

# STRUCTURE OF THE VIRGO CLUSTER OF GALAXIES

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## ABSTRACT

A discussion of the surface distribution, morphologic types, apparent magnitudes, diameters, and velocities of over 200 bright galaxies between 12h and 13h,  $0^\circ$  and  $+20^\circ$ , indicates the presence of several distinct clouds and groups with different populations and velocities, at different distances. In particular, the Virgo cluster itself may consist of two overlapping, but separate, clouds: (1) a concentrated cluster of elliptical and lenticular galaxies centered at  $C_E(12^h 26.5m, +13^\circ 2')$  with a mean velocity  $\langle V_E \rangle \approx +950 \pm 70$  p.e. km sec $^{-1}$  and velocity dispersion  $\sigma_E \approx 550$  km sec $^{-1}$  at a distance of the order of 7-8 Mpc; (2) a diffuse cloud of spirals and irregular galaxies centered at  $C_S(12^h 27.5m, +13^\circ 9')$  with a mean velocity  $\langle V_S \rangle \approx +1450 \pm 120$  p.e. km sec $^{-1}$  and velocity dispersion  $\sigma_S \approx 750$  km sec $^{-1}$  at a distance of the order of 11-12 Mpc. The difference between the systemic velocities of the *E*- and *S*-clouds computed in various ways is from three to four times its probable error, and the velocity distributions in each cloud are widely different.

The mass of either cloud derived from velocity dispersion,  $N\mathcal{M}^* \approx 2 \times 10^{14} \odot$ , and the mean mass per galaxy,  $\mathcal{M}^* \approx 2 \times 10^{12} \odot$ , are not significantly reduced compared with previous estimates, and the discrepancy between galaxy masses derived from translational or rotational motions remains unaccounted for. However, the new evidence for an accumulation of groups, clouds, and clusters in the equatorial plane of the Local Supercluster and toward its center suggests that the observed velocity dispersion bears little relation to the masses of the individual subsystems.

## I. INTRODUCTION

The Virgo cluster of galaxies has long played an important role in extragalactic studies (Shapley and Ames 1926, 1929; Ames 1930; Hubble and Humason 1931; Smith 1936; Zwicky 1942, 1957; Holmberg 1958). As the nearest of the large clusters with a well-mixed population of galaxy types, it was used as a steppingstone for the transfer of the extragalactic distance scale from the nearby, mainly spiral and irregular, galaxies of the Local Group to the distant, mainly elliptical and lenticular, galaxies of the great clusters (Hubble 1936) and also for the calibration of apparent diameters as distance indicators (de Vaucouleurs 1959*b*). Because it is both far enough to have a significant red shift and still near enough for its distance to be derived from observations of individual objects (OB supergiants in spirals, globular clusters in ellipticals), it plays an essential part in the calibration of the velocity-distance relation (Baum 1955; Humason, Mayall, and Sandage 1956; Holmberg 1958; Sandage 1958).

Its location in the direction of maximum surface density of bright galaxies marks the Virgo cluster as the probable "nucleus" of the Local Supercluster (de Vaucouleurs 1956) and its center of differential rotation and expansion (de Vaucouleurs 1958, 1959*a*). Finally, as one of the clusters with the largest number of known radial velocities, its statistical mass has been derived from the dispersion of residual velocities (Smith 1936; Oort 1958; de Vaucouleurs 1960; van den Bergh 1960*b*).

These investigations raise a number of questions: (1) How is the cluster defined? Where are its limits and what is its apparent diameter? (2) What is its structure? Is it simple or multiple? If the latter, do the mean velocities and velocity dispersions of the various components differ significantly?

These questions are important because if the Virgo cluster is the nucleus of a super-system in a state of differential expansion and rotation, then (1) it is not correct to derive the Hubble parameter simply from the ratio  $\epsilon_1 = \langle V \rangle / R_1$  of the mean radial velocity to the distance of the cluster; in the simplest model which accounts for the non-linearity and anisotropy of the velocity field among galaxies brighter than the 14th magnitude, the Hubble parameter is given by  $H = \epsilon_\infty \approx 1.58 \epsilon_1$  (de Vaucouleurs 1958, 1959*a*); and

(2) it may not be correct to derive the mass of the cluster from the observed velocity dispersion if the latter is governed more by the dynamics of the supersystem as a whole than by its nucleus alone. This might be, at least in this particular case, a reason for the discrepancy between the mass estimated through the virial theorem and the mass inferred from plausible mass-luminosity ratios (de Vaucouleurs 1960).

Further, if the Virgo cluster is not a single nuclear condensation at the center of the Local Supercluster but is actually an agglomeration of several distinct groups or clusters at different distances from us in the denser central regions of the supersystem and overlapping in the projection, it is most important to assess their individual mean radial velocities and velocity dispersions and to evaluate the effect of this separation on mass and distance estimates. These various points will be examined in the following sections.

## II. APPARENT DISTRIBUTION

The Virgo cluster was originally described as the "Coma-Virgo group" by Shapley and Ames (1926), who located its center at approximately 12h 20m,  $+13^\circ$  (1900), and its limits at  $\alpha = 12\text{h } 03\text{m to } 12\text{h } 56\text{m}$ ,  $\delta = +5^\circ$  to  $+20^\circ$ . Hubble and Humason (1931) described it as an elliptical cloud measuring  $12^\circ \times 10^\circ$  and centered at 12h 25m,  $+15.5^\circ$  (1930). This densest region is the Virgo cluster proper.

Later, the elongated distribution of bright galaxies stretching south of the cluster through Virgo down to  $-20^\circ$  was described by Shapley and Ames (1931) as an "extension of the Coma-Virgo supergalaxy," and thus some uncertainty was introduced into the definition of the cluster area. For example, in the redshift catalogue (Humason *et al.* 1956), objects between 12h 10m and 12h 57m,  $+1.6^\circ$  and  $+18.5^\circ$  (1950), are listed as members of the Virgo cluster, while a few between 12h 33m and 13h 03m,  $-14.8^\circ$  and  $-3.5^\circ$ , are noted as in the "southern extension." Inclusion of this cloud (or string of clouds) in the Virgo cluster is, however, not warranted; an inspection of the distribution maps in the Shapley-Ames catalogue (1932) shows that the surface density of galaxies in this southern extension is very much less than in the cluster itself. In fact, the southern Virgo cloud is closely similar to the Ursa Major cloud and probably no more directly related to the Virgo cluster proper, except in so far as both are galaxy clouds within the Local Supercluster.

Another source of confusion has been the frequent inclusion in the Virgo cluster of a so-called "wing" formed by a dense group centered near 12h 17m,  $+6^\circ$  (1950). For instance, Holmberg (1958) defines the Virgo cluster as extending from 12h 08m to 12h 48m, and  $+2.5^\circ$  to  $+18.5^\circ$  (1950), thus excluding the "southern extension" but including the "wing."

In what follows, the structure of this region is analyzed through the combined use of distribution, classification, magnitude, diameter, and velocity criteria. Since an examination of the Shapley-Ames distribution maps leaves little doubt that clouds and groups south of the equator are not directly related to the original Virgo cluster, attention will be confined to the region between 12h and 13h,  $0^\circ$  and  $+20^\circ$  (1950).

## III. DISTRIBUTION AND CLASSIFICATION

Figure 1 is a plot of 212 galaxies having equatorial co-ordinates in the specified range and generally brighter than  $m_{pg} \approx 13.5$ . The Virgo cluster proper,  $12^\circ$  in diameter and centered near 12h 27m,  $+13.5^\circ$  (1950), is in evidence in the upper half of the map; the northernmost part of the elongated Virgo cloud appears in the lower half; a small, dense group is marked near 12h 17m,  $+6^\circ$ .

Among these galaxies, 143 are listed in the Shapley-Ames catalogue (1932), 198 have revised morphological types (de Vaucouleurs 1959c), 141 have corrected photographic diameters (de Vaucouleurs 1959b), and 79 have known radial velocities (Humason *et al.* 1956); these data are listed in Table 1.

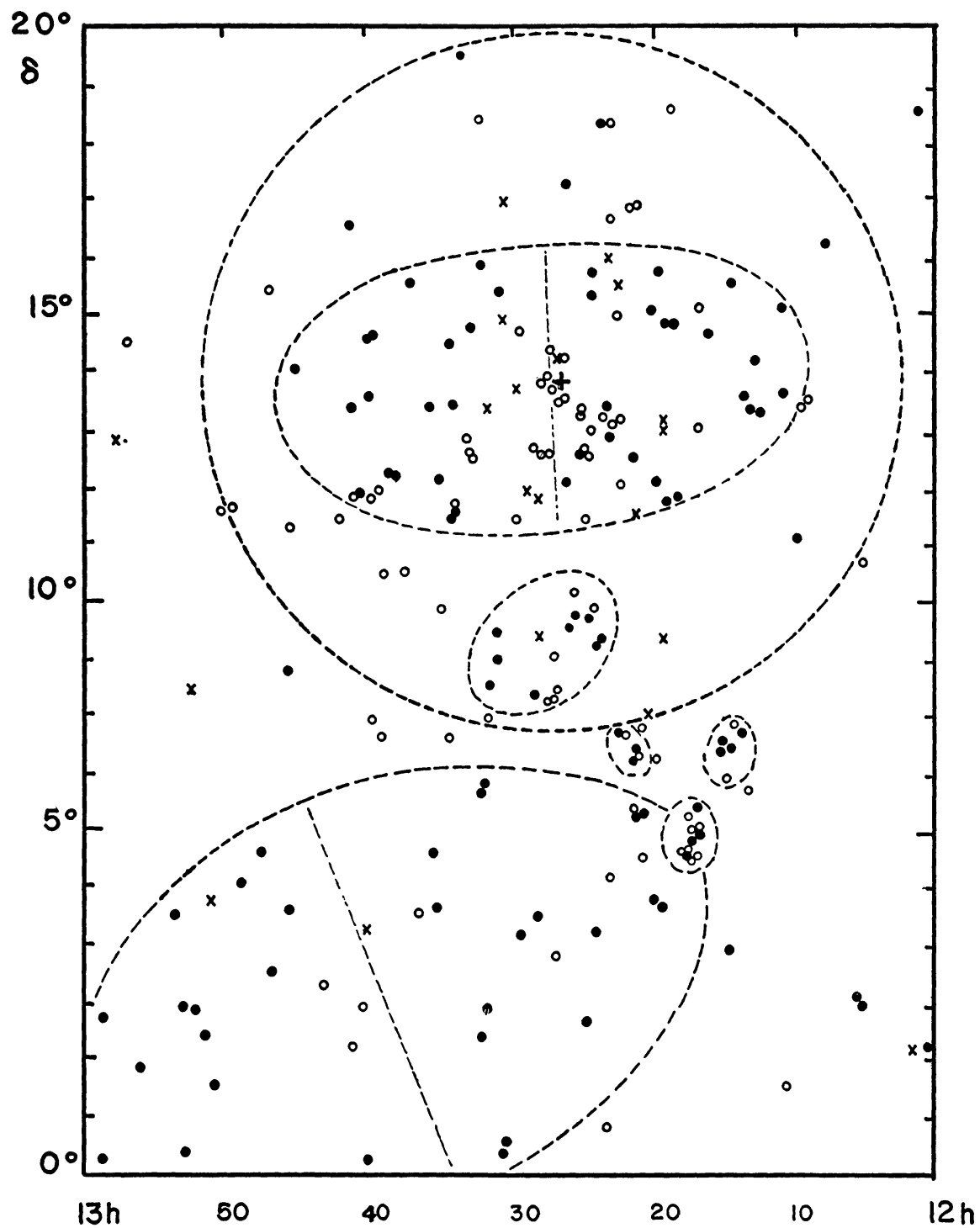


FIG. 1.—Distribution of 212 galaxies in the region of the Virgo cluster. *Dots*: spirals and irregulars; *circles*: ellipticals and lenticulars; *crosses*: type unknown.

