps universal supersystem of galaxies was not entirely abandoned, mainly through the work of Lundmark and his pupils Holmberg, Reiz and others in Sweden. In his thesis, "A study of double and multiple galaxies", Holmberg (1937) discussed the spatial arrangement of these systems "within the nearer metagalaxy"*. He concluded that : "the existence of a large metagalactic cloud is suggested. Our own Galaxy is situated somewhat apart from the centre of it. The density at the center may be about eight times the density outside the cloud". The direction of the centre was again assumed to be toward the north galactic pole at a distance of about 1.6 Mpc on the old (Hubble 1936) distance scale—about 8 Mpc on the current scale (de Vaucouleurs 1979a,b).

A few years later, Reiz (1941) investigated the spatial distribution of over 4000 galaxies in the north galactic polar cap ($b \geqslant +50°$), counted on plates taken at

*A word on nomenclature : "metagalaxy" (or "metagalactic system") is a term introduced by Lundmark (1927) and used after him by Shapley (1957) to refer to the observable part of the extragalactic universe; it does not refer to any specific system and should not be confused with "supergalaxy," the term originally used by Shapley (1930) to describe his short-lived concept of the *galactic* system as a flat cloud of spiral galaxies. This term was initially adopted by the author (1953, 1956) to refer to the "Local Supergalaxy" or second-order cluster, which we now call the Local Supercluster (de Vaucouleurs 1960) since the discovery of the universality of the superclustering phenomenon (Abell 1957, 1961, 1967; Kiang 1967; Kiang & Saslaw 1969). The alternative designation of "Virgo supercluster" used by some authors is not appropriate for a system that encircles the whole sky and could later become a source of confusion. The word "hypergalaxy" recently coined by Einasto & co-workers (1974, 1977) to designa e dense groups formed by a dominant galaxy and its retinue of satellites, refers to one of the components of a supercluster which includes also galaxy clouds, loose groups of galaxies, and field galaxies.

Heidelberg with the 16-inch (40-cm) Bruce telescope. He too found evidence of high space densities "due to the large number of metagalactic clusters situated round the northern galactic pole... it seems likely that they form together a metagalactic supercluster or cloud. The density of the cloud may be more than five times the background density". He could not estimate the distance of the centre, but placed the far edge of the cloud in the general direction of the north galactic pole, at a distance of about 8 Mpc on the old scale—or 40 Mpc on the current scale.

It was already known from the counts of fainter galaxies at Harvard Observatory (Shapley 1934) that a large imbalance exists between the numbers of galaxies brighter than a given magnitude in the northern and southern hemispheres. The imbalance persists at least down to the 16th or 17th magnitudes, but Shapley interpreted this phenomenon as due to a large-scale metagalactic density gradient across our region of the universe rather than a local cloud of galaxies.

The significance and special interest of the Local Supercluster of galaxies was brought out by a more selective approach.

2. The supergalaxy hypothesis

The remarkable richness of the nebular fields in Ursa Major, Coma, Virgo and Centaurus, stretching roughly from north to south along the meridians of right ascension 11 to 13 hr, had already been noticed and commented upon in the nineteenth century by William and John Herschel and, especially, by Proctor (1869), who had mapped the nebulae listed in Herschel's "General Catalogue" (1864). Later, Hinks (1911) and Hardcastle (1914) also studied the distribution of the brighter galaxies. However, credit for discovering the remarkable clustering of the larger spiral and "non-galactic" nebulae in both hemispheres "roughly along the median (galactic) longitude 100°" must be given mainly to Reynolds (1921, 1923, 1924, 1934), although he failed to appreciate the significance of this fact and did not proceed to investigate it further. A few years later, Lundmark (1927) discussed the galactic distribution of 780 large galaxies, and remarked that "the spirals seem to crowd around a belt perpendicular to the Milky Way and crossing the galactic plane at $l^{I} = 100°$ and $l^{I} = 295°$". But he, too, failed to follow up on this lead

The modern material for the study of the distribution of bright galaxies is the classical Harvard survey of 1250 galaxies generally brighter than the 13th magnitude (Shapley & Ames 1932). Plots of the Shapley-Ames galaxies (Figures 2 and 3) strikingly confirm the phenomenon discovered by Reynolds. Still, Shapley & Ames (1930) merely commented on the elongated cloud of galaxies stretching across Virgo and Centaurus which they described as "an extension of the Coma-Virgo supergalaxy"; later it was often called the "southern extension" to the Virgo cluster. Finally, the first intimation that the Local Group and our own Galaxy might be regarded as an outlying condensation in the great Virgo-Centaurus cloud of galaxies came from Zwicky (1938). Inspired by the large apparent diameters of many clusters he had found with the Palomar 18-inch Schmidt telescope, he remarked that the outskirts of the galaxy cloud formed by the Virgo cluster and its "extensions" might well reach almost to the Local Group. He did not specifically consider a supercluster, however, and, as a matter of fact, in later years he and his collaborators

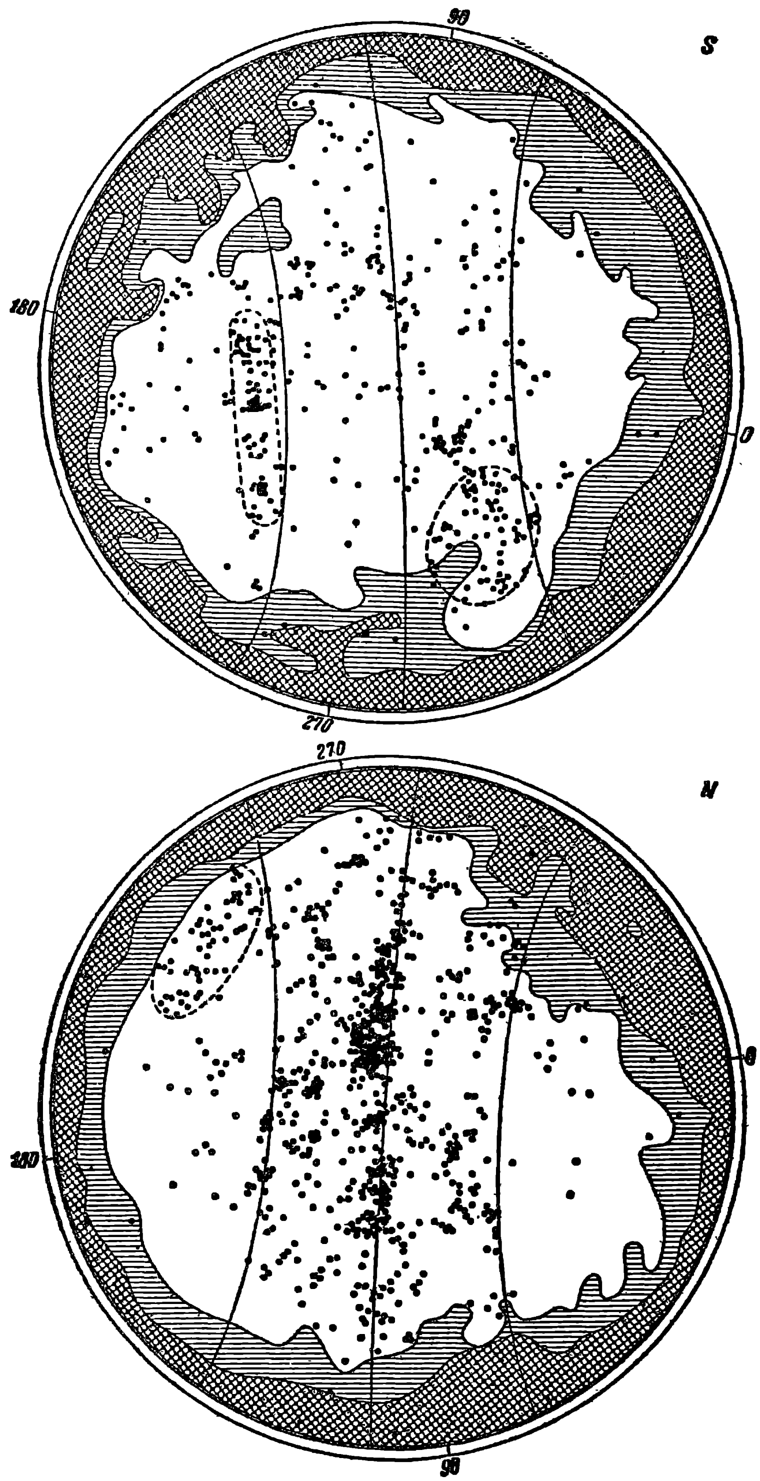

Figure 2. Distribution of the Shapley-Ames galaxies (1932) in (old) galactic coordinates. The zone of avoidance (dark) and of partial obscuration (grey) by the Milky Way is indicated. The super-galactic equator and parallels at $\pm 30°$ latitude are marked. Two external galaxy clouds in Hydra ($l^{I} = 240°$) and Pavo-Indus ($l^{I} = 310°$) and the elongated Dorado-Fornax-Eridanus stream or "southern supergalaxy" are outlined.

