DWARF GALAXIES IN THE VIRGO CLUSTER*

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Ten years ago when the writer found that so-called "IC 3475-type" dwarf galaxies are members of the Virgo cluster,[1] two questions were not adequately answered:

1. What is the nature of these IC 3475-type dwarfs?
2. What is the nature of their association with the bright galaxies of the Virgo cluster?

The 1952 work was based almost entirely on plates taken with the Lick 20-inch Carnegie astrograph. Since then, I have re-examined the Virgo area on photographs taken with the Palomar 48-inch Schmidt telescope. The purpose of this paper is to discuss some of these (and other) new observations that bear on the above questions.

THE NATURE OF THE IC 3475-TYPE DWARFS

The earlier suggestion that galaxies of the IC 3475 type are similar to NGC 3299 in Leo[1] is untenable for many reasons. The principal dissimilarity is one of physical appearance; the knots in NGC 3299 show an incipient ring or spiral pattern, whereas the IC 3475 type shows virtually no well-defined knots or knot-pattern.

It has been suggested that the IC 3475-type galaxies are the Virgo cluster counterparts of the Sculptor and Fornax type of dwarf system found in the Local Group, but this also seems to be untenable. The color-magnitude array in Figure 1 shows IC 3475, the large circle, with other galaxies for comparison. Notice that IC 3475 is about 3 magnitudes brighter than the Fornax dwarf, itself the brightest known member of its class in the Local Group. At the right, the vertical line shows an estimate of the range in absolute magnitude of the so-called IC 3475-type systems listed in the 1952 paper. Clearly, the majority of the IC 3475-type dwarfs in the Virgo cluster, including IC 3475 itself, are too

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bright to be Sculptor-type systems. Furthermore, on the basis of the color measure by de Vaucouleurs, IC 3475 is not sufficiently red. Lastly, although a lack of central concentration of light seems to be a general property of dwarfs, there is no doubt that the brighter of those dwarfs classified as IC 3475 type in 1952 show *more* central concentration than the Sculptor-type systems in the Local Group.

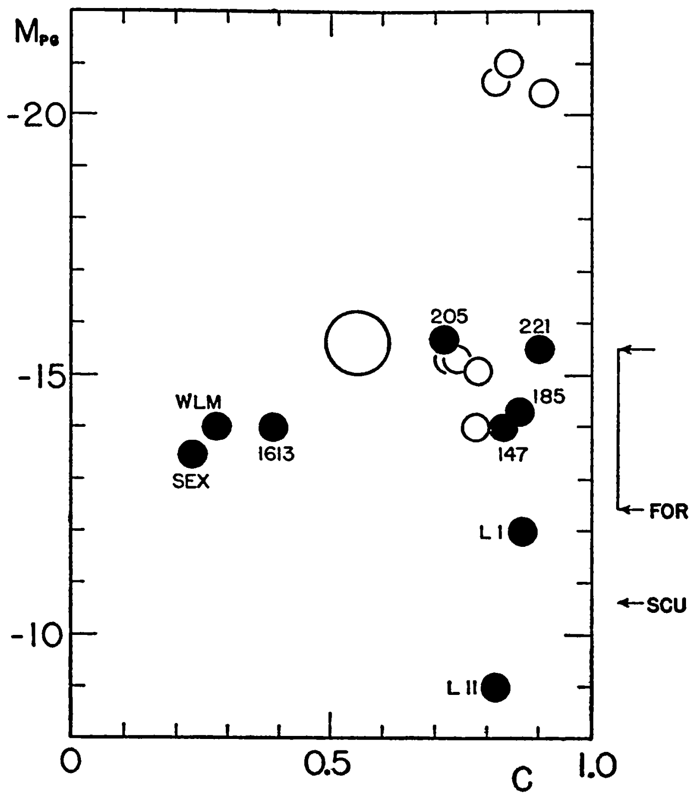

FIG. 1.—Color-magnitude array. The filled circles are Local Group dwarf galaxies as measured by E. Holmberg (*Medd. Lund Obs.*, Ser. II, No. 136, 1958). Open circles near $M_{pg} = -20$ represent the three brightest elliptical galaxies in Virgo, also measured by Holmberg; open circles near NGC 147 and NGC 205 represent the dwarf companions of NGC 4321 (J. Stebbins and A. E. Whitford, *Ap. J.*, **115**, 284, 1952). The large circle represents IC 3475 as measured by G. de Vaucouleurs (*Ap. J. Supplements*, **5**, 233, 1961 (No. 48)), converted to Holmberg's system, and averaged with the photographic magnitude determination by F. Zwicky, E. Herzog, and P. Wild, *Catalogue of Galaxies and of Clusters of Galaxies*, **1** (Pasadena: California Institute of Technology, 1961). The modulus assumed for the Virgo cluster is 30.3 mag. Magnitudes for the Sculptor and Fornax systems are from Hodge's paper presented to the A.S.P. in June 1961.