TABLE 1

## ELEMENTS OF 212 GALAXIES IN THE REGION OF THE VIRGO CLUSTER

| NGC  | 12 <sup>h</sup> + | $\delta$ | Revised Type            | $m_H$  | $m_T$   | log D | n | log D/d | log D(0) | V<br>km/s | Member-<br>ship | Rem. |
|------|-------------------|----------|-------------------------|--------|---------|-------|---|---------|----------|-----------|-----------------|------|
| 4045 | 00 <sup>m</sup> 2 | 02°15'   | SAB(r)a                 | 12.8   | 12.2:   | 0.30  | 2 | 0.06    | 0.28     | -         | -               |      |
| 4064 | 01.6              | 18 43    | SB(s)a:p                | 12.8   | 12.0:   | 0.59  | 3 | 0.45    | 0.41     | + 967     | S?              | *6°  |
| 4073 | 01.9              | 02 11    | (E?)                    | 13.2   | 12.6:   | 0.38  | 1 | 0.25    | 0.28     | -         | -               |      |
| 4116 | 05.1              | 02 58    | SB(r)dm                 | 12.4   | 12.3    | 0.57  | 5 | 0.27    | 0.46     | +1175     | -               |      |
| 4123 | 05.6              | 03 09    | SB(r)c                  | 12.3   | 11.8    | 0.60  | 5 | 0.17    | 0.53     | -         | -               |      |
| 4124 | 05.6              | 10 40    | SA(r)O <sup>+</sup>     | 12.5   | 12.0    | 0.56  | 5 | 0.51    | 0.36     | -         | E?              | <6°  |
| 4152 | 08.1              | 16 19    | SAB(rs)c                | 12.7   | 12.5:   | 0.18  | 2 | 0.06    | 0.16     | -         | S?              | <6°  |
| 4165 | 09.7              | 13 31    | SAB:(r)O/a              | (15.3) | 14.4    | 0.23  | 3 | 0.24    | 0.13     | -         | E               | <5°  |
| 4168 | 09.8              | 13 29    | E2                      | 12.8   | 12.3    | 0.18  | 5 | 0.03    | 0.17     | -         | E               | <5°  |
| 4178 | 10.2              | 11 09    | SB(rs)dm                | 12.4   | 11.7    | 0.70  | 5 | 0.44    | 0.52     | + 143     | S?              | >5°* |
| 4179 | 10.3              | 01 35    | SO sp                   | 11.8   | 11.4    | 0.39  | 6 | 0.40    | 0.23     | +1149     | -               |      |
| 4189 | 11.2              | 13 42    | SAB(rs)?cd              | 13.0   | 12.5    | 0.42  | 5 | 0.06    | 0.42     | -         | S               | <5°  |
| 4192 | 11.3              | 15 11    | SAB(s)ab                | 11.4   | 10.7    | 0.90  | 8 | 0.51    | 0.70     | -202      | S               | <5°* |
| 4193 | 11.3              | 13 27    | SAB(s)?c                | (13.5) | 13.1    | -     | - | -       | -        | -         | S               | <5°  |
| 4206 | 12.8              | 13 20    | SA:(s)bc                | (13.6) | 12.7    | -     | - | -       | -        | -         | S               | <5°  |
| 4212 | 13.1              | 14 11    | SA(rs?)b                | 12.1   | 11.7    | 0.47  | 5 | 0.22    | 0.38     | +2047     | S               | <5°  |
| 4215 | 13.4              | 06 41    | SA(r):O <sup>+</sup> sp | 12.8   | 12.6:   | 0.30  | 3 | 0.48    | 0.11     | -         | WB              |      |
| 4216 | 13.4              | 13 25    | SAB(s)b                 | 11.3   | 10.9    | 0.88  | 9 | 0.69    | 0.60     | -34       | S               | <5°* |
| 4222 | 13.8              | 13 37    | Sd: sp                  | (13.8) | -       | -     | - | -       | -        | -         | S               | <5°  |
| 4224 | 14.0              | 07 44    | SA:(s)a sp              | 13.0   | 12.9    | 0.48  | 3 | 0.47    | 0.29     | -         | WB              |      |
| 4233 | 14.6              | 07 54    | (SO or Sa)              | 13.0   | (12.7)  | 0.43  | 3 | 0.43    | 0.26     | -         | WB              |      |
| 4234 | 14.6              | 03 58    | (Im?)                   | 13.0   | (12.4:) | 0.18  | 3 | 0.01    | 0.18     | -         | X, NW           |      |
| 4235 | 14.6              | 07 28    | SA(s)a sp               | 12.8   | 12.6    | 0.62  | 5 | 0.69    | 0.34     | -         | WB              |      |
| 4237 | 14.7              | 15 36    | SAB(rs)bc               | 12.6   | 12.1    | 0.31  | 5 | 0.20    | 0.23     | -         | S               | <5°  |
| 4241 | 14.9              | 06 57    | (Sa)                    | (13.3) | 13.0    | -     | - | -       | -        | -         | WB              |      |
| 4246 | 15.3              | 07 28    | SA(s)c                  | (14.0) | 13.3    | -     | - | -       | -        | -         | WB              |      |
| 4247 | 15.3              | 07 34    | (R?)SAB(s?)ab           | (14.0) | -       | -     | - | -       | -        | -         | WB              |      |
| 4254 | 16.3              | 14 42    | SA(s)c                  | 10.5   | 10.2    | 0.72  | 8 | 0.07    | 0.69     | +2390     | S               | <5°  |
| 4257 | 16.6              | 06 01    | (S: sp)                 | (14.8) | -       | -     | - | -       | -        | -         | WA              |      |
| 4259 | 16.8              | 05 39    | (SO)                    | (13.8) | (14.6)  | -     | - | -       | -        | -         | WA              |      |
| 4260 | 16.8              | 06 23    | SB(s)a                  | 12.7   | 12.1:   | 0.43  | 5 | 0.37    | 0.28     | -         | WA              |      |
| 4261 | 16.8              | 06 06    | E2-3                    | 11.7   | 11.3    | 0.39  | 6 | 0.09    | 0.35     | +2094     | WA              |      |
| 4262 | 17.0              | 15 09    | SB(s?)O <sup>-</sup>    | 12.6   | 12.1    | -     | - | -       | -        | -         | E               | <5°  |
| 4264 | 17.0              | 06 07    | SB(rs)O <sup>+</sup>    | (14.2) | -       | -     | - | -       | -        | -         | WA              |      |
| 4266 | 17.1              | 05 50    | S sp                    | (15.0) | -       | -     | - | -       | -        | -         | WA              |      |
| 4267 | 17.2              | 13 03    | SB(s?)O <sup>-</sup>    | 12.6   | 11.7    | 0.41  | 3 | 0.01    | 0.41     | +1179     | E               | <5°  |
| 4268 | 17.2              | 05 34    | SO: sp                  | (13.8) | 13.8    | -     | - | -       | -        | -         | WA              |      |
| 4269 | 17.3              | 06 18    | (SO+SO)                 | (13.9) | -       | -     | - | -       | -        | -         | WA              |      |
| 4270 | 17.3              | 05 44    | SO                      | 12.8   | 13.1    | 0.28  | 7 | 0.41    | 0.12     | +2236     | WA              |      |
| 4273 | 17.4              | 05 37    | SB(s)c                  | 12.2   | 12.3    | 0.34  | 6 | 0.19    | 0.26     | +2191     | WA              |      |
| 4277 | 17.6              | 05 37    | (S)                     | (14.9) | 14.5    | -     | - | -       | -        | -         | WA              |      |
| 4281 | 17.8              | 05 40    | SO: <sup>+</sup> sp     | 12.2   | 12.3    | 0.39  | 6 | 0.38    | 0.24     | +2492     | WA              |      |
| 4293 | 18.7              | 18 40    | (R)SB(s)O/a             | 11.7   | 11.0    | 0.63  | 5 | 0.47    | 0.44     | + 693     | E               | <6°  |
| 4294 | 18.7              | 11 47    | SB(s)cd                 | 13.0   | 12.4    | 0.47  | 5 | 0.41    | 0.31     | -         | S               | <5°  |
| 4298 | 19.0              | 14 53    | SA(rs)c                 | 12.5   | 11.9    | 0.49  | 8 | 0.29    | 0.37     | -         | S               | <5°  |
| 4299 | 19.2              | 11 47    | SB?dp                   | 13.1   | 12.7    | 0.24  | 4 | 0.01    | 0.24     | -         | S               | <5°  |
| 4301 | 19.9              | 04 50    | (Sc <sup>+</sup> )      | (14.0) | 13.3    | -     | - | -       | -        | -         | X, NW?          |      |
| 4302 | 19.2              | 14 53    | Sc: sp                  | 13.2   | 12.4    | 0.72  | 5 | 0.72    | 0.43     | -         | S               | <5°  |
| 4303 | 19.4              | 04 45    | SAB(rs)bc               | 10.4   | 10.0    | 0.72  | 8 | 0.03    | 0.71     | +1557     | X, NW           |      |
| 4305 | 19.5              | 13 01    | -                       | (12.9) | -       | -     | - | -       | -        | -         | (S?)            | <5°  |
| 4306 | 19.5              | 13 04    | -                       | (13.2) | -       | -     | - | -       | -        | -         | (S?)            | <5°  |
| 4307 | 19.5              | 09 20    | -                       | 13.0   | (12.5)  | 0.56  | 3 | 0.70    | 0.28     | -         | (S?)            |      |
| 4309 | 19.7              | 07 15    | SAB(r)O <sup>+</sup>    | (13.6) | -       | -     | - | -       | -        | -         | W?              |      |
| 4312 | 20.0              | 15 49    | SO/a:                   | (12.1) | 12.5    | -     | - | -       | -        | -         | S               | <5°  |
| 4313 | 20.1              | 12 04    | SAab: sp                | (12.1) | -       | -     | - | -       | -        | -         | S               | <5°  |

TABLE 1 -- Continued

| NGC  | $12^h+$ | $\delta$ | Revised Type            | $m_H$  | $m_T$  | log D             | n  | log D/d | log D(0) | V<br>km/s | Member-<br>ship | Rem.  |
|------|---------|----------|-------------------------|--------|--------|-------------------|----|---------|----------|-----------|-----------------|-------|
| 4321 | 20.4    | 16 06    | SAB(s)bc                | 10.8   | 10.0   | 0.81              | 9  | 0.02    | 0.80     | +1551     | S               | < 5°  |
| 4324 | 20.6    | 05 31    | SA(r)O <sup>+</sup>     | 12.5   | 12.1   | 0.35              | 4  | 0.38    | 0.20     | +1605     | X,NW            |       |
| 4326 | 20.6    | 06 21    | (SAB(r)ab?)             | (15.3) | -      | -                 | -  | -       | -        | -         | W'?             |       |
| 4333 | 20.8    | 06 19    | (SB(s)ab)               | (14.6) | -      | -                 | -  | -       | -        | -         | W'?             |       |
| 4334 | 20.8    | 07 45    | (SB0:c)                 | (15.1) | -      | -                 | -  | -       | -        | -         | W'?             |       |
| 4339 | 21.0    | 06 22    | E0                      | 12.6   | 12.0:  | 0.26              | 4  | 0.01    | 0.26     | +1173     | X,NW?           |       |
| 4340 | 21.0    | 17 00    | SB(r)O <sup>+</sup>     | 13.1   | 12.1   | 0.48              | 7  | 0.08    | 0.45     | -         | E               | < 5°  |
| 4341 | 21.3    | 07 23    | (S: sp)                 | (14.5) | 14.1   | -                 | -  | -       | -        | -         | W'              |       |
| 4342 | 21.1    | 07 22    | SO <sup>-</sup> sp      | 12.8   | 13.5?  | 0.08 <sub>s</sub> | 6  | 0.28    | -0.03    | + 614     | W'?             |       |
| 4343 | 21.1    | 07 16    | SA(rs:)b                | (13.0) | 13.2   | -                 | -  | -       | -        | -         | W'              |       |
| 4350 | 21.4    | 16 58    | SAO sp                  | 12.0   | 11.8   | 0.42              | 7  | 0.41    | 0.26     | +1122     | E               |       |
| 4351 | 21.5    | 12 29    | SA(s:)ab                | (13.3) | (12.5) | -                 | -  | -       | -        | -         | S               | < 5°  |
| 4352 | 21.5    | 11 29    | -                       | (13.5) | (13.1) | -                 | -  | -       | -        | -         | (S?)            | < 5°  |
| 4353 | 20.6    | 08 05    | (I?)                    | (14.2) | -      | -                 | -  | -       | -        | -         | W'              |       |
| 4365 | 22.0    | 07 36    | E3-4                    | 11.0   | 10.7   | 0.61              | 4  | 0.25    | 0.51     | +1130     | W'?             | *     |
| 4370 | 22.4    | 07 43    | SAA sp                  | (13.6) | -      | -                 | -  | -       | -        | -         | W'              |       |
| 4371 | 22.4    | 11 59    | SB(r)O <sup>+</sup>     | 12.1   | 11.8   | 0.42              | 4  | 0.19    | 0.34     | -         | E               | < 5°  |
| 4374 | 22.6    | 13 10    | E+1                     | 10.9   | 10.2   | 0.41              | 9  | 0.09    | 0.37     | + 880     | E               | core  |
| 4377 | 22.7    | 15 02    | SAO <sup>-</sup>        | 12.9   | 12.5   | -                 | -  | -       | -        | -         | E               |       |
| 4378 | 22.8    | 05 12    | (R)SA(s)a               | 12.8   | 12.0   | 0.52              | 4  | 0.07    | 0.49     | -         | X,NW            |       |
| 4379 | 22.8    | 15 33    | (SBO:)                  | 13.0   | 12.7:  | -                 | -  | -       | -        | -         | E?              |       |
| 4380 | 22.9    | 10 17    | SA(rs?)b:               | 12.8   | 11.8:  | 0.54              | 4  | 0.35    | 0.40     | -         | S'              |       |
| 4382 | 22.8    | 18 28    | SA(s)O <sup>+</sup> p   | 10.5   | 10.0   | 0.67              | 10 | 0.21    | 0.59     | + 721     | E               | < 6°  |
| 4383 | 23.0    | 16 45    | (SO/a?)                 | 12.9   | (12.4) | 0.23              | 6  | 0.26    | 0.13     | -         | E               | < 5°  |
| 4385 | 23.1    | 00 50    | SB(rs)O <sup>+</sup> :  | 12.9   | 12.6   | 0.30              | 4  | 0.27    | 0.19     | -         | X,NW?           |       |
| 4387 | 23.2    | 13 05    | (SO:a)                  | (13.9) | -      | 0.02              | 3  | 0.11    | -0.02    | + 439     | E               | core  |
| 4388 | 23.3    | 12 56    | SB:c sp                 | 12.2   | 11.7   | 0.66              | 10 | 0.67    | 0.39     | -         | S               | < 5°  |
| 4390 | 23.3    | 10 44    | -                       | (14.0) | (12.8) | -                 | -  | -       | -        | -         | (S?)            | < 5°  |
| 4394 | 23.4    | 18 29    | (R)SB(r)bc              | 12.2   | 11.5   | 0.59              | 7  | 0.08    | 0.56     | + 720     | S?              | < 5°  |
| 4396 | 23.5    | 15 57    | (S:)                    | (12.4) | -      | -                 | -  | -       | -        | -         | (S?)            |       |
| 4402 | 23.6    | 13 24    | S:c sp                  | (13.4) | 12.5   | -                 | -  | -       | -        | -         | S               | < 5°  |
| 4406 | 23.7    | 13 13    | E+3                     | 10.9   | 10.0   | 0.54              | 8  | 0.15    | 0.48     | - 418     | E               | core* |
| 4410 | 23.9    | 09 18    | (S+S)                   | (14.7) | 13.7   | -                 | -  | -       | -        | -         | S'              | A,B   |
| 4411 | 24.0    | 09 09    | (Sc <sup>+</sup> )      | -      | 13.5   | -                 | -  | -       | -        | -         | S'              | A     |
| 4411 | 24.1    | 09 09    | (SC <sup>+</sup> )      | -      | 12.9   | -                 | -  | -       | -        | -         | S'              | B     |
| 4412 | 24.0    | 04 14    | SB(r)p                  | 12.8   | 12.6:  | 0.18              | 4  | 0.03    | 0.17     | -         | X,NW            |       |
| 4413 | 24.0    | 12 53    | SB(r)O?                 | (12.3) | -      | -                 | -  | -       | -        | -         | E               | core  |
| 4417 | 24.3    | 09 52    | SB(s)O:                 | 12.3   | 12.1   | 0.42              | 5  | 0.57    | 0.19     | -         | E               | < 5°  |
| 4419 | 24.4    | 15 19    | SB(s)a sp               | 12.2   | 11.9:  | 0.48              | 5  | 0.47    | 0.29     | -         | S               | < 5°  |
| 4420 | 24.4    | 02 46    | SB(r)bc                 | 12.5   | 12.2:  | 0.30              | 3  | 0.33    | 0.17     | -         | X,NW            |       |
| 4421 | 24.5    | 15 44    | (SBa)                   | -      | (12.4) | -                 | -  | -       | -        | +1628     | S               | < 5°  |
| 4424 | 24.6    | 09 42    | SB(s)a:                 | 12.6   | 12.3   | 0.47              | 6  | 0.42    | 0.30     | -         | S'              |       |
| 4425 | 24.7    | 13 01    | SO: sp                  | 13.1   | 12.8   | 0.43              | 6  | 0.48    | 0.24     | +1809     | E               | core  |
| 4429 | 24.9    | 11 23    | SA(r)O <sup>+</sup>     | 11.7   | 11.1   | 0.60              | 5  | 0.41    | 0.44     | +1027     | E               | < 5°  |
| 4431 | 24.9    | 12 34    | (SO?)                   | (14.1) | -      | -                 | -  | -       | -        | -         | E               | core  |
| 4435 | 25.2    | 13 21    | SB(s)O°                 | 11.8   | 11.5   | 0.30              | 4  | 0.18    | 0.23     | + 796     | E               | core  |
| 4436 | 25.2    | 12 36    | (SO?)                   | (14.2) | -      | -                 | -  | -       | -        | -         | E               | core  |
| 4438 | 25.3    | 13 17    | SA:(s)O/ap              | 11.9   | 10.9   | 0.92              | 3  | 0.43    | 0.75     | - 105     | E               | core* |
| 4440 | 25.4    | 12 34    | SB(rs)a                 | (13.1) | 12.5:  | -                 | -  | -       | -        | -         | S               |       |
| 4442 | 25.6    | 10 05    | SB(s)O°                 | 11.4   | 11.5   | 0.54              | 5  | 0.50    | 0.34     | + 493     | E               | < 5°  |
| 4445 | 25.7    | 09 42    | (SBA <sup>-</sup> : sp) | (14.1) | -      | -                 | -  | -       | -        | -         | S'              |       |
| 4450 | 25.9    | 17 21    | SA(s)ab                 | 11.4   | 10.8   | 0.61              | 6  | 0.19    | 0.53     | +1995     | S?              | < 5°  |
| 4451 | 26.1    | 09 32    | (SB)                    | (13.7) | -      | -                 | -  | -       | -        | -         | S'              |       |
| 4452 | 26.2    | 12 02    | (Sa)                    | 13.2   | (13.4) | 0.34              | 2  | 0.70    | 0.06     | -         | S               | < 5°  |
| 4457 | 26.4    | 03 51    | (R)SAB(s)O/a            | 11.7   | 11.6:  | 0.32              | 3  | 0.18    | 0.25     | -         | X,NW            |       |
| 4458 | 26.4    | 13 31    | E0-1                    | (12.5) | 12.9:  | 0.11              | 3  | 0.00    | 0.11     | + 309     | E               | core  |
| 4459 | 26.5    | 14 15    | SA(r)O <sup>+</sup>     | 11.9   | 11.6   | 0.41              | 4  | 0.18    | 0.34     | +1042     | E               | core  |
| 4461 | 26.6    | 13 28    | SB(s)O <sup>+</sup> :   | 12.4   | 11.9   | 0.53              | 5  | 0.49    | 0.33     | +1813     | E               | core  |
| 4464 | 26.8    | 08 26    | (E3)                    | (13.6) | -      | 0.00              | 2  | 0.00    | 0.00     | +1104     | E               | < 5°  |
| 4467 | 27.0    | 08 16    | (E2)                    | (14.7) | -      | -0.06             | 3  | 0.04    | -0.07    | +1379     | E               | < 5°  |