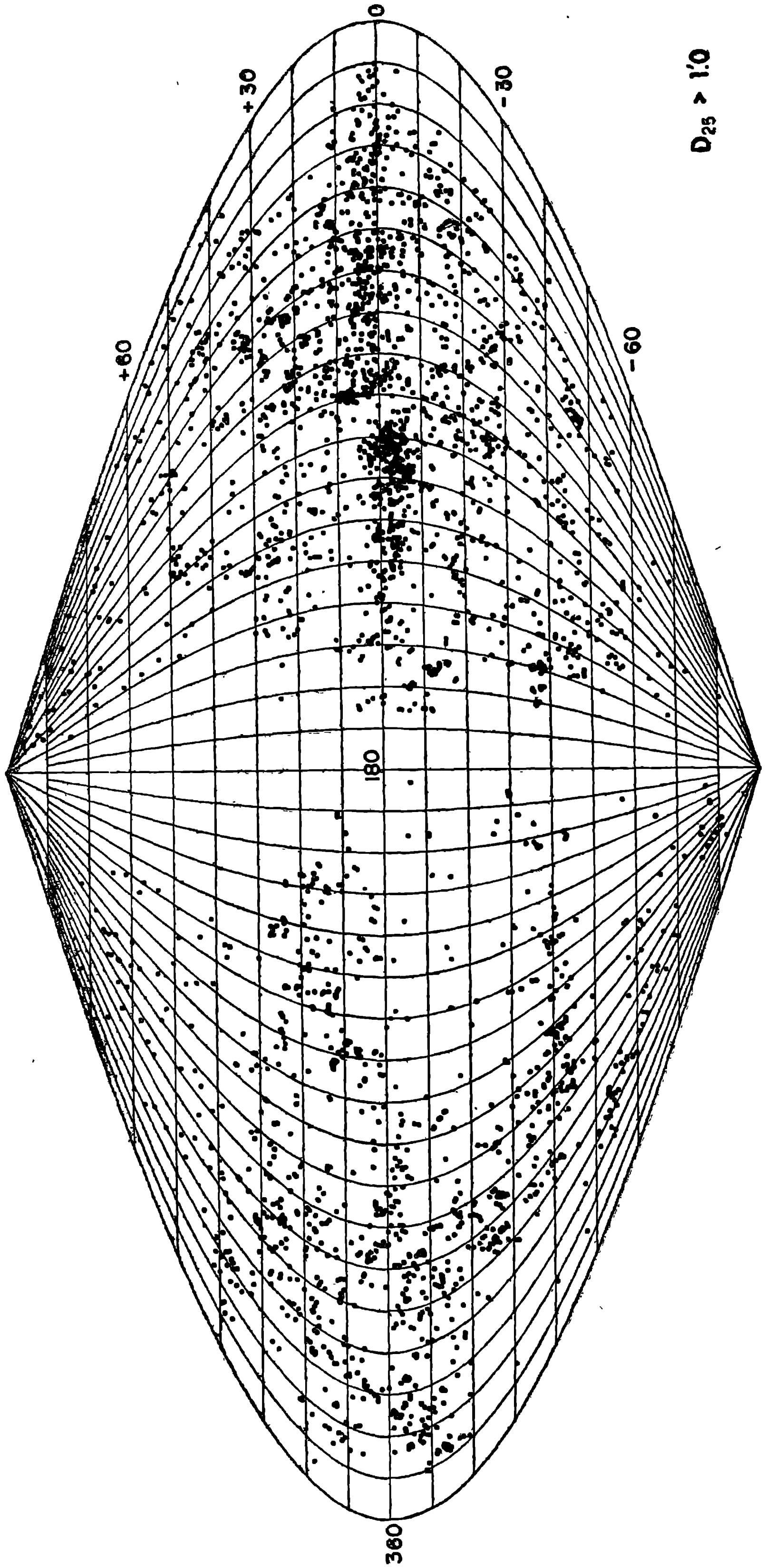

Figure 3. Distribution in supergalactic coordinates of 3456 galaxies having major diameters $D_{25} > 1'.0$ in the *Second Reference Catalogue of Bright Galaxies* (1976).

(Zwicky & Rudnicki 1966; also Karpowicz 1967, 1970, 1971). maintained vigorously that there is no second-order clustering of clusters, either locally or at large. The disagreement was partly a question of nomenclature because apparently Zwicky called "cluster" any grouping of galaxies ranging from small groups to superclusters 50 Mpc across.

The subject was reopened by the author (1953, 1956) who once again called attention to the remarkable concentration of the brighter galaxies toward and along a great circle of the sphere. This "Milky Way" of galaxies could be traced all around the sky in both hemispheres, although it is but thinly populated in the southern galactic hemisphere where it affects only the brighter galaxies. It seemed obvious that unless improbable chance encounters had accidentally brought together nearly exactly in the same plane a number of independent clusters and clouds of galaxies, this phenomenon indicated the existence of a large, flattened supersystem of galaxies including our own Galaxy and Local Group in a peripheral location reminiscent of the outlying position of the Sun in the Galaxy. The north pole of the system was placed at $l^{\rm I} = 15°$, $b^{\rm I} = +5°$ (corresponding to $l^{\rm II} = 47\overset{\circ}{.}37$, $b^{\rm II} = +6\overset{\circ}{.}32$). A supergalactic coordinate system L, B was introduced with the equator defined by the great circle best fitting the ridge line of the galaxy density distribution (de Vaucouleurs 1960). Supergalactic longitude is measured from the ascending node of the supergalactic equator on the galactic equator originally placed at $l^{\rm I} = 105°$, $b^{\rm I} = 0°$ and later revised to $l^{\rm II} = 137\overset{\circ}{.}29$, $b^{\rm II} = 0°$ to conform to the re-definition of the galactic coordinates system. Counts of galaxies in the supergalactic equatorial belt located the center in the direction of the Virgo cluster, at superglactic longitude $L = 104°$ and supergalactic latitude $B = -2°$. It seemed therefore, reasonable to assume that if the supergalaxy is a roughly circular disk-like system, the Virgo cluster is, if not the nucleus, at least a major condensation in the central part of the system.*

3. Supergalactic latitude effects

3.1 *Supergalactic Concentration*

The strong concentration of galaxies of all types toward the supergalactic plane in the northern galactic hemisphere is well documented at all magnitudes $m < 14$ (de Vaucouleurs 1960, 1975c). It is still in evidence at $m \simeq 15$ in plots of the Zwicky catalogue and is probably detectable down to $m \simeq 16$ (Carpenter 1961) (Figure 4). In the southern galactic hemisphere, the supergalactic concentration is significant

*The supergalaxy hypothesis was initially rejected by many as sheer speculation; Baade was quoted (Pfeiffer 1956) as off-handedly dismissing the observed galaxy distribution as an accidental alignment of two or three clusters with the Local Group. A historian of modern cosmology, North (1965), in his otherwise excellent book *The Measure of the Universe*, relegated the discussion of galaxy clustering and superclustering, and in particular the "Supergalaxy," to a one-page appendix, where concerning the flattening of the supergalaxy the reader is informed that "it is generally agreed that no analysis of this feature which ignores magnetohydrodynamics will be at all satisfactory." It is unfortunate that the source of this revelation was not disclosed.

As recently as 1976, some authors were still attempting to prove that the "supercluster effect" could be a random clumping accident (Bahcall & Joss 1976), but in the process they succeeded only in demonstrating how unlikely the chance hypothesis really is (de Vaucouleurs 1976a).