A re-examination of the dwarfs previously classified as IC 3475 type, and of other such dwarfs in Virgo, shows that many of the brighter dwarfs are very similar in appearance to NGC 147 in the Local Group, whereas for some of the much fainter ones, a similarity to the Sculptor-type systems is definitely indicated. The absolute magnitude estimates shown in Figure 1 support this identification. This interpretation for Virgo parallels Baade's recognition of the NGC 205–NGC 147/185–Sculptor sequence in the Local Group.[2] Note that the (single) color measure of IC 3475 does *not* support this interpretation; more quantitative observations are needed to test further the validity of the hypothesis outlined above.

It should not be assumed, however, that the dwarf populations of the Virgo cluster and the Local Group are similar in *all* respects. Type I irregular dwarfs have not been found in significant number in the Virgo cluster, whereas the data displayed in Figure 1 suggest that if such irregular systems were actually present, they would have been recognized. They are, of course, numerous in the Local Group.

ASSOCIATION OF THE DWARFS WITH BRIGHT GALAXIES

Last year at the Santa Barbara Conference on the Instability of Systems of Galaxies, Ambartsumian noted[3] that if there were equipartition of energy among the galaxies of the Virgo cluster, the less massive dwarfs would be found over a much larger region than the more massive bright galaxies. Since this is not observed, he concluded that the cluster must be unstable.

An alternative hypothesis, compatible with the idea of a stable cluster, is that the dwarfs are satellites of normal galaxies and thus share their motions. This will qualitatively account for the observed ". . . distribution of the IC 3475-type objects [which] is as much related to the *individual* bright galaxies as to the [Virgo] *cluster as a whole*."[1] This is certainly a reasonable starting assumption, for several galaxies are known to have a number of dwarf companions: M 31,[2] M 81,[4] M 100,[5] M 83,[6] and probably our Galaxy. For M 81 and our Galaxy, many of the dwarfs are of the Sculptor-Fornax type.

Will these satellite systems be stable if the energies of the bright Virgo cluster galaxies with which the dwarfs are supposedly associated are assumed to satisfy the virial theorem—that is, if the cluster as a whole is assumed to be gravitationally stable? The answer is probably yes—if we may apply to these satellite systems in the Virgo cluster reasoning analogous to that which Spitzer and Baade[7] applied to the bright galaxies in the Coma cluster. In order to estimate the collisional cross-section, we note that some of the objects in Virgo tentatively classified as Sculptor-type systems (Table I) appear to have the very rapid luminosity decrease toward the edge characteristic of the Fornax, Sculptor, and Leo II systems of the Local Group.[8] If we interpret this, as Hodge has done for the Local Group dwarfs, as a tidal limitation in size, we obtain a (crude) indication of the order of distance from the primary bright galaxy to the orbiting satellite dwarfs. The calculation is summarized in Figure 2, a graph of Hodge's formula[8] $r = R_G\ (M_D/3M_G)^{\frac{1}{3}}$, where r is the tidal radius of the dwarf galaxy, R_G its distance from its primary, M_D the mass of the dwarf, and M_G the mass of the primary. The values of M_D given on the ordinate at the right are for an M_G of $10^{11}\ m_\odot$; the photographic absolute magnitudes corresponding to these masses are given on the next ordinate according to Poveda's mass-luminosity relation[9] for dust-poor stellar systems. The average apparent radius of the objects listed in Table I is 1.7 kpc. Assuming this as the tidal radius, and an estimated photographic absolute magnitude of −13, we find that R_G is about 30 kpc. (Data for the

TABLE I

OBJECTS TENTATIVELY IDENTIFIED AS SCULPTOR-TYPE DWARFS IN THE VIRGO CLUSTER

Number	α (1950)	δ (1950)
84	$12^h05^m.7$	+13°03′
85	15.0	14 37
31	18.3	15 17
86	18.9	15 19
87	19.3	18 43
44	23.7	15 12
88	29.0	14 20
89	36.5	13 13
90	12 45.5	+13 58

This numbering continues that used earlier. Numbers 31 and 44 were catalogued as Virgo dwarfs in the 1952 paper; numbers 84 through 90 are so catalogued for the first time.