TABLE 1 -- Continued

| NGC  | $12^h+$ | $\delta$ | Revised Type          | $m_H$  | $m_T$  | log D | n  | log D/d | log D(0) | V<br>km/s | Member-<br>ship | Rem.  |
|------|---------|----------|-----------------------|--------|--------|-------|----|---------|----------|-----------|-----------------|-------|
| 4468 | 27.0    | 14 19    | -                     | (13.1) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4469 | 27.0    | 09 02    | SB(s?)O/a sp          | 12.5   | 12.0:  | 0.54  | 4  | 0.52    | 0.33     | -         | E               | <5°   |
| 4472 | 27.3    | 08 16    | E2                    | 10.1   | 9.3    | 0.64  | 7  | 0.11    | 0.64     | + 918     | E               | <5°   |
| 4473 | 27.3    | 13 42    | E5                    | 11.7   | 11.1   | 0.42  | 4  | 0.27    | 0.31     | +2173     | E               | core  |
| 4474 | 27.4    | 14 21    | (SO:)                 | 12.9   | 12.5   | 0.29  | 4  | 0.40    | 0.13     | +1458     | E               | core  |
| 4476 | 27.5    | 12 37    | SA(r:)O <sup>-</sup>  | 13.2   | 13.1:  | 0.08  | 4  | 0.25    | -0.02    | -         | E               | core  |
| 4477 | 27.6    | 13 55    | SB(s?)O°              | 11.8   | 11.2   | 0.50  | 4  | 0.06    | 0.48     | +1195     | E               | core  |
| 4478 | 27.8    | 12 36    | E2                    | 12.5   | 12.1   | 0.11  | 4  | 0.03    | 0.10     | +1410     | E               | core  |
| 4479 | 27.8    | 13 51    | SB(s?)O°:             | (13.1) | 13.5   | 0.06  | 6  | 0.06    | 0.04     | + 753     | E               | core  |
| 4480 | 27.9    | 04 31    | (Sc <sup>-</sup> )    | (13.9) | 13.0   | -     | -  | -       | -        | -         | X,NW            |       |
| 4483 | 28.2    | 09 17    | (S)                   | 13.3   | -      | -     | -  | -       | -        | -         | (S?)            |       |
| 4486 | 28.3    | 12 40    | E0-1p                 | 10.7   | 9.7    | 0.54  | 7  | 0.03    | 0.53     | +1171     | E               | core  |
| 4491 | 28.4    | 11 45    | -                     | (13.7) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4492 | 28.4    | 08 21    | (Sa)                  | (13.9) | -      | 0.11  | 3  | 0.08    | 0.08     | +1642     | S'              | <6°   |
| 4496 | 29.1    | 04 12    | SB(rs)m               | 12.0   | 11.9   | 0.58  | 5  | 0.14    | 0.52     | -         | X,NW            |       |
| 4497 | 29.1    | 11 53    | -                     | (14.4) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4498 | 29.2    | 17 08    | -                     | (13.7) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4501 | 29.5    | 14 42    | SA(rs)b               | 10.9   | 10.1   | 0.78  | 8  | 0.27    | 0.67     | +2060     | S               | <5°   |
| 4503 | 29.6    | 11 27    | SBO <sup>-</sup> :    | 12.8   | 12.0:  | -     | -  | -       | -        | -         | E               | <5°   |
| 4506 | 29.7    | 13 42    | -                     | (13.1) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4516 | 30.6    | 14 51    | -                     | (13.2) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4517 | 30.2    | 00 23    | SA:(s)cd              | 11.6   | 11.1   | 0.98  | 7  | 0.83    | 0.65     | +1098     | X,NW?           | A=R80 |
| 4519 | 29.9    | 00 40    | SB(rs)dm              | (13.0) | 12.5   | -     | -  | -       | -        | -         | X,NW?           |       |
| 4519 | 31.0    | 08 56    | SB(rs)d               | 12.6   | 12.2   | 0.50  | 7  | 0.14    | 0.44     | +1123     | S'              |       |
| 4522 | 31.2    | 09 27    | (Scp)                 | 12.9   | (12.2) | 0.54  | 4  | 0.61    | 0.30     | -         | S'              |       |
| 4523 | 31.1    | 15 26    | SAB(s?)cd             | -      | -      | -     | -  | -       | -        | -         | S               | <5°   |
| 4526 | 31.6    | 07 56    | SAB(s:)O°             | 10.7   | 10.5   | 0.75  | 6  | 0.58    | 0.52     | + 357     | E               | <5°   |
| 4527 | 31.6    | 02 56    | SAB(s)bc              | 11.3   | 11.3   | 0.77  | 7  | 0.51    | 0.57     | +1615     | X,NW            |       |
| 4531 | 31.7    | 13 21    | -                     | (13.9) | -      | -     | -  | -       | -        | -         | ?               |       |
| 4532 | 31.8    | 06 44    | IBm                   | 12.1   | 12.2   | 0.41  | 4  | 0.43    | 0.34     | -         | X,NW            |       |
| 4535 | 31.8    | 08 28    | SAB(s)c               | 11.1   | 10.4   | 0.83  | 10 | 0.19    | 0.75     | +1925     | S'              |       |
| 4536 | 31.9    | 02 28    | SAB(rs)bc             | 11.2   | 10.9   | 0.87  | 6  | 0.44    | 0.69     | +1819     | X,NW            |       |
| 4539 | 32.1    | 18 29    | (Sa)                  | (13.9) | -      | -     | -  | -       | -        | -         | S?              | <5°   |
| 4540 | 32.3    | 15 50    | SAB(rs)cd             | 12.9   | 12.6:  | 0.23  | 6  | 0.20    | 0.15     | -         | S               | <5°   |
| 4548 | 32.9    | 14 46    | SB(rs)b               | 11.9   | 10.9   | 0.67  | 6  | 0.11    | 0.63     | + 372     | S               | <5°   |
| 4550 | 32.9    | 12 30    | SO sp                 | 12.7   | 12.3   | 0.44  | 6  | 0.57    | 0.21     | + 280     | E               | <5°   |
| 4551 | 33.1    | 12 33    | E3                    | (12.8) | -      | 0.09  | 5  | 0.17    | 0.03     | + 908     | E               | <5°   |
| 4552 | 33.1    | 12 50    | E0                    | 11.3   | 11.0   | 0.35  | 5  | 0.00    | 0.35     | + 194     | E               | <5°   |
| 4561 | 33.6    | 19 36    | SB(rs)dm              | 12.9   | 12.6:  | 0.25  | 3  | 0.09    | 0.21     | -         | S?              | <6°   |
| 4564 | 34.0    | 11 43    | (E7)                  | 12.1   | (11.7) | 0.36  | 6  | 0.52    | 0.15     | -         | E               | <5°   |
| 4567 | 34.0    | 11 32    | SAB(rs)bc             | 12.3   | 12.0   | 0.39  | 9  | 0.20    | 0.31     | +2206     | S               | <5°   |
| 4568 | 34.1    | 11 31    | SAB(rs)bc             | 12.2   | 11.6   | 0.60  | 8  | 0.39    | 0.44     | +2355     | S               | <5°   |
| 4569 | 34.3    | 13 26    | SAB(rs)ab             | 11.2   | 10.1   | 0.89  | 6  | 0.32    | 0.76     | + 896     | S               | <5°   |
| 4570 | 34.4    | 07 31    | SO sp                 | 12.0   | 11.6   | 0.51  | 4  | 0.51    | 0.31     | +1640     | E?              | <6°   |
| 4571 | 34.3    | 14 28    | SA(r:)cd              | 12.8   | 11.7   | 0.49  | 4  | 0.02    | 0.48     | -         | S               | <5°   |
| 4576 | 35.0    | 04 38    | (Sc <sup>-</sup> )    | -      | 14.2   | -     | -  | -       | -        | -         | X,NW            |       |
| 4578 | 35.0    | 09 50    | (SO or E)             | 12.5   | 11.9   | 0.44  | 4  | 0.13    | 0.39     | +2201     | E               | <5°   |
| 4579 | 35.1    | 12 05    | SAB(rs)b              | 11.0   | 10.3   | 0.62  | 4  | 0.03    | 0.61     | +1679     | S               | <5°   |
| 4580 | 35.3    | 05 30    | SAB(rs)a              | 12.8   | 12.1   | 0.30  | 4  | 0.12    | 0.25     | -         | X,NW            |       |
| 4584 | 35.8    | 13 23    | (SB(s)a:)             | -      | -      | -     | -  | -       | -        | -         | S               | <5°   |
| 4586 | 35.9    | 04 35    | SA(s)O/a:             | 13.0   | 12.5   | 0.53  | 3  | 0.44    | 0.35     | -         | X,NW            |       |
| 4595 | 37.3    | 15 34    | (Sc?)                 | 13.1   | -      | -     | -  | -       | -        | -         | S               | <5°   |
| 4596 | 37.4    | 10 27    | SB(r)O <sup>+</sup>   | 12.2   | 11.6:  | 0.41  | 3  | 0.40    | 0.25     | -         | E               | <5°   |
| 4606 | 38.4    | 12 10    | SB(s)a                | (13.0) | 12.6   | -     | -  | -       | -        | -         | S               | <5°   |
| 4607 | 38.7    | 12 10    | SB(s)? sp             | -      | 13.7:  | -     | -  | -       | -        | -         | S               | <5°   |
| 4608 | 38.7    | 10 26    | SB(r)O°               | 12.7   | 12.0   | 0.41  | 3  | 0.20    | 0.33     | -         | E               | <5°   |
| 4612 | 39.0    | 07 35    | (R)SAB <sub>0</sub> ° | 12.6:  | 12.0:  | 0.24  | 2  | 0.02    | 0.23     | -         | E?              | <6°   |
| 4621 | 39.5    | 11 55    | E5                    | 11.4   | 10.9   | 0.46  | 4  | 0.24    | 0.36     | + 339     | E               | <5°   |
| 4623 | 39.6    | 07 56    | (E:5)                 | 13.2   | -      | -     | -  | -       | -        | -         | E?              | <6°   |
| 4630 | 40.0    | 04 14    | (Pec)                 | 13.1   | -      | -     | -  | -       | -        | -         | X,SE            |       |