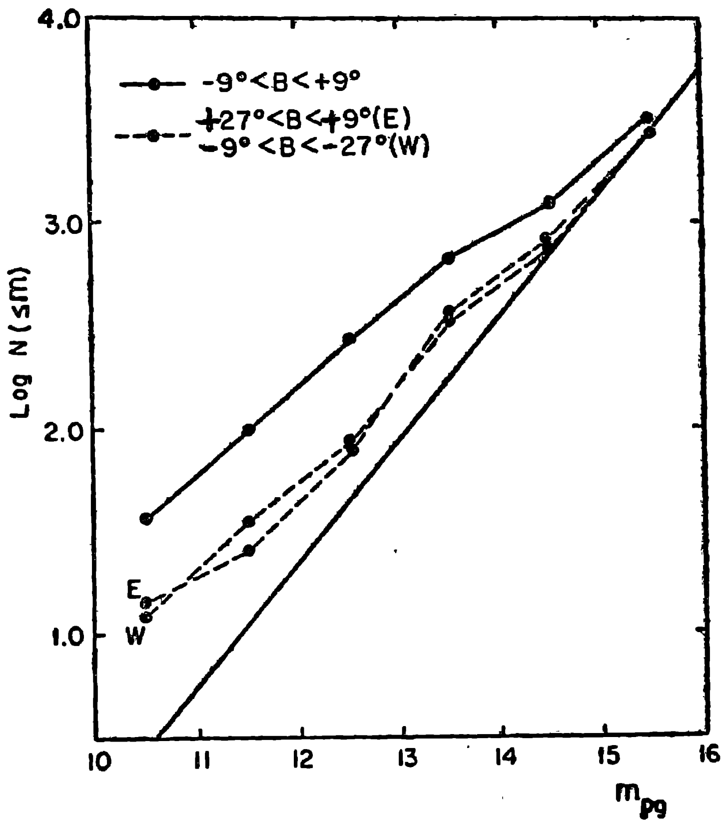

Figure 4. Counts of galaxies to the 16th magnitude by Carpenter (1961) in two zones of supergalactic latitude show a density excess over expectation for a homogeneous distribution (solid line) at all magnitudes $m < 15$; it is more pronounced in the lower latitude zone.

only for the brighter galaxies ($m < 11$), a manifestation of the outlying location of the Local Group in the supergalaxy (Figure 5).

Large galaxy clouds within the Local Supercluster (LSC) tend to be flattened or elongated in directions inclined less than 35° to the equatorial plane of the system (de Vaucouleurs 1975c). The Local Group itself and nearby groups are concentrated towards the equator of a *Local Cloud* inclined 14° to the equatorial plane of the LSC (de Vaucouleurs 1975a). This local plane controls the distribution of the nearest interglactic H I clouds (de Vaucouleurs & Corwin 1975) including the Magellanic Stream and the presumed orbital plane of the Magellanic Clouds (Einasto *et al.* 1976; Mathewson *et al.* 1977; Davies & Wright 1977; de Vaucouleurs 1976b; Kunkel & Demers 1976).

The nearby dwarf elliptical galaxies of the Sculptor type are also strongly concentrated toward the supergalactic equator, especially in the northern galactic hemisphere (Karachentseva 1969) as are the DDO Magellanic dwarf irregulars (de Vaucouleurs 1975b) and more generally the low velocity galaxies of all types (de Vaucouleurs 1975a,b; Tully & Fisher 1978) (Figures 6, 7).

3.2 *Orientation of Galactic Planes*

Other effect are less well established. An unpublished search by the author in 1953–54 failed to detect any strong tendency of the planes of the galaxies toward parallelism to the supergalactic plane either in the position angles of the major axes

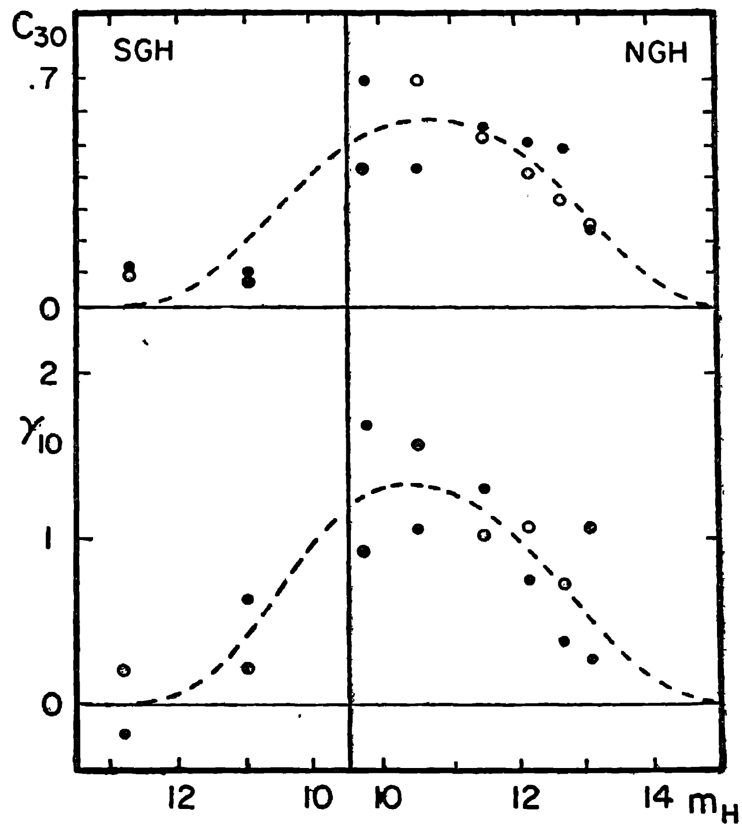

Figure 5. Supergalactic concentration indices C_{30} and γ_{10} measuring the excess density of Shapley-Ames galaxies within 30° and 10° of the supergalactic equator as functions of apparent magnitude on the Harvard scale. The supergalactic centre sector is in the north galactic hemisphere (at right), the anti-centre, in the southern hemisphere. The outlying location of the Galaxy in the "Super-galaxy" is indicated by the vanishing concentration at $m \gtrsim 11$ in the southern hemisphere, while it is still strong at all $m < 14$ in the northern hemisphere.

of galaxies close to the supergalactic equator in the Reinmuth catalogue (1926) or in the distribution of the poles of 200 large spirals in the Danver catalogue (1942).

However, Reinhardt & Roberts (1972) reported that the mean apparent ellipticity of galaxies in the (first) Reference Catalogue of Bright Galaxies (RC1) (de Vaucouleurs & de Vaucouleurs 1964) is greater at low supergalactic latitudes. Nilson (1974) was led to a similar conclusion from an analysis of his galaxy catalogue (UGC, Nilson 1973). An unpublished analysis of the mean ellipticity of disk galaxies (lenticulars and spirals) in the Second Reference Catalogue (RC2) (de Vaucouleurs, de Vaucouleurs & Corwin 1976) by type confirms this finding: galaxies of a given type tend to have greater than average ellipticity near the supergalactic equator; surprisingly, the effect is noticeable in both galactic hemispheres. It is difficult to find a plausible explanation for this result.

In apparent contradiction to these results Jaaniste & Saar (1977) concluded from a study of 1027 galaxies from RC1 and UGC generally within 25 Mpc ($V < 2500$ km s^{-1} or $m < 12.5$) that their spin axes tend of be aligned parallel of the supergalactic plane. They point out that (a) exclusion of near face-on galaxies in previous work tends to bias the statistics and (b) inclusion of objects external to the Local