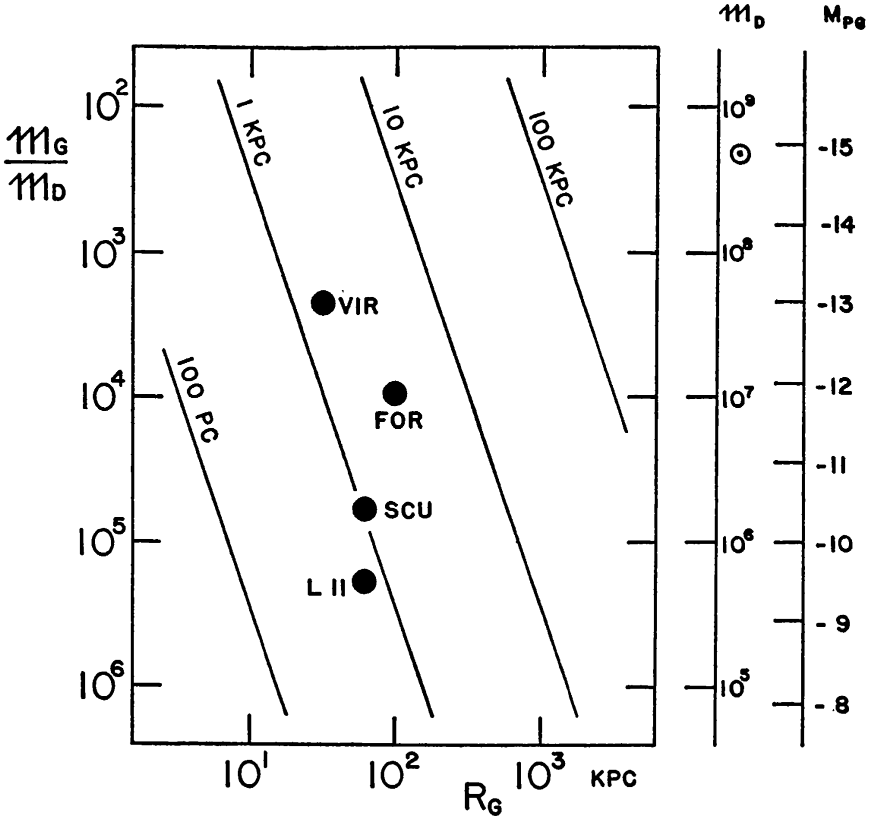

FIG. 2.—Tidal radius as a function of orbital radius and mass ratio.

three Local Group dwarfs investigated by Hodge are plotted for comparison; note that the R_G values are comparable.) With a cross-sectional radius of 30 kpc, each satellite system will have suffered something of the order of a dozen "collisions" during the last 10^{10} years, but since the average relative velocity of collision ($\sim$1500 km/sec) of the galaxies is so much greater than either the internal stellar velocities or the orbital velocities of the dwarfs ($\sim$100 km/sec), the gravitational perturbations during collision may be expected to be relatively insignificant. The above method of computing R_G yields a minimum value; if the distances of the dwarfs from their primaries prove to be comparable to the distances between bright galaxies, the satellite systems will be *unstable*. Our knowledge of the distribution of galaxies in the Virgo cluster is not yet sufficient to settle this point.

Another factor tending to disrupt these satellite systems is the inhomogeneity of the gravitational field of the cluster as a whole. This factor is probably negligible, since $R_G << a$, where a is some measure of the "radius" of the orbit of the bright galaxy around the center of mass of the entire cluster, and also because, during the last 10^{10} years, an average galaxy has made less than half a dozen circuits of its orbit. However, if the age of the Virgo cluster is as great as the 10^{15} years suggested for the Coma cluster,[10] the situation would be entirely different.

It is quite possible that the correct explanation of the character of the relationship between dwarf and bright galaxies bears little resemblance to either of the hypotheses outlined above. Vorontsov-Velyaminov,[11] for example, has repeatedly emphasized that forces other than gravitation must play a significant part in determining the structure (and arrangement?) of interacting galaxies. As a case in point, according to Zwicky[12] a Palomar 200-inch reflector plate shows Reinmuth No. 143, IC 790, NGC 4410, and Reaves No. 43 all embedded in a complicated filamentary luminous cloud of intergalactic material. If this is not a chance superposition, and if similar interactions are found for other Virgo dwarfs, their relationship to nearby bright galaxies may not be nearly so simple as in either of the above hypotheses.

This re-examination of the dwarfs in Virgo was begun at the American Museum–Hayden Planetarium, New York, and continued at the Pasadena offices of the Mount Wilson and Palomar Observatories. I greatly appreciate having been permitted to use these facilities. I am especially indebted to Dr. W. A. Baum for the opportunity to examine some exceptionally high-quality 48-inch Schmidt plates of the Virgo region.

[1] G. Reaves, Dissertation, University of California, Berkeley, 1952; a portion of this was published in *A.J.*, **61**, 69, 1956.

[2] W. Baade, *Ap. J.*, **100**, 147, 1944.

[3] V. A. Ambartsumian, *A.J.*, **66**, 536, 1961.

[4] *Carnegie Inst. Washington Yearbook* No. 53, 23, 1954.

[5] W. Baade, quoted by J. Stebbins and A. E. Whitford, *Ap. J.*, **115**, 284, notes to Table 2, 1952.

[6] G. Reaves, unpublished.

[7] L. Spitzer, Jr. and W. Baade, *Ap. J.*, **113**, 413, 1951.

[8] P. W. Hodge, *A.J.*, **67**, 125, 1962, and earlier papers in that series.

[9] A. Poveda, *Ap. J.*, **134**, 910, 1961.

[10] F. Zwicky, *Pub. A.S.P.*, **72**, 365, 1960.

[11] B. Vorontsov-Velyaminov, *A.J.*, **66**, 551, 1961.

[12] F. Zwicky, *Ergeb. d. Exakt. Naturwiss.*, **29**, 344, Plate VI and Figure 2, 1956.