TABLE 1 -- Continued

| NGC    | 12 <sup>h</sup> + | $\delta$ | Revised Type               | $m_H$  | $m_T$  | log D | n | log D/d | log D(0) | V<br>km/s | Member-<br>ship | Rem. |
|--------|-------------------|----------|----------------------------|--------|--------|-------|---|---------|----------|-----------|-----------------|------|
| 4632   | 40.0              | 00 11    | Sac                        | 12.1   | 11.8:  | 0.56  | 2 | 0.41    | 0.40     | -         | X,SE            |      |
| 4633   | 40.1              | 14 38    | SB(s)d: sp                 | -      | 13.7   | -     | - | -       | -        | -         | S               | <5°  |
| 4634   | 40.2              | 14 34    | Sd:                        | -      | 13.1   | -     | - | -       | -        | -         | S               | <5°  |
| 4636   | 40.3              | 02 57    | E <sup>+</sup> 0-1         | 10.8   | 10.4   | 0.63  | 3 | 0.14    | 0.57     | + 858     | X,SE            |      |
| 4637   | 40.3              | 11 43    | -                          | -      | -      | -     | - | -       | -        | -         | ?               |      |
| 4638   | 40.2              | 11 43    | SO <sup>-</sup> sp         | 12.2   | 12.1   | 0.19  | 6 | 0.34    | 0.05     | +1011     | E               | <5°  |
| 4639   | 40.3              | 13 31    | (Sbc)                      | 12.3   | 12.1   | 0.23  | 4 | 0.08    | 0.20     | -         | S               | <5°  |
| 4643   | 40.8              | 02 15    | SB(rs)0/a                  | 11.6   | 11.5:  | 0.35  | 4 | 0.31    | 0.23     | +1324     | X,SE            |      |
| 4647   | 41.0              | 11 51    | SAB(rs)c                   | 12.0   | 12.0   | 0.39  | 6 | 0.04    | 0.37     | +1379     | S               | <5°  |
| 4649   | 41.1              | 11 49    | E2                         | 10.6   | 9.9    | 0.50  | 7 | 0.04    | 0.48     | +1248     | E               | <5°  |
| 4651   | 41.2              | 16 40    | SA(rs)c                    | 11.8   | 11.2   | 0.54  | 5 | 0.17    | 0.47     | -         | S?              | <5°  |
| 4654   | 41.4              | 13 23    | SAB(rs)cd                  | 11.7   | 11.0   | 0.61  | 5 | 0.25    | 0.51     | -         | S               | <5°  |
| 4660   | 42.0              | 11 26    | (E6 or SO <sup>-</sup> sp) | 12.3   | 12.0   | 0.25  | 4 | 0.32    | 0.12     | + 950     | E               | <5°  |
| 4665   | 42.6              | 03 19    | SB(s)0/a                   | 11.8   | 11.4:  | 0.47  | 3 | 0.06    | 0.45     | + 684     | X,SE            |      |
| 4688   | 45.3              | 04 36    | (S)                        | 13.0   | (12.2) | 0.39  | 4 | 0.04    | 0.37     | -         | X,SE            |      |
| 4689   | 45.2              | 14 01    | SA(rs)bc                   | 12.0   | 11.5   | 0.50  | 3 | 0.09    | 0.46     | -         | S               | <5°  |
| 4694   | 45.7              | 11 15    | SBOp                       | 12.6   | 12.0:  | 0.47  | 2 | 0.48    | 0.28     | -         | E               | <6°  |
| 4698   | 45.8              | 08 45    | SA(s)ab                    | 12.2   | 11.5   | 0.52  | 4 | 0.36    | 0.37     | + 955     | S?              | >6°  |
| 4701   | 46.6              | 03 39    | SA(s)cd                    | 12.8   | 12.5:  | 0.20  | 2 | 0.16    | 0.14     | -         | X,SE            |      |
| 4710   | 47.1              | 15 26    | SA:(r)0 <sup>+</sup> sp    | 12.0   | 11.8:  | 0.61  | 5 | 0.69    | 0.33     | -         | E?              | <6°  |
| 4713   | 47.5              | 05 35    | SAB(rs)d                   | 12.3   | 11.8:  | 0.41  | 5 | 0.14    | 0.35     | + 574     | X,SE            | *    |
| 4734   | 48.7              | 05 07    | (Sc:)                      | (13.5) | -      | -     | - | -       | -        | -         | X,SE            |      |
| 4754   | 49.7              | 11 35    | SB(r: )0 <sup>-</sup>      | 12.0   | 11.4:  | 0.61  | 6 | 0.36    | 0.47     | +1398     | E?              | <6°  |
| 4762   | 50.4              | 11 31    | SB?(r)0 <sup>o</sup> sp    | 11.8   | 11.1   | 0.95  | 2 | 0.90    | 0.59     | + 870     | E?              | >6°  |
| 4765   | 50.7              | 04 45    | (S?)                       | 12.9   | (12.8) | -     | - | -       | -        | -         | X,SE            |      |
| 4771   | 50.8              | 01 33    | SAd?                       | 12.9   | 12.2:  | 0.67  | 3 | 0.76    | 0.37     | -         | X,SE            |      |
| 4772   | 51.0              | 02 27    | SA(s)a                     | 12.6   | 11.9:  | 0.57  | 2 | 0.47    | 0.38     | -         | X,SE            |      |
| 4795   | 52.5              | 08 20    | (S?)                       | 13.1   | (12.3) | -     | - | -       | -        | -         | -               |      |
| 4808   | 53.3              | 04 35    | SA(s: )cd                  | 12.5   | 12.1:  | 0.61  | 6 | 0.48    | 0.42     | -         | X,SE            |      |
| 4809   | 52.3              | 02 52    | Imp                        | (13.4) | -      | 0.29  | 5 | 0.44    | 0.11     | + 870     | X,SE            |      |
| 4810   | 52.3              | 02 51    | Imp                        | (13.6) | -      | 0.06  | 5 | 0.18    | -0.01    | + 810     | X,SE            |      |
| HA88-2 | 52.6              | 00 23    | SB(s)d                     | 12.9   | 12.5   | -     | - | -       | -        | -         | X,SE            | No4  |
| 4845   | 55.5              | 01 51    | SA(s)ab                    | 12.6   | 11.8:  | 0.62  | 4 | 0.55    | 0.40     | -         | X,SE            |      |
| 4866   | 57.0              | 14 27    | SA(r)0 <sup>+</sup> : sp   | 12.1   | 11.9   | 0.57  | 5 | 0.67    | 0.30     | +1862     | -               |      |
| 4880   | 57.7              | 12 45    | (Sa or Sm)                 | 13.1   | -      | 0.45  | 2 | 0.12    | 0.45     | -         | -               |      |
| 4900   | 58.2              | 02 46    | SB(rs)c                    | 11.8   | 11.8:  | 0.34  | 8 | 0.03    | 0.33     | + 958     | X,SE            |      |
| 4904   | 58.4              | 00 15    | SB(s)cd                    | 12.8   | 12.2:  | 0.39  | 2 | 0.23    | 0.30     | -         | X,SE            |      |

Notes to Table 1

4178, nearby dwarf.  
 4192, 4216, foreground.  
 4342, 4365, 4406, 4438, 4548, 4713, foreground?

( \* ) The entries are as follows:

NGC identification, Right ascension and declination (1950).  
 Revised morphological type (de Vaucouleurs 1959c).  
 $m_H$  = Harvard magnitude from Shaply-Ames Catalogue (H.A. 88, 2), or, when in parenthesis, in similar system, generally from Lund data.  
 $m_T$  = Total photographic magnitude from various sources (Holmberg, Sandage, de Vaucouleurs).  
 log D = logarithm of apparent major diameter in minutes of arc from various sources reduced to homogeneous system (de Vaucouleurs 1959b).  
 n = number of diameter sources.  
 log D/d = logarithm of axial ratio from same sources.  
 log D(0) = logarithm of corrected ("face on") apparent major diameter in minutes of arc (de Vaucouleurs 1959b).  
 V = corrected radial velocity from red-shift catalogue (Humason et al. 1956).  
 Membership in the several clouds discussed in text.  
 Remarks and distance to centers of E or S clouds.

Figure 2 is a plot of galaxies whose revised types are E or SO (called here the "ellipticals" for brevity); Figure 3 is a plot of galaxies having revised types Sa, b, c, d, m, or Im (the "spirals"). Some striking distributional differences are in evidence. In the Virgo cluster proper the ellipticals are scattered mainly in two opposite fan-shaped sectors to the northwest and southeast of a dense central core of 19 systems, centered at  $C_E(12^{\text{h}} 26.5^{\text{m}}, +13^{\circ}.2)$ , and  $2^{\circ}$  in diameter. The spirals are more uniformly distributed in an elliptical cloud measuring  $9^{\circ}$  east-west by  $5^{\circ}$  north-south, with a vacant area  $2^{\circ}$  in diameter near its center at  $C_S(12^{\text{h}} 27.5^{\text{m}}, +13^{\circ}.9)$ . The dense group of ellipticals is apparently the core of both distributions, but neither the shapes nor the orientations of the  $E$ -cloud and of the  $S$ -cloud agree. The mean radial density distributions, given in Table 2, are also completely different.

TABLE 2  
RADIAL DISTRIBUTIONS IN VIRGO CLUSTER

|                                             | CENTER                                              |               |                                                     |               |
|---------------------------------------------|-----------------------------------------------------|---------------|-----------------------------------------------------|---------------|
|                                             | $C_E(12^{\text{h}} 26.5^{\text{m}}, +13^{\circ}.2)$ |               | $C_S(12^{\text{h}} 27.5^{\text{m}}, +13^{\circ}.9)$ |               |
|                                             | $N^*$                                               | $N/A \dagger$ | $N^*$                                               | $N/A \dagger$ |
| $0^{\circ}-1^{\circ}$ .....                 | 17                                                  | 5.4           | 1                                                   | 0.32          |
| $1^{\circ}-2^{\circ}$ .....                 | 8                                                   | 0.85          | 10                                                  | 1.06          |
| $2^{\circ}-3^{\circ}$ .....                 | 3                                                   | 0.20          | 14                                                  | 0.89          |
| $3^{\circ}-4^{\circ}$ .....                 | 9                                                   | 0.41          | 15                                                  | 0.68          |
| $4^{\circ}-5^{\circ}$ .....                 | 10                                                  | 0.35          | 15                                                  | 0.53          |
| $5^{\circ}-6^{\circ}$ .....                 | 9                                                   | 0.26          | 6                                                   | 0.17          |
| $6^{\circ}-7^{\circ}$ .....                 | 8                                                   | 0.20          | .....                                               | .....         |
| $\langle V_0 \rangle \pm \text{p.e.} \dots$ | $+962 \pm 69$                                       |               | $+1362 \pm 128$                                     |               |
| $\sigma, (n) \dots \dots \dots$             | 631 (38)                                            |               | 825 (19)                                            |               |

\* Number of objects.

† Number per square degree.

The Virgo cloud extension (Cloud  $X$ ) is poor in ellipticals and rich in spirals. It may overlap, at least in the projection, with the southernmost fringe of the Virgo cluster. In addition, a conspicuous excess of both  $E$  and  $S$  systems is present in a region, about  $3^{\circ}$  in diameter, around the group near  $12^{\text{h}} 17^{\text{m}}, +6^{\circ}$  (Cloud  $W$ ).

#### IV. DISTRIBUTION AND VELOCITY

##### a) The $E$ - and $S$ -Clouds

The velocity distributions also show remarkable differences set out in Table 2A. Within  $6^{\circ}.5$  from  $C_E$  there are 64 ellipticals, of which 38 have known velocities; the mean radial velocity of this group is  $\langle V_E \rangle = +962 \pm 69$  (p.e.)  $\text{km sec}^{-1}$ , and the velocity dispersion is  $\sigma_E = 631 \text{ km sec}^{-1}$ . Within  $6^{\circ}$  from  $C_S$  there are 61 spirals, of which 19 have known velocities; the mean radial velocity of this group is  $\langle V_S \rangle = +1362 \pm 128$  (p.e.)  $\text{km sec}^{-1}$ , and the velocity dispersion is  $\sigma_S = 825 \text{ km sec}^{-1}$ . The difference between the mean velocities of the two groups is  $\delta V = \langle V_S \rangle - \langle V_E \rangle = +400 \pm 146$  (p.e.)  $\text{km sec}^{-1}$ . The probability that the mean radial velocities of the  $E$ - and  $S$ -clouds are actually equal and that the observed difference  $\delta V/\text{p.e.} \approx 2.8$  is due to chance is only 6 per cent for Gaussian distributions.