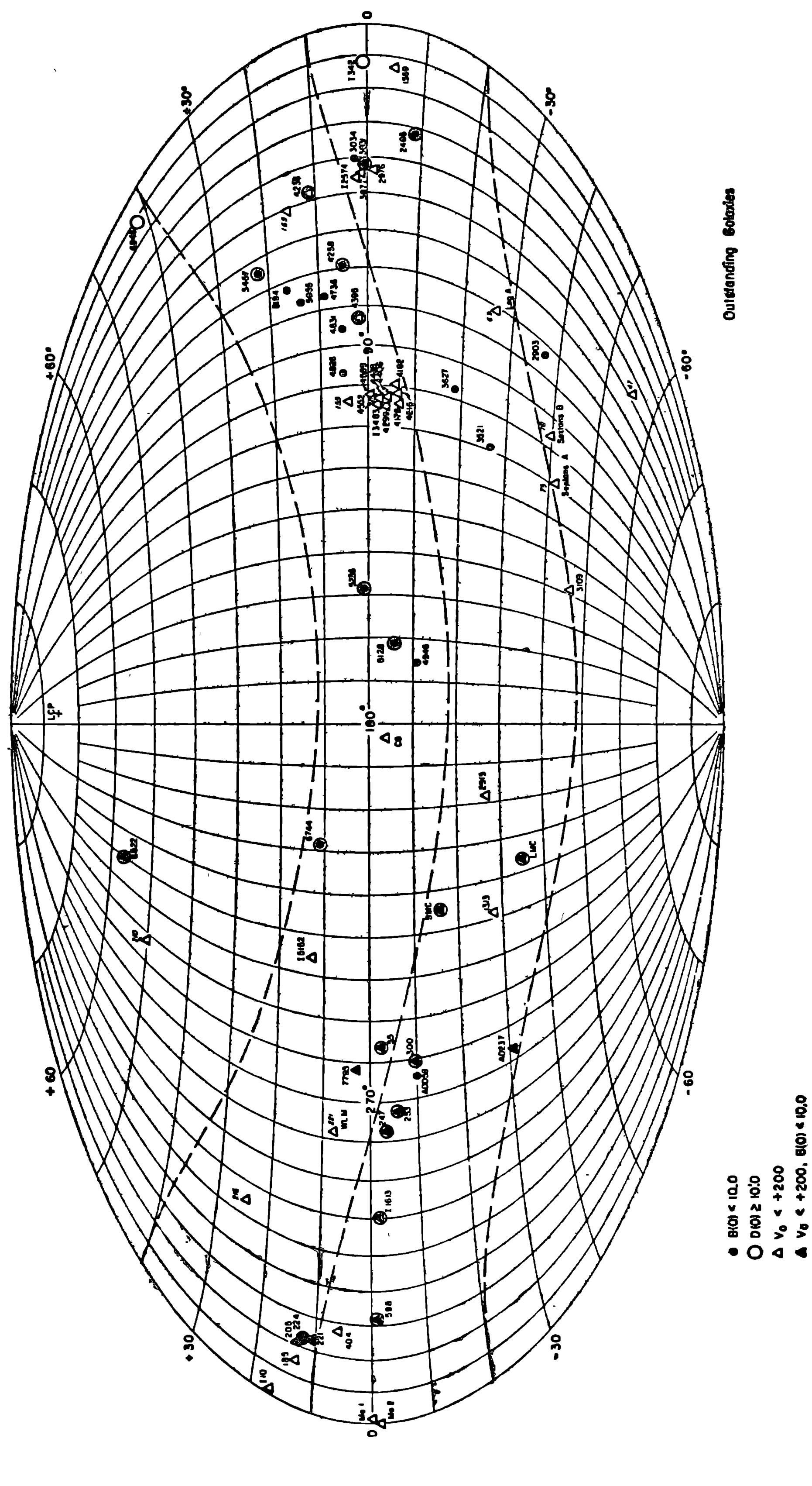

Figure 6 (a). The nearest galaxies are concentrated toward the equator of a Local Cloud of galaxies which is inclined 14° to the main supergalactic plane.

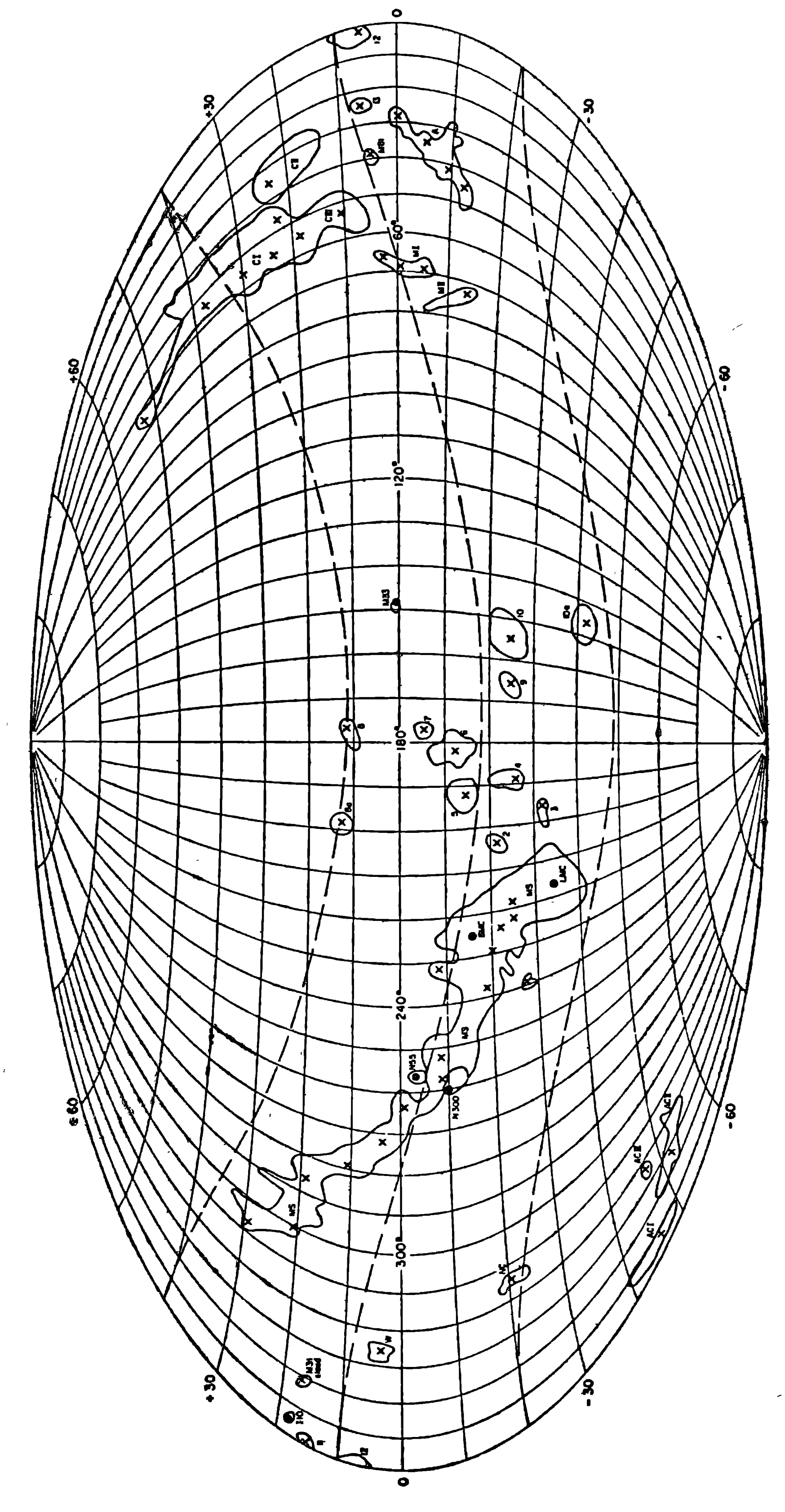

Figure 6 (b). High-velocity H I clouds are also concentrated toward the equator of a Local Cloud of galaxies which is inclined 14° to the main supergalactic plane.

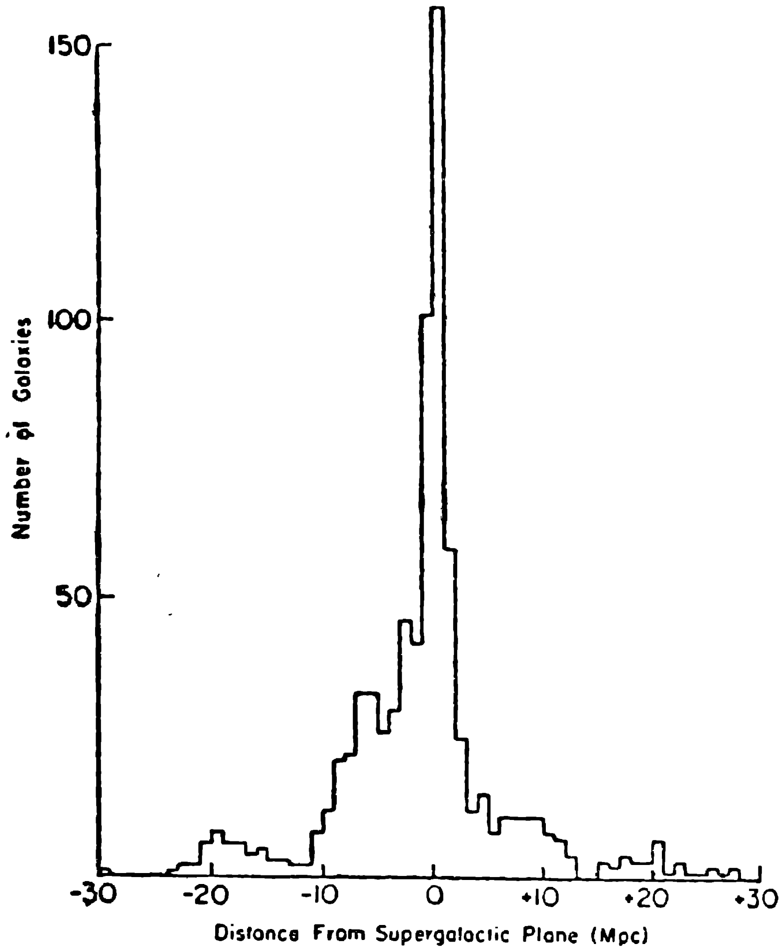

Figure 7. The strong concentration of nearby galaxies to the supergalactic plane is strikingly illustrated by this graph prepared by Tully & Fisher (1978) showing the space density of low-redshift galaxies as a function of distance to the supergalactic plane (in megaparsecs) in the northern galactic hemisphere.

supercluster, particularly members of the Perseus supercluster whose plane is almost orthogonal, had probably confused previous studies. It is interesting to note that the plane of our own Galaxy is very nearly normal ($i = 85°$) to the supergalactic plane. Had the two systems been co-planar, most of the nearby galaxies would have been hidden in the zone of avoidance and detection of the Local Supercluster would have been much more difficult.