Further division of the material leads to the results summarized by Table 6. The  $E$ -cloud may be divided into three parts: (a) a core, including 19 objects within  $1^{\circ}.25$  from

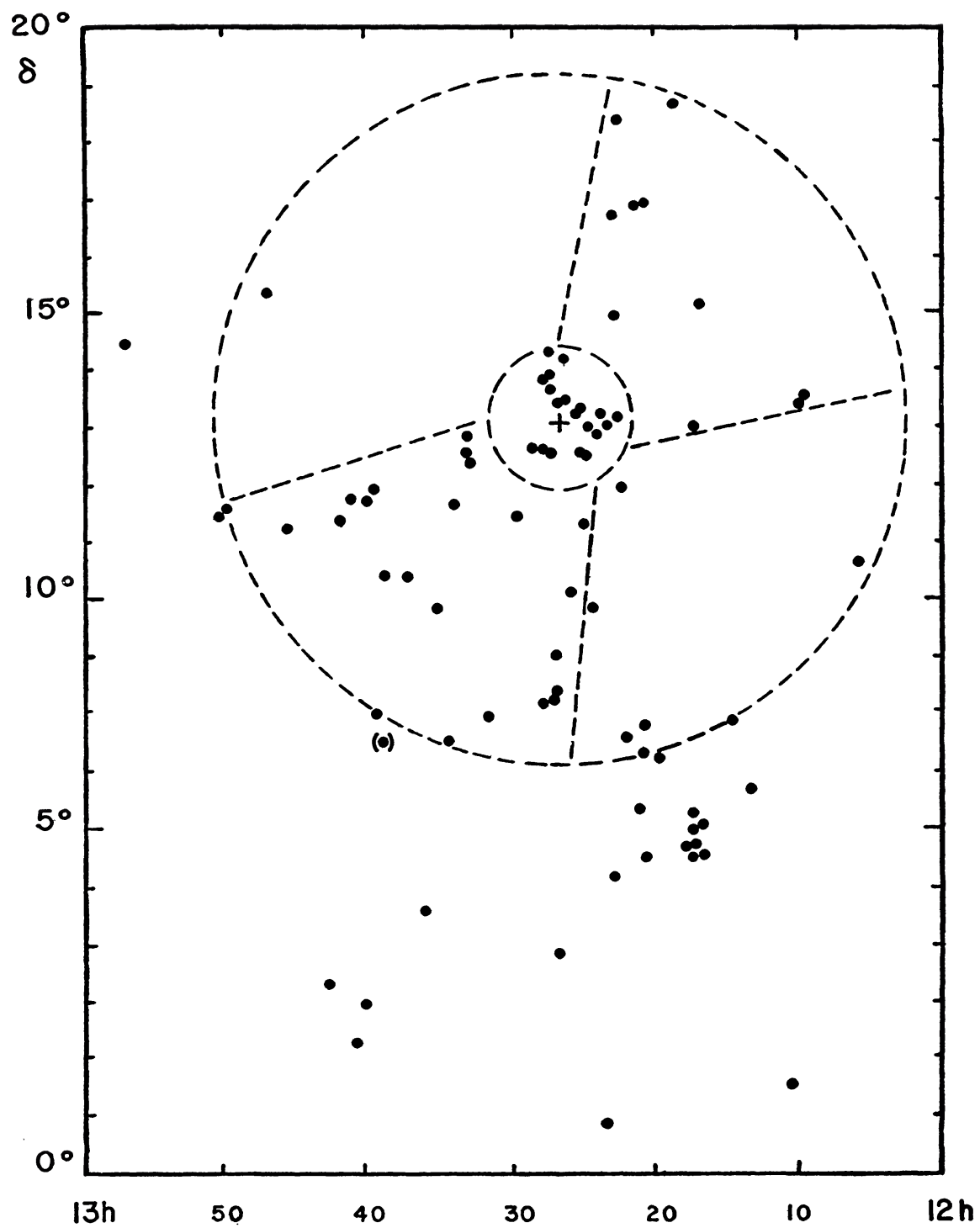


FIG. 2.—Distribution of elliptical and lenticular galaxies

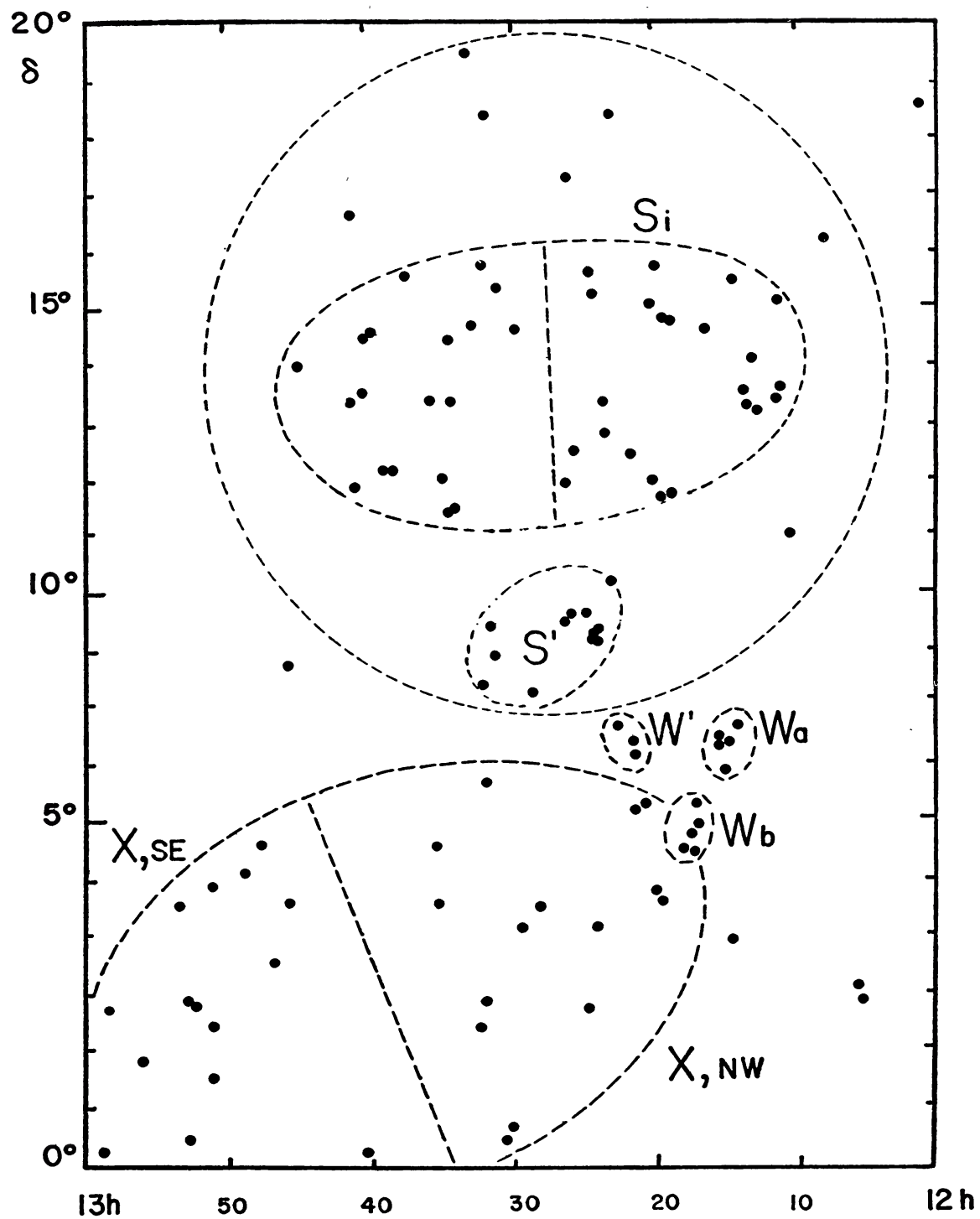


FIG. 3.—Distribution of spiral and irregular galaxies

$C_E$ ; (b) the north-preceding sector ( $NGC < 4400$ ), including 11 objects within  $6^\circ$  from  $C_E$ ; and (c) the south-following sector ( $NGC > 4400$ ), including 21 objects within  $6^\circ$  from  $C_E$ .

The mean magnitudes, diameters, and velocities of the three parts agree closely; the mean velocity of the whole cloud so defined is  $\langle V_E \rangle = +935 \pm 70$  (p.e.)  $\text{km sec}^{-1}$  ( $n = 33$ ), or  $+1012 \pm 64$  if two objects with negative velocities are rejected.

The inner, elliptical part of the  $S$ -cloud may be divided into two parts: (a) the preceding half ( $NGC < 4500$ ), including 23 objects within  $4.5^\circ$  in R.A. from  $C_S$  and (b) the following half ( $NGC > 4500$ ), including 19 objects within  $4.5^\circ$  in R.A. from  $C_S$ . The mean magnitudes, diameters, and velocities of the two halves are also in close agreement but are consistently higher than for the various parts of the  $E$ -cloud; the mean velocity is  $\langle V_S \rangle = +1405 \pm 166$  (p.e.)  $\text{km sec}^{-1}$  ( $n = 13$ ), or  $+1682 \pm 128$  if two objects with negative velocities are rejected.

TABLE 2A  
VELOCITY DISTRIBUTIONS IN VIRGO CLUSTER\*

| $V$ (km/sec) | $E$ -Cloud |    | $S$ -Cloud |   |
|--------------|------------|----|------------|---|
| - 500.....   |            | 1  |            | 1 |
| - 250....    | 2          |    | 2          |   |
| 0.....       |            | 3  |            | 3 |
| 250...       | 7          |    | 2          |   |
| 500.....     |            | 9  |            | 2 |
| 750...       | 8          |    | 2          |   |
| 1000.....    |            | 14 |            | 2 |
| 1250...      | 13         |    | 2          |   |
| 1500.....    |            | 5  |            | 5 |
| 1750...      | 3          |    | 6          |   |
| 2000.....    |            | 4  |            | 5 |
| 2250...      | 2          |    | 5          |   |
| 2500.....    |            | 0  |            | 2 |

\*  $r < 6^\circ$ .

The velocity-dispersion values range from 258 to 720  $\text{km sec}^{-1}$  in the several parts of the  $E$ -cloud, with a mean  $\sigma_E \approx 550 \text{ km sec}^{-1}$ , and from 390 to 1090 in the  $S$ -cloud, with a mean  $\sigma_S \approx 750 \text{ km sec}^{-1}$ .

A small group ( $S'$ ) of 11 spirals lies  $4^\circ$ - $5^\circ$  south of  $C_S$  (Fig. 3); the mean velocity  $\langle V_{S'} \rangle = +1563 \pm 158$  (p.e.)  $\text{km sec}^{-1}$  ( $n = 3$ ) does not differ significantly from that of the restricted  $S$ -cloud. Including all objects within  $6^\circ$  from  $C_S$ , the mean velocity of the whole cloud is  $\langle V_S \rangle = +1362 \pm 128$  (p.e.)  $\text{km sec}^{-1}$  ( $n = 19$ ), or  $+1536 \pm 111$  if two objects with negative velocities are rejected.

The velocity difference between the  $S$ - and  $E$ -clouds so defined is  $\delta V = \langle V_S \rangle - \langle V_E \rangle = +427 \pm 146$  (p.e.) (no rejection), or  $+524 \pm 128$  (p.e.) (rejecting two  $E$  and two  $S$  systems with negative velocities). The difference,  $\delta V$ , is 2.9 times its probable error in the first case, 4.1 times in the second.

If the frequency distributions of the velocities in each cloud were Gaussian, the probability that these differences were due to sampling fluctuations would be less than 0.05 and 0.01, respectively. However, as Table 2A and Figure 4 show, while the  $E$ -cloud has a velocity distribution reasonably symmetrical about its mean, the velocity distribution in the  $S$ -cloud departs widely from a Gaussian distribution. The probability of drawing such a highly asymmetrical distribution by random sampling of a Gaussian velocity distribution with mean  $\langle V \rangle \approx 1000 \text{ km sec}^{-1}$  and  $\sigma \approx 550 \text{ km sec}^{-1}$  is obviously very small. We conclude that, except for the approximate correspondence of the core of the  $E$ -cloud with the "hole" in the center of the  $S$ -cloud, the surface distributions, mean velocities, and

velocity distributions of the *E*- and *S*-clouds are so markedly different as to make their physical association appear very doubtful.

To state the results differently, if in a first approximation one assumes that the velocity-distance relation is linear with  $\Delta = V/120$  ( $\Delta$  Mpc,  $V$  km sec<sup>-1</sup>; van den Bergh 1960*a*), the mean velocities, taken at face value, imply that the distance of the *E*-cloud is  $\Delta_E = 8.0 \pm 0.7$  (p.e.) Mpc, and of the *S*-cloud  $\Delta_S = 11.3 \pm 1.3$  (p.e.) Mpc. Since the apparent radii of the two groups are  $R \approx 6^\circ$ , the maximum linear radii of the two clouds are 0.8 and 1.1 Mpc, respectively, and they may be separated by a near-empty gap whose width is at least  $(11.3 - 8.0) - (0.8 + 1.1) = 1.4$  Mpc.

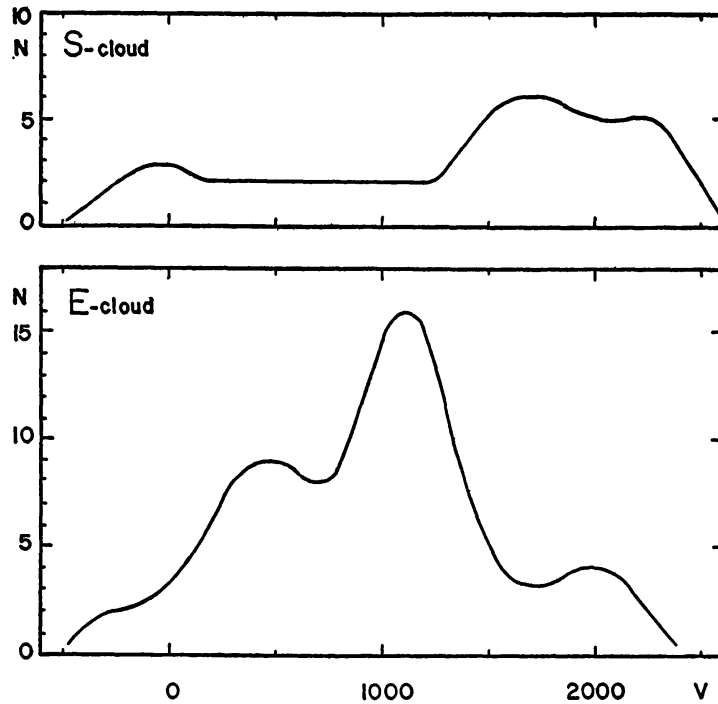


FIG. 4.—Velocity distributions in the *E*- and *S*-clouds

In a second approximation one should take into account the non-linearity and anisotropy of the velocity field among bright galaxies (de Vaucouleurs 1958, 1959*a*) and derive the velocity-distance relation in the direction of the Virgo cluster from the relation

$$V_r = R_1[\omega(R) - \omega_1] \sin(L - L_0) - R_1[\epsilon(R) - \epsilon_1] \cos(L - L_0) + \epsilon(R)r,$$

where

$$\omega(R) = \omega_0 e^{-(R/R_1)^2} \quad \text{and} \quad \omega_1 = \frac{\omega_0}{e} = 0.368\omega_0,$$

$$\epsilon(R) = \epsilon_\infty(1 - e^{-R/R_1}) \quad \text{and} \quad \epsilon_1 = \epsilon_\infty(1 - e^{-1}) = 0.632\epsilon_\infty,$$

with  $R_1\omega_1 = 500$  km sec<sup>-1</sup> and  $R_1\epsilon_1 = 1100$  km sec<sup>-1</sup>. The curves in Figure 5 are for supergalactic longitudes  $L_0$  and  $L_0 + 15^\circ$ , which cover the region of interest; through the curve for  $L_0$  the velocities  $V_E$  and  $V_S$  correspond to distances  $\Delta_E = (0.70 \pm 0.10) R_1$  and  $\Delta_S = (1.45 \pm 0.15) R_1$ , or 7.0 and 14.5 Mpc, if  $R_1 = 10$  Mpc. The separation is even larger than on the assumption of a linear velocity-distance relation.

We conclude with a probability of 95–99 per cent or greater that the Virgo “cluster” is

a chance superposition of (at least) two nearby, but separate, clouds aligned at different distances on the line of sight in the dense central regions of the Local Supercluster. If so, the center of gravity and of the presumed rotation and expansion of the system need not be identified with any particular cluster.

*b) The X- and W-Clouds*

The Virgo extension (Cloud X) south of  $+7^\circ$  includes 42 objects (9 *E*, 29 *S*, 4 unclassified), of which 6 ellipticals and 8 spirals have known velocities; the mean velocity is

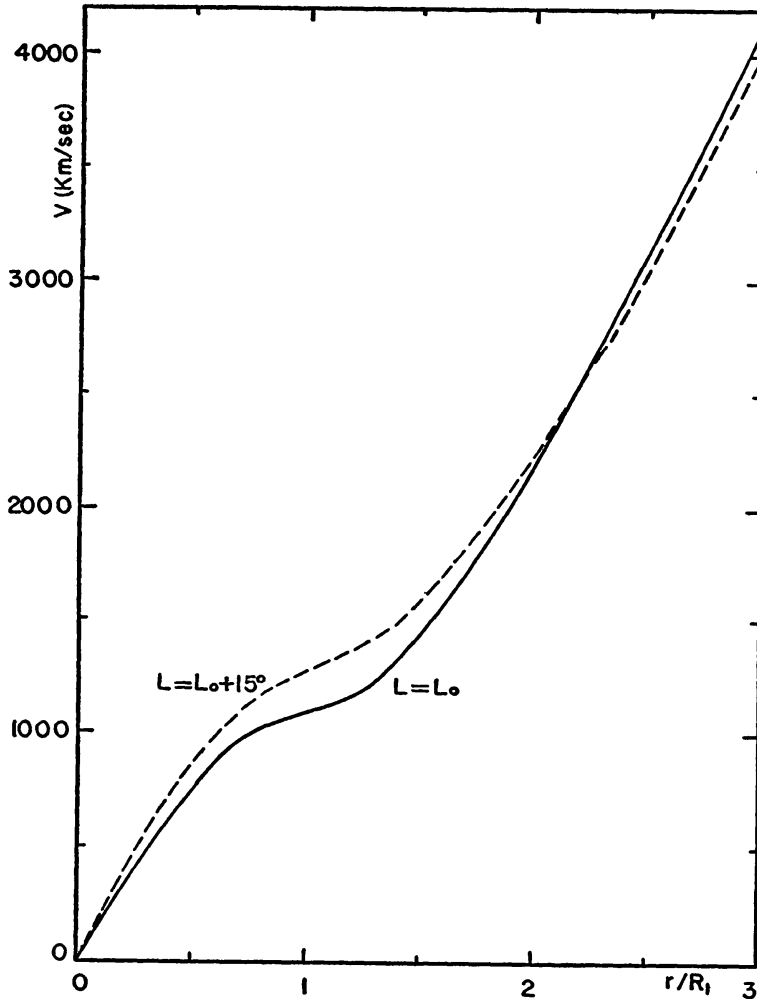


FIG. 5.—Velocity-distance relations in the directions  $L_0$  of the Virgo cluster and  $L_0 + 15^\circ$

$\langle V_X \rangle = +1185 \pm 74$  (p.e.)  $\text{km sec}^{-1}$ . In this direction the velocity-distance relation is as shown by the curve  $L_0 + 15^\circ$  in Figure 5, and the corresponding distance is  $\Delta_X = (0.9 \pm 0.2) R_1$ , or about 9 Mpc on the same distance scale.

There are striking differences and apparent inconsistencies set out in Table 3 between the velocities, magnitudes, and apparent diameters of the northwest and southeast halves of Cloud X separated by its minor axis. Magnitudes and diameters indicate that the northwest half is the nearer, at about two-thirds of the distance of the southeast half, while the velocities suggest the converse situation. The velocity differential,  $\delta V = V(\text{NW}) - V(\text{SE}) = +632 \pm 100$  (p.e.)  $\text{km sec}^{-1}$ , is apparently significant. On the as-

sumption that it is due to rotation, as the elliptical outline of the cloud might suggest (Fig. 1), the mass of the cloud is of the order of

$$N \mathcal{M} \approx \frac{2}{G} \left( \frac{\delta V}{2} \right)^2 \frac{\Delta_X}{20} = 2.1 \times 10^{13} \odot$$

if the tilt of the equatorial plane is about  $45^\circ$  and the radius  $6^\circ$ . When this mass is divided among the 42 systems within the outline of Cloud X, their mean mass comes out  $\langle \mathcal{M} \rangle \leq 5 \times 10^{11} \odot$ , which is almost one order of magnitude too high. The velocity dispersion for the whole cloud is  $\sigma_X = 408 \text{ km sec}^{-1}$ , and the virial theorem would lead to still higher masses. It is therefore possible that Cloud X is not a stable physical unit, but again results from the accumulation along the line of sight of several independent groups, all in the Local Supercluster.

TABLE 3  
ELEMENTS OF CLOUD VIRGO X

|                                              | NW half         | <i>n</i> | SE half         | <i>n</i> | $\Delta(\text{NW})/\Delta(\text{SE})$ |
|----------------------------------------------|-----------------|----------|-----------------|----------|---------------------------------------|
| Mean velocity: $\langle V_0 \rangle$ .....   | $+1501 \pm 70$  | 7        | $+869 \pm 75$   | 7        | (1.73* or 2.64†)                      |
| Brightest S: $\langle m_H \rangle$ .....     | $11.1 \pm 0.2$  | 4        | $11.8 \pm 0.1$  | 4        | 0.72                                  |
| Brightest S: $\langle m_T \rangle$ .....     | $10.8 \pm 0.2$  | 4        | $11.6 \pm 0.1$  | 4        | 0.69                                  |
| Largest S: $\langle \log D(0) \rangle$ ..... | $0.65 \pm 0.02$ | 4        | $0.41 \pm 0.01$ | 4        | 0.57                                  |

\* For a linear velocity-distance relation.

† For the velocity-distance relation of Fig. 5.

TABLE 4  
ELEMENTS OF CLOUD VIRGO W

|                                                | W-a            | <i>n</i> | W-b   | <i>n</i> |
|------------------------------------------------|----------------|----------|-------|----------|
| Listed in Table 1.....                         | *              | 12       | †     | 7        |
| Mean velocity: $\langle V_0 \rangle$ .....     | $+2253 \pm 57$ | 5        | ..... | 0        |
| Brightest S, S0: $\langle m_H \rangle$ .....   | 12.5           | 4        | 12.9  | 4        |
| Largest S, S0: $\langle \log D(0) \rangle$ ... | 0.22           | 4        | 0.25  | 4        |

\* Near 12h 17m,  $+6^\circ$ : NGC 4257, 4259, 4260, 4261, 4264, 4266, 4268, 4269, 4270, 4273, 4277, 4281.

† Near 12h 14m,  $+7^\circ 5'$ : NGC 4215, 4224, 4233, 4235, 4241, 4246, 4247.

The compact group at 12h 17m,  $+6^\circ$  (Group W-a), includes 12 objects (7 E, 5 S), of which 3 ellipticals and 1 spiral have known velocities; the mean velocity,  $\langle V_W \rangle = +2253 \pm 54$  (p.e.)  $\text{km sec}^{-1}$ , indicates a distance about twice that of the Virgo cluster, or, more precisely,  $\Delta_W = (2.03 \pm 0.03) R_1$ , about 20 Mpc, according to Figure 5.

This group is apparently at about the same distance as the nearby group centered near 12h 14m,  $+7^\circ 5'$  (Group W-b), which includes 7 objects (2 E, 5 S). No velocities are available, but, as shown in Table 4, the apparent magnitudes and reduced (i.e., "face-on") apparent diameters of the 4 brightest or largest systems are about the same in groups W-a and W-b.

The small grouping near 12h 21m,  $+7^\circ 5'$  (Table 5), results apparently from the projection of 4 ellipticals (NGC 4324, 4339, 4342, 4365,  $\langle m_H \rangle = 12.2$ ,  $\langle V \rangle = +1130 \text{ km sec}^{-1}$ ) in front of a more distant group (Virgo W') of 8 spirals whose 4 brightest members average  $\langle m_H \rangle = 13.9$ . No reduced diameters or velocities are available, but, from the appar-

ent magnitudes, the predicted values are  $\langle D(0) \rangle = 1'.0$  (4 largest) and  $\langle V \rangle = 4000\text{--}5000 \text{ km sec}^{-1}$ . This distant group is clearly not a part of the Virgo cluster.

#### V. VELOCITY AND MAGNITUDE

We now confine our attention to the Virgo cluster(s) proper, i.e., to galaxies located within  $6^\circ$  from  $C_E$  or  $C_S$ , excluding members of clouds Virgo  $X$ ,  $W$ , and  $W'$ .

Figure 6 shows plots of velocity versus total magnitude  $m_T$  for 20 galaxies of the  $S$ -cloud and 34 galaxies of the  $E$ -cloud. The systematic difference between the velocities of the two clouds is again in evidence. Neither shows any indication of the velocity-distance

TABLE 5  
ELEMENTS OF GROUP VIRGO  $W'$

|                                                        | Foreground $W'$ | $n$ | Group $W'$ | $n$ |
|--------------------------------------------------------|-----------------|-----|------------|-----|
| Listed in Table 1 . . . . .                            | *               | 4   | †          | 8   |
| Mean velocity: $\langle V_0 \rangle$ . . . . .         | +1130           | 4   | .....      | 0   |
| Brightest $E$ : $\langle m_H \rangle$ . . . . .        | 11.8            | 2   | .....      | 0   |
| Brightest $S$ , $S0$ : $\langle m_H \rangle$ . . . . . | 12.6            | 2   | 13.9       | 4   |
| Largest $E$ : $\langle \log D(0) \rangle$ . . . . .    | 0.38            | 2   | .....      | 0   |

\* NGC 4324, 4339, 4342, 4365 (types ranging from E0 to S0<sup>+</sup>;  $m_H \leq 12.8$ ; probably part of  $E$ -cloud).

† NGC 4309, 4326, 4333, 4334, 4341, 4343, 4353, 4370 (types from S0<sup>+</sup> to I,  $m_H \geq 13.6$ ).

relation in the range  $10 \leq m_T \leq 13$  ( $S$ -cloud) and  $9.3 \leq m_T \leq 14.1$  ( $E$ -cloud), which confirms that each cloud is a physical unit. However, in the  $S$ -cloud the velocity-magnitude distribution is clearly not an equilibrium configuration; there is, in fact, an empty area near the center of the distribution at  $\langle m_T \rangle = 11.2$ ,  $\langle V_0 \rangle \approx +1400$ . The frequency distributions of velocities are compared in Table 2A and in Figure 4; their great dissimilarity is obvious.

Four systems with low velocities, of which three are negative, stand out in the accompanying table. NGC 4178 is clearly a dwarf irregular in the foreground; the large ap-

|                 | NGC  |       |      |         |
|-----------------|------|-------|------|---------|
|                 | 4178 | 4192  | 4216 | 4438    |
| Type . . . . .  | SBdm | SABab | SABb | SA0/a p |
| $m_T$ . . . . . | 11.7 | 10.7  | 10.9 | 10.9    |
| $V_0$ . . . . . | +143 | -202  | -34  | -105    |

parent diameters of the others (Sec. VI) also suggest that they are probably foreground objects. NGC 4178, 4192, and 4216 are projected on the preceding edge of the  $S$ -cloud, and, in particular, 4178 is well outside the main cloud (Fig. 3).

In the  $E$ -cloud there is a definite concentration about the center of the distribution near  $\langle m_T \rangle = 11.6$ ,  $\langle V_0 \rangle \approx +1,000$ , but the distribution is not symmetrical. Only one system, NGC 4406, is outstanding at  $m_T = 10.0$ ,  $V_0 = -418$ ; since it is also one of the largest and brightest elliptical in the Virgo cluster, it may be in the foreground. Two systems—NGC 4473 and 4578—have velocities in excess of  $+2150 \text{ km sec}^{-1}$ ; since all others are less than  $+1850$ , there is a possibility that these systems are not part of the  $E$ -cloud; if so, the velocity range is from  $+200$  to  $+1800 \text{ km sec}^{-1}$ .