3.3 *Colour 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 colours C_0 of 510 galaxies in RC1. This result was confirmed by an independent analysis of colour residuals of 282 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 colours of galaxies (Abadi & 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. An unpublished detailed analysis of the fully corrected total colours $(U-V)_T^0$ of 468 galaxies in RC2 fails to detect any significant colour excess near the supergalactic plane in either hemisphere. It is not clear why the two previous studies showed a positive effect, but the null result from the new data, which are far superior in quality and quantity, has greater weight.

3.4 *Intergalactic Extinction*

There in 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 densities 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 supergalactic 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 colours.

4. Supergalactic longitude distribution and shape of supercluster

The direction of the supergalactic centre is determined by the apparent density distribution of galaxies in the equatorial belt ($|B| < 30°$) as a function of supergalactic longitude L. This direction coincides with that of the Virgo cluster ($L = 104°$) whether the cluster itself is included in the counts or not, and it is the same for intermediate or low latitudes ($|B| < 10°$) (Figure 8). This result holds at all magnitudes $11 < m < 14$ (de Vaucouleurs 1975b) within the statistical fluctuations caused by the clumpy 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 ($L < 90°$) (de Vaucouleurs 1960, Figure 3).

There is also a remarkable void in velocity space beyond the Virgo cluster (Figure 9) which detracts from the initial concept of a disk-like distribution centred at the Virgo cluster. The recent discovery that many superclusters have elongated, string-like structures (Einasto *et al.* 1977) suggests that the Local Supercluster itself might have this shape. If so the belt of galaxies which marks the supergalactic equator in the north galactic hemisphere might be the trace of a roughly cylindrical structure rather than the projection of an edge-on disk or plane. Such structures have been known for a long time; examples are the Perseus Supercluster which was already apparent on maps of "General Catalogue" nebulae (J. Herschel 1864; von Humboldt 1866; Proctor 1869) and has been rediscovered many times since (Tombaugh 1937; Joeveer *et al.* 1977), and the stream of galaxies centred at the Fornax cluster, which the author described as the "Southern Supergalaxy" (de Vaucouleurs 1953).

A final determination of the true shape of the Local Supercluster will emerge only when precise distances (not inferred from redshift) become available for galaxies within 30 to 40 Mpc.

(a)

(b)

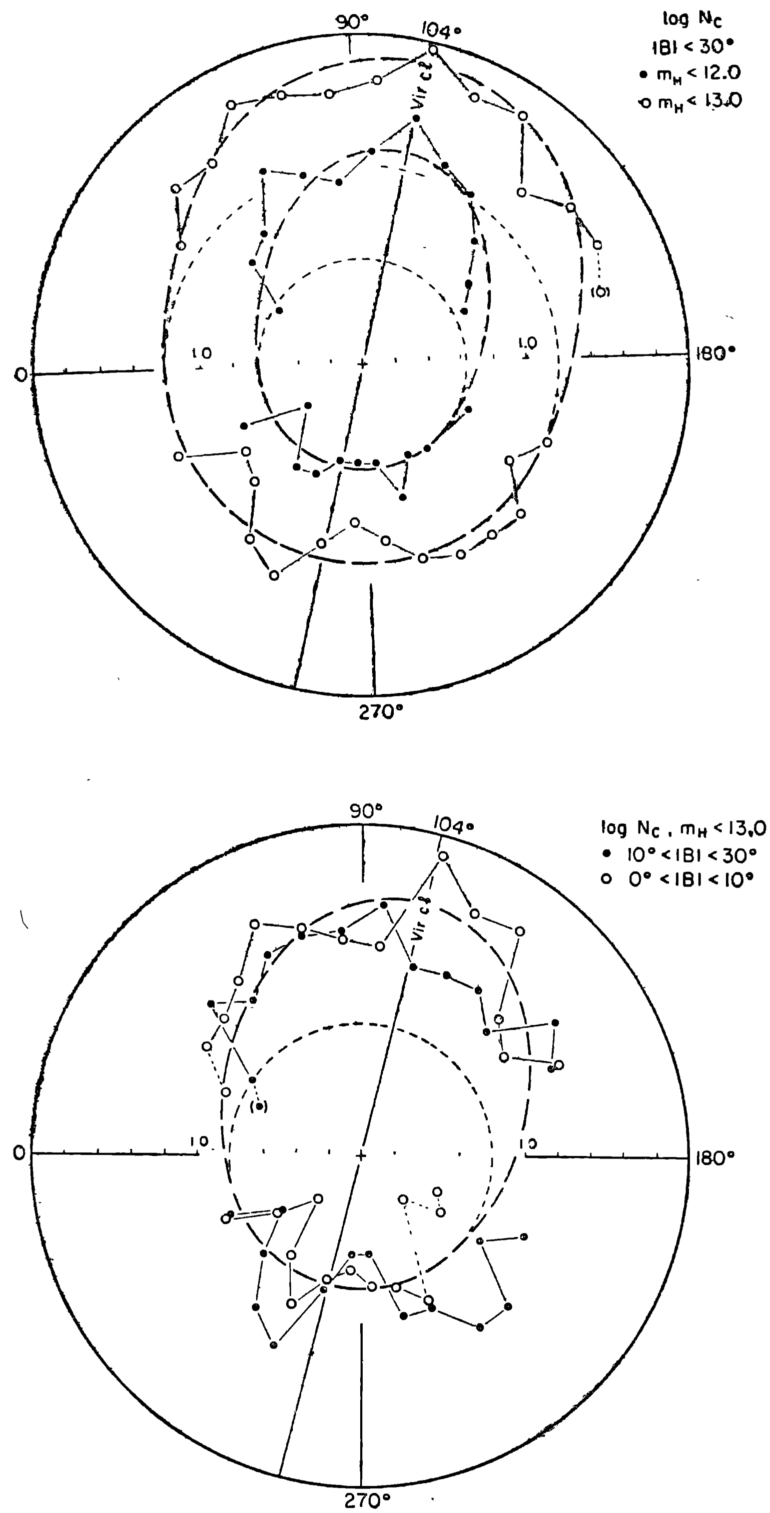

Figure 8. The longitude distributions of the Shapley-Ames galaxies (a) brighter than $m=$ 12.0 (filled circles) and $m=13.0$ (open circles) in the supergalactic equatorial belt $|B| < 30°$ (left), and (b) in two zones of supergalactic latitude $|B| < 10°$ (open circles) and $10° < |B| < 30°$ (filled circles) show that the longitude of the Virgo cluster, $L = 104°$, coincides with the direction of the supergalactic centre defined by the major axes of the curves, and that the excess density over an isotropic distribution (dashed circles) is detectabe at all longitudes within $\pm 90°$ from this centre at all latitudes $|B| < 30°$.