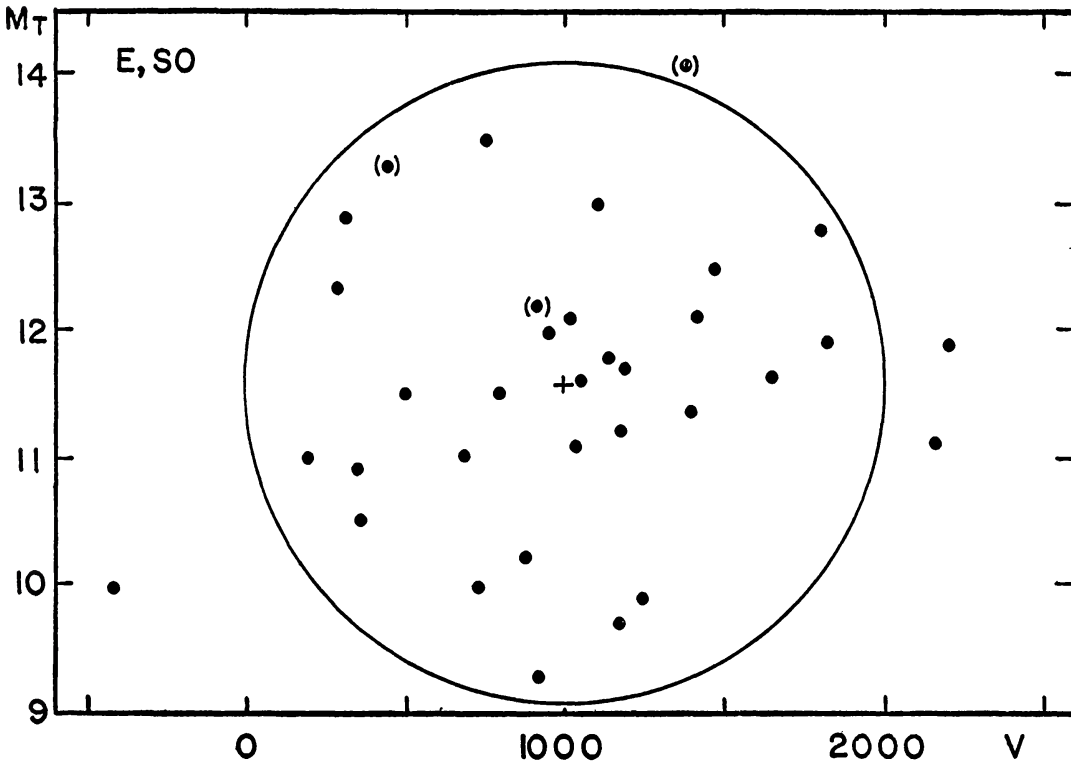
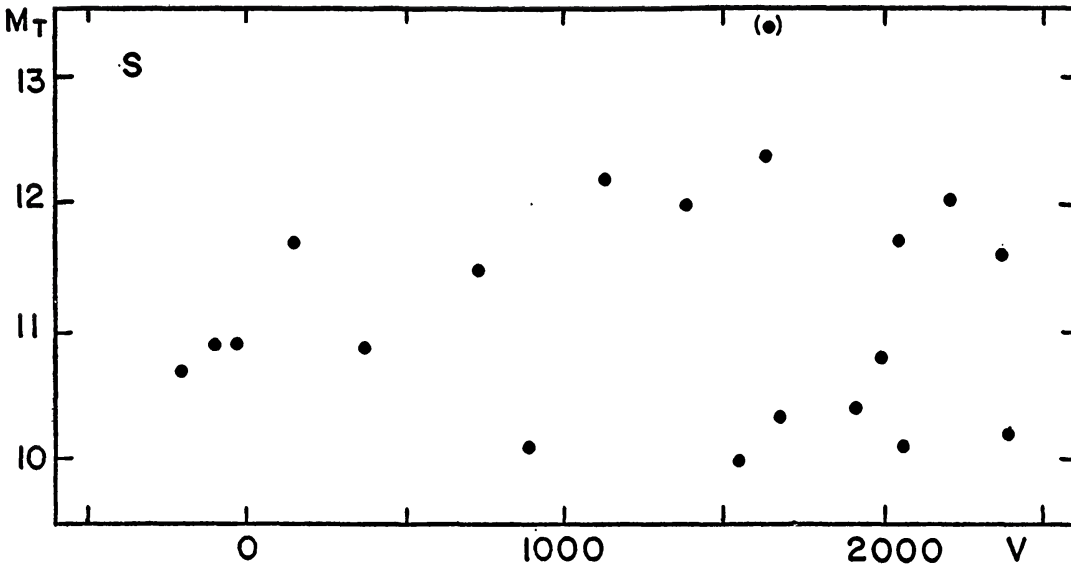


FIG. 6.—Velocity-magnitude distributions in the *E*- and *S*-clouds

## VI. VELOCITY AND DIAMETER

Figure 7 shows plots of velocity versus  $\log D(0)$  for 19 galaxies in the *S*-cloud and for 38 galaxies in the *E*-cloud. Again, for the *S*-cloud there is no concentration near the center of the distribution at  $\langle V_S \rangle \approx +1500$ ,  $\langle \log D(0) \rangle = 0.54$ , but a weak correlation is indicated between diameter and velocity, as might be introduced by the inclusion of a few foreground and background objects affected by the velocity-distance relation. In particular, the two outstanding objects with negative velocities—NGC 4192 and 4216—have above-average diameters, and they may be in the foreground. The mean reduced diameter of the four largest systems in the *S*-cloud is  $D(0) = 5'.6$ .

In the *E*-cloud the distribution is fairly symmetrical about the center at  $\langle V_E \rangle \approx +1000$ ,  $\langle \log D(0) \rangle = 0.28$ . There is no correlation between diameter and velocity. Four systems are clearly outstanding: NGC 4406 and 4438 with  $V < 0$  and NGC 4473 and 4578 with  $V > +2000$ . The mean reduced diameter of the four largest systems in the *E*-cloud is  $D(0) = 3'.9$ . The elements of the two clouds in the Virgo cluster are listed in Table 6.

The reduced apparent diameters of spirals can be used to estimate relative distances (de Vaucouleurs 1956*b*, 1959*b*). In Table 7, line 3, geometric distance moduli are computed for a mean reduced diameter of the four largest spirals equal to 20 kpc (cf. de Vaucouleurs 1959*b*). For comparison, photometric distance moduli ( $m - M - 0.2$ ) are given in lines 8 and 9 for an assumed mean absolute magnitude of the four brightest galaxies,  $M_T = -20.0$ , or approximately  $M_H \approx -19.5$ .

The major diameters of the various clouds are given in line 11 for the adopted distances of line 10. The groups have diameters of the order of 0.5–1 Mpc (about equal to the diameter of the Local Group); the larger clouds have diameters of the order of 1–2 Mpc.

It is not possible to determine the relative distances of the *E*- and *S*-clouds from the present data; however, it was shown previously (de Vaucouleurs 1958), from the residuals in the velocity-magnitude relation, that the dispersions of absolute photographic magnitudes of giant *E* and *S* systems are very nearly equal and that, on the average,  $\langle M_E \rangle - \langle M_S \rangle = +0.4$  mag. If so, the relative distances of the *E*-cloud and of the ellipticals in the foreground of group *W'* can be estimated as shown in Table 7. The reduced apparent diameters of ellipticals cannot be used at present for distance estimates because the corresponding linear diameters have not yet been estimated; however, the ratio  $15.5/7.1 = 2.2$  of distances derived from magnitudes in Table 7 is in good agreement with the ratio 1.9 of the apparent diameters in the *E*-cloud and the *W'* foreground group.

The ratio of distances of the *S*- and *E*-clouds,  $11.0/7.1 = 1.55$  in Table 7, is also in fair agreement with the ratio 1.4 (or 2.1) derived from velocities in Section IV. However, peculiar velocities of individual clouds and groups introduce a substantial scatter in the distances derived from velocities. Note, in particular, the low velocity of Cloud X(SE) in relation to its estimated distance and also the negative velocities of the group of foreground objects discussed in Section V.

The picture emerging from this discussion is of an irregular distribution of groups, clouds, and clusters with diameters of the order of 0.5–2 Mpc and peculiar velocities of the order of 500 km sec<sup>-1</sup> scattered in depth in the equatorial plane of the Local Supercluster toward its center. The Virgo "cluster" itself is to some extent an appearance resulting from the superposition of at least two clouds, the *E*-cloud and the *S*-cloud, with different populations and velocities and at different distances.

An inspection of the Lick (Shane 1956) and Palomar (Abell 1958) charts of galaxy and cluster distributions indicates that similar conditions prevail in other, more distant superclusters, outside the local supersystem.

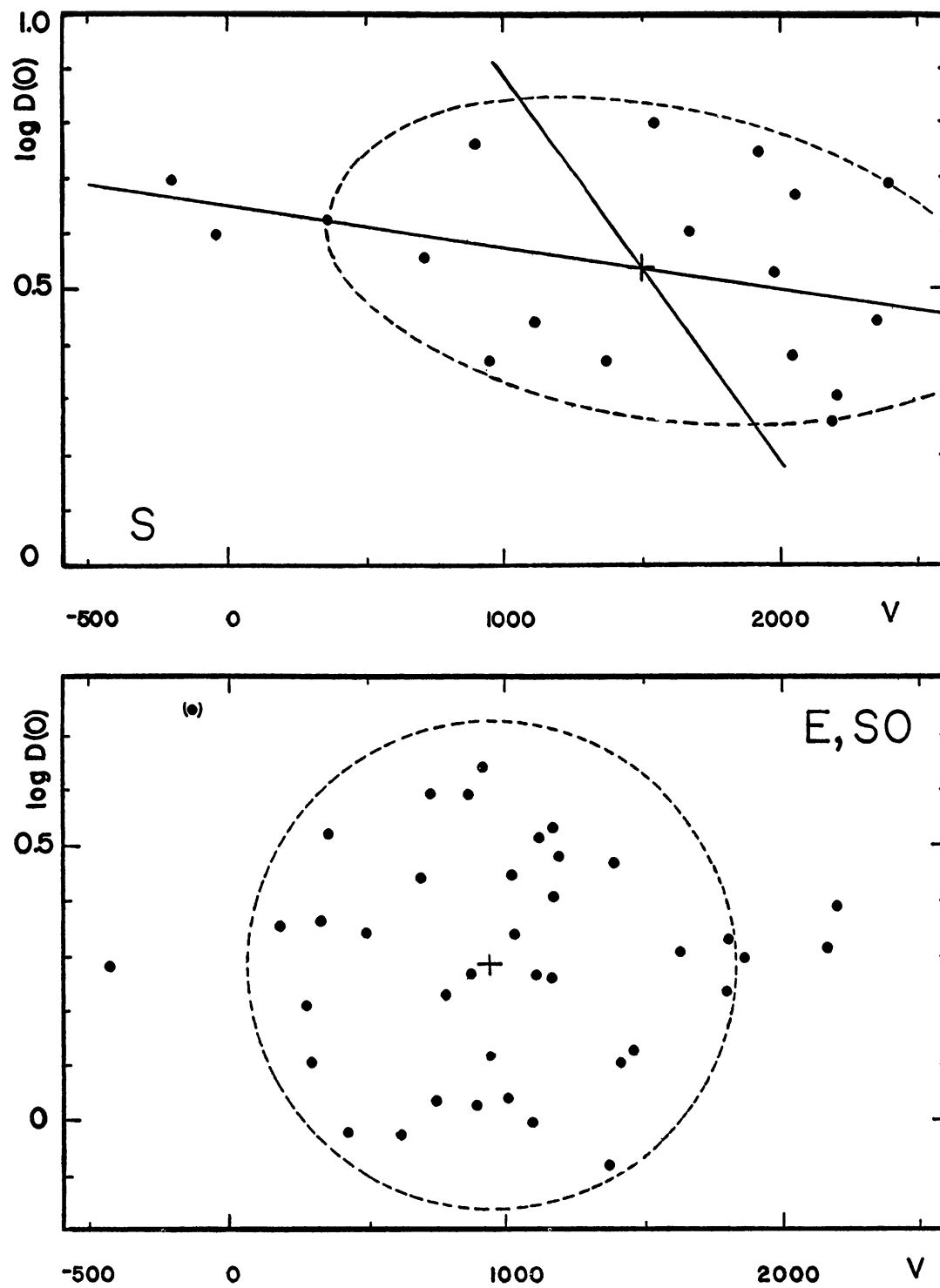


FIG. 7.—Velocity-diameter distributions in the *E*- and *S*-clouds

TABLE 6

## ELEMENTS OF THE E- AND S-CLOUDS OF THE VIRGO CLUSTER

| Group                            |        | Mean magnitudes and 4 brightest |      |       |      | Mean log D(0) and 4 largest |      |          |     | Mean Velocity and p.e. | Velocity Dispersion |     | Rem. |
|----------------------------------|--------|---------------------------------|------|-------|------|-----------------------------|------|----------|-----|------------------------|---------------------|-----|------|
|                                  |        | $m_H$                           | n    | $m_T$ | n    | log D(0)                    | n    | log D(0) | n   |                        | $\sigma$            | n   |      |
| E                                | np     | 12.32                           | (10) | 12.01 | (11) | 0.32                        | (9)  | 0.47     | (4) | 929 $\pm$ 87           | 258                 | 4   | 1    |
|                                  |        | 11.58                           | (4)  | 11.25 | (4)  |                             |      |          |     |                        |                     |     |      |
|                                  | Core   | 12.36                           | (17) | 11.67 | (15) | 0.28                        | (16) | 0.56     | (4) | 981 $\pm$ 125          | 720                 | 15  |      |
|                                  |        | 11.05                           | (4)  | 10.20 | (4)  |                             |      |          |     | (1173 $\pm$ 103)       | (553                | 13) |      |
|                                  | sf     | 12.15                           | (21) | 11.44 | (18) | 0.27                        | (20) | 0.52     | (4) | 886 $\pm$ 97           | 538                 | 14  |      |
|                                  |        | 10.67                           | (4)  | 10.15 | (4)  |                             |      |          |     |                        |                     |     |      |
| All E                            |        | 12.26                           | (48) | 11.66 | (44) | 0.29                        | (45) | 0.63     | (4) | 935 $\pm$ 70           | 595                 | 33  |      |
| n ( $r < 6^\circ$ )              |        | 10.48                           | (4)  | 9.73  | (4)  |                             |      |          |     | (1012 $\pm$ 64)        | (523                | 31) |      |
| $S_I$                            | p      | 12.38                           | (19) | 11.96 | (18) | 0.42                        | (14) | 0.70     | (4) | 1230 $\pm$ 300:        | 1090:               | 6   | 2    |
|                                  |        | 11.00                           | (4)  | 10.45 | (4)  |                             |      |          |     | (1904 $\pm$ 132:)      | (390:               | 4)  |      |
|                                  | f      | 12.02                           | (13) | 11.81 | (16) | 0.47                        | (12) | 0.67     | (4) | 1564 $\pm$ 187         | 733                 | 7   |      |
|                                  |        | 11.20                           | (4)  | 10.35 | (4)  |                             |      |          |     |                        |                     |     |      |
| All $S_I$ (inner-cloud)          |        | 12.24                           | (32) | 11.89 | (34) | 0.44                        | (26) | 0.74     | (4) | 1409 $\pm$ 166         | 890                 | 13  |      |
|                                  |        | 10.80                           | (4)  | 10.10 | (4)  |                             |      |          |     | (1686 $\pm$ 126)       | (632                | 11) |      |
| $S_O$                            | S'     | 12.96                           | (8)  | 12.38 | (8)  | 0.38                        | (6)  | 0.47:    | (4) | 1563 $\pm$ 158:        | 406:                | 3   | 3    |
|                                  |        | 12.3:                           | (4)  | 11.7: | (4)  |                             |      |          |     |                        |                     |     |      |
|                                  | Others | 12.53                           | (8)  | 11.85 | (7)  | 0.38                        | (7)  | 0.52     | (4) | 953 $\pm$ 370:         | 947:                | 3   |      |
|                                  |        | 11.95                           | (4)  | 11.3: | (4)  |                             |      |          |     |                        |                     |     |      |
| All $S_O$ (outer-cloud)          |        | 12.75                           | (16) | 12.13 | (15) | 0.38                        | (13) | 0.59     | (4) | 1258 $\pm$ 202         | 732                 | 6   |      |
|                                  |        | 11.63                           | (4)  | 10.95 | (4)  |                             |      |          |     |                        |                     |     |      |
| All $S_I, S_O$ ( $r < 6^\circ$ ) |        | 12.40                           | (48) | 11.96 | (49) | 0.42                        | (39) | 0.75     | (4) | 1362 $\pm$ 128         | 825                 | 19  |      |
|                                  |        | 10.80                           | (4)  | 10.10 | (4)  |                             |      |          |     | (1536 $\pm$ 11)        | (678                | 17) |      |

1 rejecting 2 negative velocities NGC 4406, 4438F.

2 rejecting 2 negative velocities NGC 4192, 4216.

3  $r < 6^\circ$ , but outside inner cloud.

## VII. MASS FROM VELOCITY DISPERSION

This study of the Virgo region was initially undertaken to find out whether the abnormally high mass value,  $N\mathcal{M}^* \approx 6 \times 10^{14} \odot$ , for the Virgo cluster derived from the virial theorem (de Vaucouleurs 1960) could be explained by the mixing of two or more independent clusters having different mean velocities. Since at least two distinct clouds seem to be involved, it is interesting to see whether any reduction in the mass estimate results from the separation of the two components.

TABLE 7  
RELATIVE DISTANCES IN THE REGION OF THE VIRGO CLUSTER

|                                   | CLOUD |       |           |           |           |              |       | NOTES |
|-----------------------------------|-------|-------|-----------|-----------|-----------|--------------|-------|-------|
|                                   | S     | X(NW) | X(SE)     | W-a       | W-b       | W'           | E     |       |
| $\langle \log D(0) \rangle$ ..... | 0.75  | 0.65  | 0.41      | 0.22      | 0.25      | .....        | 0.50  | 1     |
| $(m-M)_0$ .....                   | 30.4  | 30.9  | 32.1      | 33.0      | 32.9      | .....        | ..... | 2     |
| $\langle V_0 \rangle$ .....       | 1450  | 1500  | 870       | 2250      | .....     | .....        | 950   | 3     |
| $(m-M)_0$ .....                   | 30.4  | 30.5  | 29.3      | 31.4      | .....     | .....        | 29.5  | 4     |
| $\langle m_T \rangle$ .....       | 10.2  | 10.8  | 11.6      | .....     | .....     | .....        | 9.7   | 5     |
| $\langle m_H \rangle$ .....       | 10.9  | 11.1  | 11.8      | 12.5      | 12.9      | 13.9         | 11.6  | 6     |
| $(m-M-0.2)_T$ .....               | 30.0  | 30.6  | 31.4      | .....     | .....     | .....        | 29.1  | 7     |
| $(m-M-0.2)_H$ .....               | 30.2  | 30.4  | 31.1      | 31.8      | 32.2      | 33.4         | 29.4  | 8     |
| $\Delta$ (Mpc).....               | 11.2  | 13.2  | 16. $\pm$ | 25. $\pm$ | 32. $\pm$ | (60. $\pm$ ) | 7.4   | 9     |
| Diameter (Mpc).....               | 2.3   | 1.3   | 1.6       | 0.4       | 0.8       | 1.0          | 1.5   | 10    |

## NOTES TO TABLE 7

1. Mean log diameter of four largest.
2. Geometric modulus for  $\langle D(0) \rangle = 20$  kpc.
3. Mean radial velocity.
4. Geometric modulus for  $V/\Delta = 120$  km sec<sup>-1</sup> Mpc<sup>-1</sup>.
5. Mean total magnitude of four brightest.
6. Mean Harvard-Lund magnitude of four brightest.
7. Corrected photometric modulus for  $\langle M_T \rangle = -20.0$  (four brightest).
8. Corrected photometric modulus for  $\langle M_H \rangle \approx -19.5$  (four brightest).
- 9, 10. Adopted distance and diameter in megaparsecs.

The surface and velocity distributions of galaxies in the *S*-cloud (Figs. 3 and 5) strongly suggest that it is not an equilibrium configuration, and an application of the virial theorem would be meaningless. However, it might be estimated from the velocity range, about 3000 km sec<sup>-1</sup> (Fig. 4), that the escape velocity is probably less than  $(V_e)_S = 1500$  km sec<sup>-1</sup> and that the mass is  $N\mathcal{M}_S^* = V_e^2 R/2G \leq 3 \times 10^{14} \odot$  (cf. Smith 1936). If the total population of giant spirals in the *S*-cloud is  $n_S \approx 100$ , the mean mass per galaxy is still of the order of  $\mathcal{M}_S^* \approx 10^{12} \odot$ , as before.

The surface and velocity distributions of the *E*-cloud are sufficiently concentrated and symmetrical to encourage an application of the virial theorem. Schwarzschild (1954) has shown that the mass is given by

$$N\mathcal{M}^* = \frac{3}{G} \langle \sigma^2 \rangle \langle R \rangle,$$

where

$$\langle R \rangle = 2 \frac{\left( \int_0^R S dq \right)^2}{\int_0^R S^2 dq}$$

if the  $S(q)$ 's are the "strip counts" (marginal distributions). This method is simpler than using a harmonic mean distance and less arbitrary than using a theoretical model. The results are collected in Table 8 for 58 E and S0 galaxies within  $6^\circ$  from  $C_E$ ; values are also given for 47 objects within  $5^\circ$  from  $C_E$ , rejecting NGC 4406, 4438, 4473, and 4578 to eliminate possible foreground and background objects. In both cases the assumed distance is  $\Delta_E = 7.5$  Mpc (mean of estimates in Secs. IV and VI). The derived masses are

$$N\mathcal{M}_E^* \leq 2.3 \times 10^{14} \odot \quad (n = 33)$$

or

$$N\mathcal{M}_E^* \geq 1.0 \times 10^{14} \odot \quad (n = 26).$$

The apparent mass of the cluster is still of the order of  $N\mathcal{M}_E^* \approx 1.5 \times 10^{14} \odot$ , and for a population  $N_E \approx 100$  the mean mass per galaxy is  $\mathcal{M}_E^* \approx 1.5 \times 10^{12} \odot$ .

TABLE 8  
APPARENT MASS OF THE E-CLOUD FROM VELOCITY DISPERSION

|                           | $q$  |           |           |           |           |           |           |
|---------------------------|------|-----------|-----------|-----------|-----------|-----------|-----------|
|                           | 0    | $1^\circ$ | $2^\circ$ | $3^\circ$ | $4^\circ$ | $5^\circ$ | $6^\circ$ |
| $S\alpha$ .....           | 30   | 12        | 5         | 5         | 3         | (3)       |           |
| $S\delta$ .....           | 23   | 14        | 4         | 6         | 4         | (11)      |           |
| $\langle S \rangle$ ..... | 26.5 | 13        | 5.5       | 4.5       | 3.5       | (5)       |           |

| $\Sigma Sdq$ | $\langle R \rangle$ | $\langle V_0 \rangle$ | $\sigma_E$ | $n$ | $N\mathcal{M}_E^*$   | $\mathcal{M}^*$               |
|--------------|---------------------|-----------------------|------------|-----|----------------------|-------------------------------|
| 58.....      | $7^\circ 0$         | 935                   | 595        | 33  | $2.3 \times 10^{14}$ | $\sim 2 \times 10^{12} \odot$ |
| 47.....      | $5^\circ 4$         | 945                   | 456        | 26  | $1.0 \times 10^{14}$ | $\sim 1 \times 10^{12} \odot$ |

We must conclude that resolving the multiple structure of the Virgo cluster into its separate components does not reduce significantly the high mass values derived from velocity dispersion (de Vaucouleurs 1960; van den Bergh 1960*b*).

#### VIII. DISCUSSION AND CONCLUSIONS

If the velocity dispersion and escape velocity in the two clouds are related to a gravitational potential, it must be with the potential of the Local Supersystem as a whole; if so, the escape velocity,  $V_e \approx 1500$  km sec $^{-1}$ , should be associated with the average radius,  $\langle R \rangle \approx 10$  Mpc, of the supersystem, and a mass  $N\mathcal{M}^* \approx 3 \times 10^{15} \odot$  follows. Similarly, if the velocity dispersion,  $\sigma \approx 650$  km sec $^{-1}$ , is associated to  $\langle R \rangle \approx 10$  Mpc, then again  $N\mathcal{M}^* \approx 3 \times 10^{15} \odot$ . This result is of the same order of magnitude as the value  $N\mathcal{M} \approx 10^{15} \odot$  derived from the general rotation of the system (de Vaucouleurs 1958). If the total population of the supersystem is  $N \approx 10^4$ – $10^5$ , the mean mass per galaxy is  $\mathcal{M}^* \approx 3 \times 10^{15} / 3 \times 10^4 = 10^{11} \odot$ , a plausible, though still high, value.

It is also possible that the velocity dispersion and escape velocity have little or nothing to do with the mass of the supersystem, for in  $10^{10}$  years a galaxy whose velocity is  $V_e = 1.5 \times 10^3$  km sec $^{-1}$  will move  $4.5 \times 10^{25}$  cm = 15 Mpc, which is equal to the estimated maximum radius of the system (de Vaucouleurs 1956, 1958). Objects formed with initial velocities greater than  $V_e$  will have escaped, while objects with velocities less than  $V_e$  will still be found inside the system, irrespective of its mass, as long as it is not large

enough to slow down appreciably the escaping systems. This would be the case if  $V_e$  were the maximum peculiar velocity at the time of formation, i.e., it may be characteristic of the initial velocity field of the original medium.

In either case it is difficult to understand why velocities as high as  $V_e$  are still observed in the central clouds of the supersystem. For example, with  $V_e = 1.5 \times 10^3$  km sec<sup>-1</sup>, the expansion age of the *S*-cloud would be  $T = R/V_e = 0.8 \times 10^9$  years only.

On the other hand, the relaxation time (Chandrasekhar 1942) for a system of volume  $V = 3 \times 10^3$  Mpc<sup>3</sup>, comprising  $N = 3 \times 10^4$  "particles" of mean mass  $\mathcal{M} = 5 \times 10^{10} \odot$  (mean density 10 per Mpc<sup>3</sup> =  $3 \times 10^{-29}$  gm cm<sup>-3</sup>) and space velocity dispersion  $\langle V^2 \rangle^{1/2} = 1 \times 10^3$  km sec<sup>-1</sup>, is  $T_E \approx 2 \times 10^{12}$  years. While the symmetrical velocity distribution in the *E*-cloud might indicate a substantial degree of relaxation (if one overlooks the anisotropic structure), the highly asymmetrical velocity distribution in the *S*-cloud is hardly compatible with such a long time scale.

It is clearly difficult to offer any definite conclusion; the following is merely a summary of the main points:

1. The velocity dispersion,  $\sigma \approx 10^3$  km sec<sup>-1</sup>, in the *E*- and *S*-clouds is not primarily determined by their gravitational potentials, and masses derived by application of the virial theorem are illusory.
2. Establishment of statistical equilibrium in the supercluster would require a time scale of the order of  $10^{12}$  years, and it does not seem to obtain now, at least in subsystems such as the *S*-cloud.
3. The present existence of well-defined clouds of diameter 1–2 Mpc is difficult to reconcile with the observed velocity range  $2V_e \approx 3000$  km sec<sup>-1</sup>, which leads to expansion ages of the order of  $10^9$  years.

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