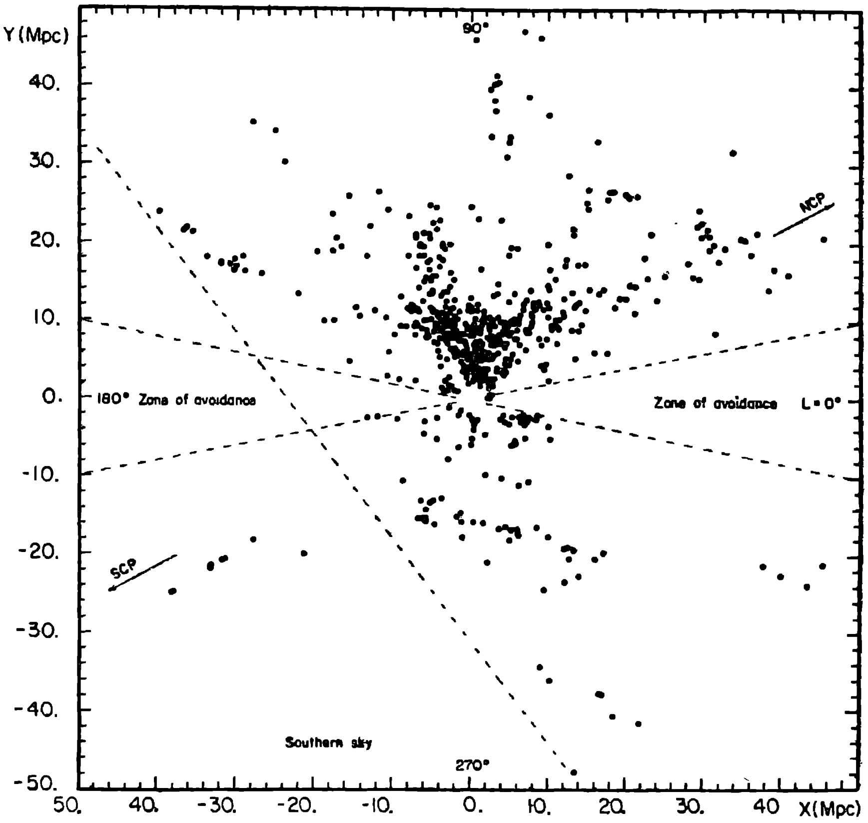

Figure 9. Distribution in velocity space of 637 galaxies within 3 Mpc of the supergalactic plane versus supergalactic longitude L. The Virgo cluster is in evidence at $L = 104°$; its fictitious needle-like shape reflects the large velocity dispersion. Note the large "vacuole" covering several tens of megaparsecs beyond the Virgo cluster. Departures from an ideal Hubble law distort the picture. The approximate borders of the vacant sectors caused by galactic extinction (zone of avoidance) and the incompletely explored southern sky are marked by the dashed lines. Galaxies within 2 Mpc (Local Group at centre of map) are not plotted.

5. Supergalactic kinematics

An important consequence of the concentration of matter in the Local Supercluster is that it will cause departures from the ideal linear, isotropic velocity-distance relation expressed by the Hubble law, $V = H\Delta$, that would be valid in a homogeneous universe. In a clumpy universe, the local expansion rate or Hubble ratio $\partial V/\partial\Delta$ cannot be a constant, but must fluctuate with the local density of matter, being lower than average (and possibly nil) in regions of high density and approaching asymptotically its low density limit, the Hubble constant, only over long paths, say in excess of 100 million light years between independent superclusters. Thus, it is generally believed that individual galaxies (mean density $\rho \simeq 10^{-23}$ g cm^{-3}) do not partake in the universal expansion, and it is often asserted that the Local Group with a mean density $\rho \simeq 10^{-26}$g cm^{-3} is also stable, although in the latter case the evidence is moot; recent studies (de Vaucouleurs, Peters & Corwin 1977) suggest that it may be expanding at a significant fraction of the Hubble rate. In superclusters, typical densities are of the order of 10^{-28} g cm^{-3}, which is still two or three orders of magnitude greater than the mean density of the universe at large, $10^{-30.5}$ g cm^{-3}, as defined by the Lick Observatory counts (see *e.g.* de Vaucouleurs 1970, Table 1). A significant reduction of the expansion rate could therefore be expected in the Local Supercluster, particularly in its denser central parts. This necessity has been thoroughly confirmed by general relativistic treatments of the effects of density inhomogeneities in an expanding universe (Silk 1974, 1977; Silk & Wilson 1979a,b; White & Silk 1979; Hoffman, Olson & Salpeter 1980).

A first exploration of the velocity field in the Local Supercluster (de Vaucouleurs 1958) did in fact disclose conspicuous departures from linearity and isotropy in the velocity-distance relation for galaxies in the supergalactic equatorial belt (Figure 10). A simple flat disk model in differential expansion and rotation about the Virgo cluster gave an excellent fit to the data with just two free parameters, (the expansion rate $\epsilon_1 R_1 = 1100$ km s^{-1} and the rotation velocity $\omega_1 R_1 = 500$ km s^{-1} at the Local Group), but with admittedly arbitrary expansion and rotation laws. Later this model was refined to a flattened ellipsoid (de Vaucouleurs & Peters 1968, de Vaucouleurs 1972) with similar results : the best fit constants were $\epsilon_1 R_1 = 1250 \pm 50$ km s^{-1}, $\omega_1 R_1 = 400 \pm 50$ km s^{-1}*; in addition, a velocity component of the Local Group normal to the supergalactic plane $\dot{Z} = -250 \pm 50$ km s^{-1} was necessary to account for the systematic departure of the apex from the supergalactic equator (see section 6 blow). A number of objections or alternative interpretations were examined and tested as follows :

(a) Some critics simply insisted that the velocity anisotropy does not exist or is not significant (Bahyl 1974; Sandage & Tammann 1975). A detailed discussion (de Vaucouleurs 1976b) of the sample of ScI galaxies and nearby galaxies presented by the latter authors as counter-evidence showed that the typical velocity anisotropy previously derived from the totality of available (m, z) data is in fact also present in this selected sample with the same phase and amplitude (at a given distance modulus μ_0). The importance of adequate angular resolution in such studies was stressed. Independently, Tully & Fisher (1977, 1978, personal communication) confirmed the centre anti-centre anisotropy in their extensive sample of spiral and irregular galaxies. Lately, efforts to deny the reality of the supergalactic anisotropy of the redshift law have apparently been abandoned by all or most authors (see section 6).

(b) Van Albada (1962) suggested that the anisotropy of the (m, z) relation could conceivably be produced by an anisotropy of the distribution of absolute magnitudes at given m rather than a velocity anisotropy. This is mathematically correct, but replaces an easily understood effect by an unexplained ad hoc postulate. A detailed examination of the superglactic distribution of luminosity classes gave no support to this suggestion (de Vaucouleurs 1964).

(c) Another possible cause of apparent 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; Teerikorpi & Jaakkola 1977). Because such effects must be proportional to the variance σ_M^2 of the luminosity function, a simple test consists in comparing the amplitudes of the velocity anisotropy in two samples, on having a large variance (*e.g.* $\sigma_M \simeq 1.0$ mag

*Stewart & Sciama (1967) had derived $\omega_1 R_1 = 340 \pm 120$ km s^{-1} from a first-order Oort-type analysis of 8 groups nearer than 8 Mpc (*cf.* Pskovskii 1961).

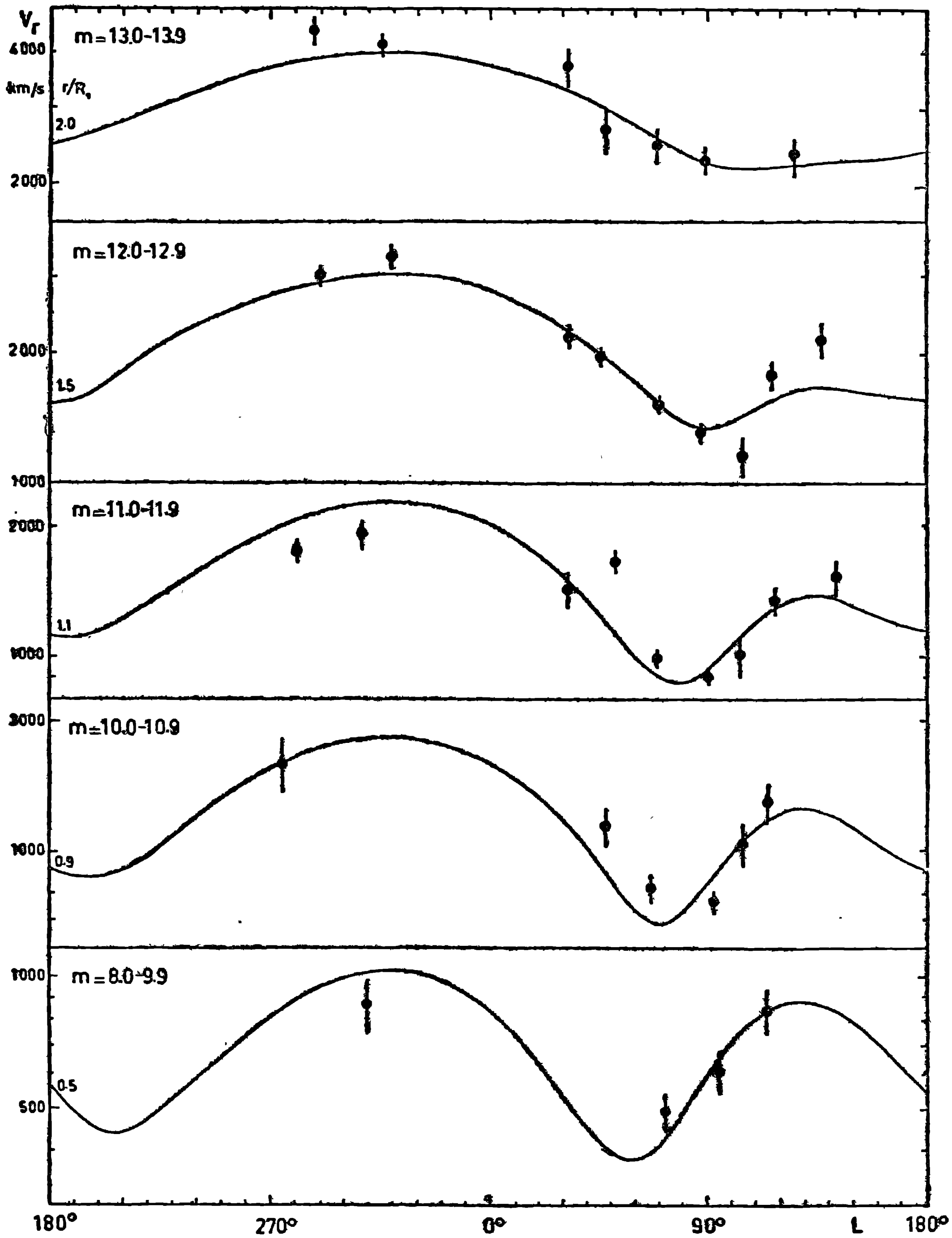

Figure 10. The supergalactic anisotropy of the redshifts was demonstrated in 1958 by this plot of the mean radial velocities (corrected to the Local Group frame of reference) of 307 galaxies of all types E to Sc in the supergalactic equatorial belt ($|B| < 30°$) versus supergalactic longitude for several intervals of apparent magnitude. The curves calculated for a simple disk model of the Local Supercluster in differential expansion and rotation gave a good fit to the data, including the displacement of the minimum from the direction $L = 104°$ of the Virgo cluster.

as in the 1958 magnitude samples) and another having a small variance (*e.g.* $\sigma_M \simeq$ 0.4 mag as in our recent distance modulus samples). No significant change is indicated either in the phase, or in the amplitude of the effect (de Vaucouleurs 1978e,

Figure 2). Comparisons of the mean absolute magnitude differences of galaxies in the north and south galactic polar caps (roughly corresponding to the supercluster center and anti-center sectors) calculated with the (incorrect) assumption of a linear isotropic (i.e. unperturbed) Hubble flow lead to the same conclusion (de Vaucouleurs 1978e, Table 1).

6. Solar motion and Hubble constant

In the past few years the accumulating evidence not only for the existence of the Local Supercluster but also for the reality of the perturbations of the ideal Hubble flow has gained general acceptance and more rapid progress should follow.

Not only have Tully & Fisher (1977, 1978) confirmed the concentration of dwarf and nearby galaxies to the supergalactic plane, and—with some hesitation—the north-south velocity anisotropy, but others have now reached essentially identical conclusions : Peebles (1976) and recently Davies *et al.* (1980) and Hoffman, Olson & Salpeter (1980) have estimated the amplitude of the dipole term of the local velocity anisotropy from a global analysis of galaxy redshifts within the framework of a spherically symmetric model of the Local Supercluster, which is at best a rather crude approximation, but at present the only one which is amenable to theoretical treatment. This point of view has finally been accepted by Tammann, Yahil & Sandage (1979) in a welcome reversal of their previous stand, although they still minimize it and insist that deceleration of the Local Group is the only type of motion involved, a conclusion implicit in their assumptions and model, but which is contradicted by our detailed mapping of the velocity field. For example, the mean velocity of spiral galaxies having good distaces from tertiary indicators (de Vaucouleurs 1979a, b; de Vaucouleurs & Bollinger 1979) plotted as a function of supergalactic longitude in the equatorial belt ($|B| < 30°$) shows conspicuous departures from the simple harmonic (or dipole) variation predicted for a Virgo-centric motion (Figure 11). In particular the pronounced velocity minimum at longitudes $60° < L < 90°$ over a wide range of distaces ($20 < \Delta < 70$ Mpc) in the north galactic hemisphere, roughly in the direction of UMa and CVn, was already clearly indicated by the initial analysis (de Vaucouleurs 1958) and it was even detectable in the small sample of 100 redshifts published by Humason in 1936 (Robin 1951a,b, Ogorodnikov 1952). It was not and will not be erased by additional redshifts. Whether this telltale dip will be explained by effects of differential rotation of a disk system, as initially proposed by the author, or by streaming motions along a bar-like supercluster, or by mass motions of individual galaxy clouds, the sub-units of the LSC, remains to be seen, but it clearly shows that the kinematics of the Local Supercluster involves effects more complex than a mere reflection of Local Group motion.

In any case it is now quite clear that the Hubble constant cannot be simply equated to the apparent Hubble ratio, as has been done for so long, in the domain dominated by the Local Supercluster. At the very least, allowance must be made for the peculiar motion of the Local Group (and perhaps of a somewhat larger co-moving nearby region) and solutions must be made simultaneously for solar motion and Hubble constant. This conclusion appears to be gaining general acceptance. Thus, a Local Group motion of 350 ± 50 km s^{-1} toard $L = 80° \pm 10°$, $B = -5° \pm 15°$ and a

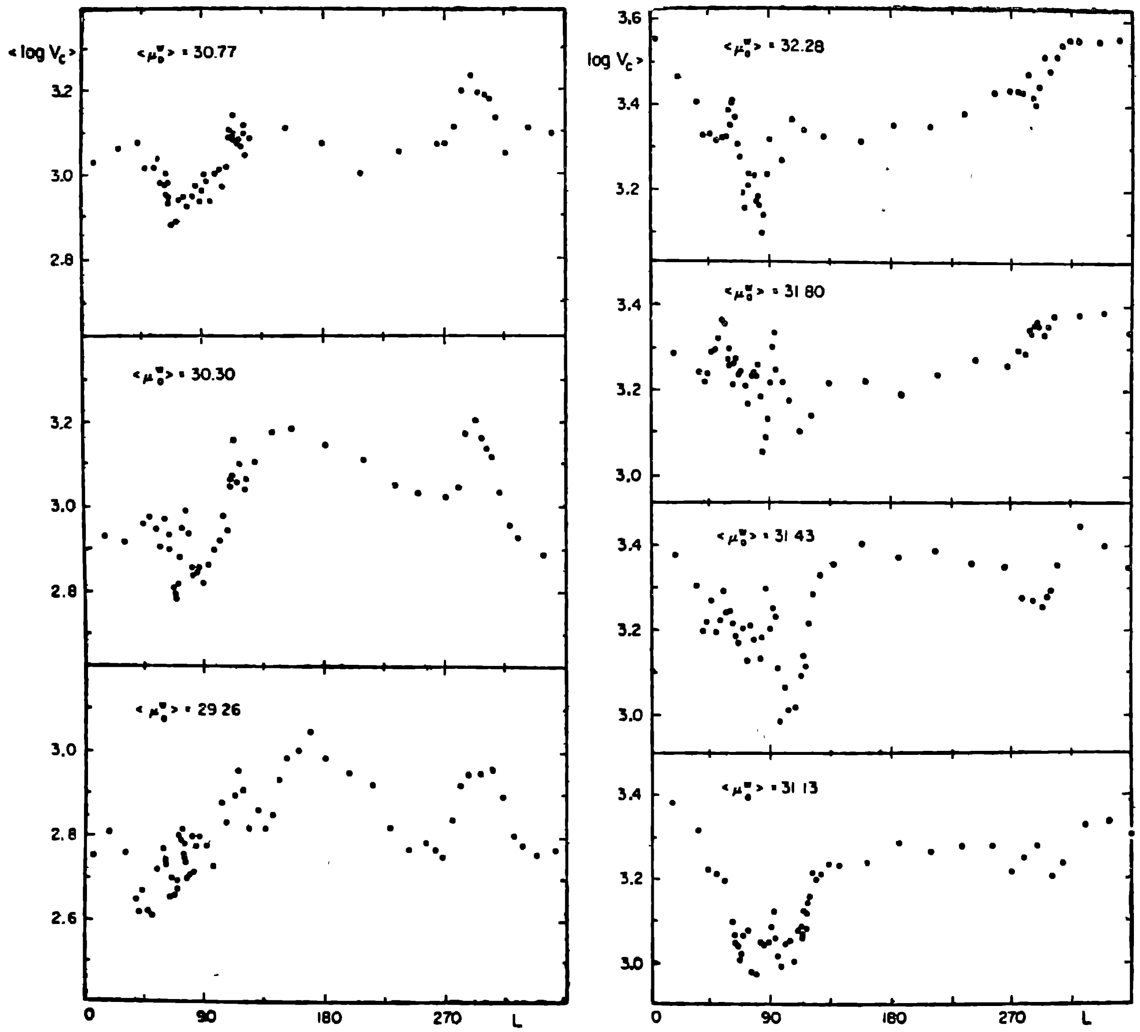

Figure 11. An up-dated version of Figure 10 prepared in 1979 shows the mean corrected velocities V_c of 222 spirals in the supergalactic equatorial belt (excluding the Virgo cluster) in seven distance intervals ranging from 7 to 38 Mpc. Points are running means of five galaxies. Note that the deep minima at longitudes $50° \leqslant L \leqslant 90°$ are not in the direction of the Virgo cluster ($L = 104°$). The variations are not merely a reflection of Local Group motion toward the Virgo cluster.

mean Hubble ratio $H = 97$ km s^{-1} Mpc^{-1} was derived three years ago by our group from a preliminary analysis of 200 galaxies in the distance range $5 < \Delta < 20$ Mpc (de Vaucouleurs 1978e). A more detailed analysis of a slightly larger sample two years ago gave for the all sky mean Hubble ratio $H = 95$, and for the asymptotic Hubble constant $H_0 = 100 \pm 10$ (m.e.) (de Vaucouleurs & Bollinger 1979), when the densely populated northern equatorial belt of the Local Supercluster is rejected.

This value was independently confirmed by Aaronson *et al.* (1980) who found $H = 95 \pm 10$ (on the Sandage-Tammann scale) for a sample of spirals in four distant clusters or superclusters. The distances of these clusters which are located well outside the sphere of influence of the LSC were derived from an infrared (1.6 μ H band) version of the Tully-Fisher relation.

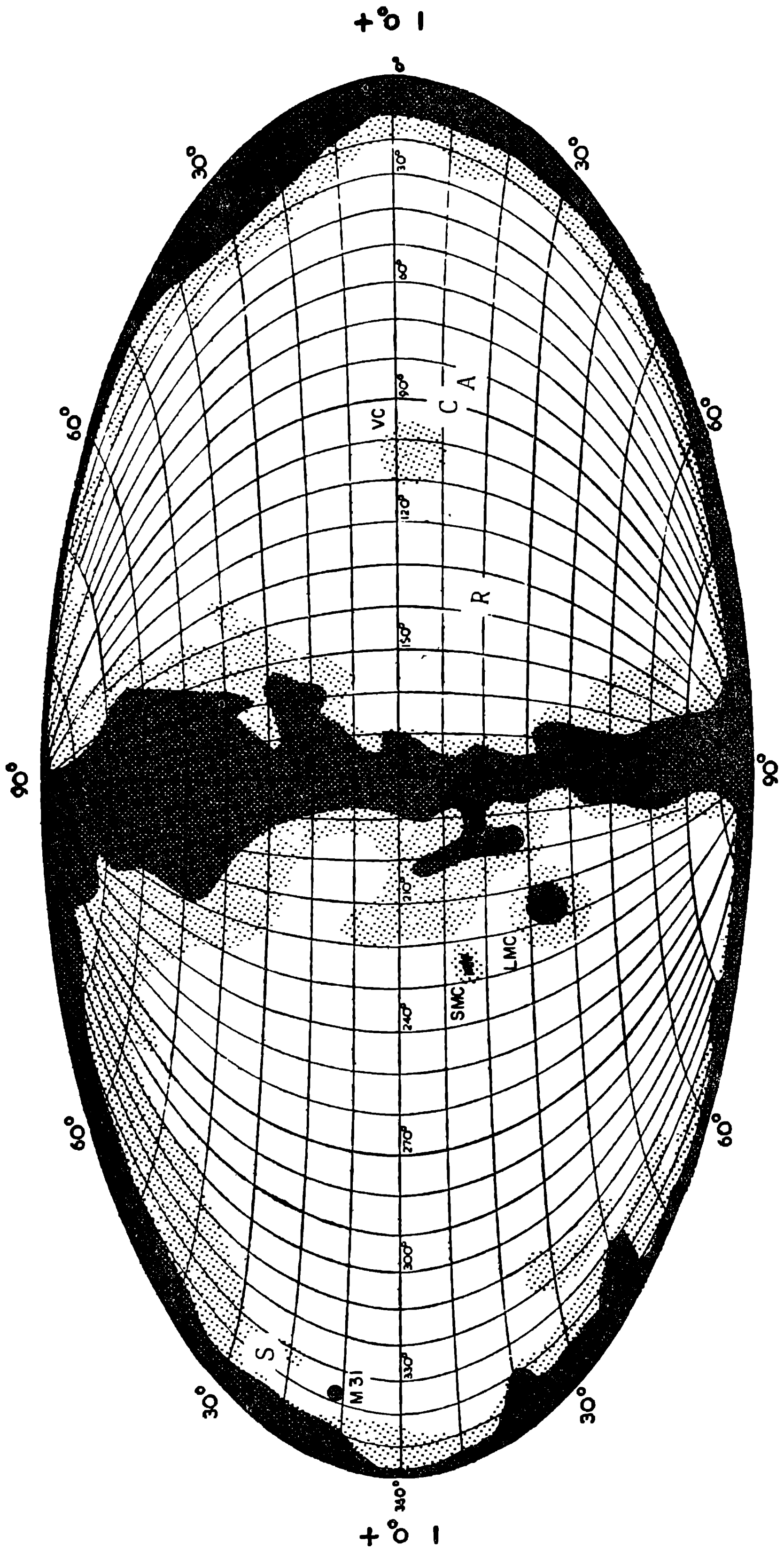

Figure 12. The apices of the solar motion within the Local Group (S) and of the Local Group (A) with respect to nearby galaxies ($2 < \Delta < 32$ Mpc) and to the 3 K background radiation (R) are plotted on this equal area map of the sky in supergalactic coordinates. All three are displaced from the Virgo cluster. The zones of avoidance (dark) and of partial galactic obscuration (gray), the Magellanic Clouds, M31 and the Virgo cluster are marked.

In a new and very detailed re-analysis of the radial velocities of an all-sky sample of several hundred spirals having the best distance determinations from optical and radio (21 cm) indicators, Peters and the author have recently refined our determinations of the Local Group apex; the results (Figure 12) confirm once again that the net space motion of the Local Group is not directed precisely toward the Virgo cluster, but some 25° to the north-east ($L = 84°$, $B = -16°$) with a velocity of 250 km s^{-1} confirming our previous results and well within the range (120 to 480) of other determinations. The Hubble constant derived from both the optical tertiary indicators (de Vaucouleurs 1979b) and a revised version of the Tully-Fisher relation (Bottinelli *et al.* 1980) is still $H_0 = 100 \pm 10$ km s^{-1} Mpc^{-1} subject only to the basic uncertainty of the primary and secondary indicators (about 0.2 mag, de Vaucouleurs 1978a, b, c, d).

It is noteworthy that the Local Group motion relative to the nearby galaxies is not too different from the motion relative to the background radiation determined by radio techniques (marked on Figure 12). The radio apex is only 50° away to the south of our latest optical determination but the velocity is ~300 km s^{-1} greater. This result suggests that the kinematics of the Local Supercluster makes a significant contribution to the total motion relative to the universal frame of reference. Additional contributions arise from the peculiar motion of the Local Supercluster as a whole and of any higher order cluster in which it might be embedded.

Not only is supergalactic kinematics important for a proper evaluation of the Hubble constant, but the dynamics may also lead to improved estimates of the deceleration parameter q_0, the other basic cosmic parameter. As was first shown by Silk (1974); the local deceleration of the Hubble expansion by the density excess in the supercluster could provide an indirect estimate of the overall deceleration of the cosmic expansion by the much lower average density of the universe. This method, however, requires rather precise evaluations of (a) the peculiar velocity of the Local Group (relative to the unperturbed Hubble flow), which, as noted earlier, is still uncertain; (b) the average density of the Local Supercluster, which is not easy to define; and (c) the "mean density" of very large volumes of space—a task which is difficult at best and encounters serious conceptual difficulties in the presence of hierarchical clustering in the universe (de Vaucouleurs 1970, 1971). Recent estimates of the deceleration parameter q_0 and of the mean density Ω of the universe (Peebles 1976; Tammann, Yahil & Sandage 1979; Aaronson *et al.* 1980; Hoffman, Olson & Salpeter 1980; Davis *et al.* 1980) sill cover a wide range of possibilities ($0 \lesssim \Omega \lesssim 1$), which would be even larger if cosmological models with a non-zero Λ term were considered, or if proper models for a hierarchical universe were developed.

At any rate, it is clear that the Local Supercluster has at long last become a distinct and active new field of research in extragalactic astronomy with important implications for cosmology. Its detailed study will help our understanding of the structure, kinematics and dynamics of other superclusters—and of the universe at large.

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