accuracy, the current probability that the α-Capricornids are of complex origin should serve to caution against the use of less precise methods for determining radiants and velocities of meteor streams whose purity may be challenged.

This investigation was made possible by the support of the U. S. Navy Bureau of Ordnance, the U. S. Office of Naval Research and the U. S. Army Office of Ordnance Research.

REFERENCES

Bernhard, H. J., Bennett, D. A. and Rice, H. S. 1954, *Handbook of the Heavens* (Mentor Book), by arr. with McGraw-Hill Book Co., New York, p. 105.
Celoria, G. 1884, *A. N.* **110**, 173.
Cunningham, L. E. 1949, *Harv. Announcement Card*, No. 975.
Kramer, E. N. 1953, *Pub. Astr. Obs. Odessa State Univ.* **3**, 225.
Matthiessen, B. 1889, *Sternw. Karlsruhe Veröff.* **3**, 179.
McCrosky, R. E. 1956, Ph.D. Thesis, Harvard University.
McIntosh, R. A. 1935, *M. N.* **95**, 711.
Rigollet, R. 1951, *Ann. Astroph.* **14**, 243.
Whipple, F. L. 1947, *Proc. Amer. Phil. Soc.* **91**, No. 2.
Whipple, F. L. and Wright, F. W. 1954, *M. N.* **114**, No. 2, 230.
Wright, F. W., Jacchia, L. G. and Whipple, F. L. 1954, *A. J.* **59**, 403.
Wright, F. W. and Whipple, F. L. 1950, *Harv. Reprin* Ser. II, No. 35.
———. 1953, *ibid.* No. 47.

Harvard College Observatory,
Cambridge, Mass.,
1955 *July.*

DWARF GALAXIES IN THE VIRGO CLUSTER *

By GIBSON REAVES†

Abstract. The problem of the discovery of dwarf galaxies outside the local group is briefly treated, and it is found that the difficulty of discovery is primarily one of recognition, not of detection.

The properties of a group of 48 faint nebulae of similar appearance in the Virgo region are discussed. Since their surface distribution coincides closely with that of the brighter galaxies in Virgo, it is concluded that these much fainter objects are dwarf galaxies in the Virgo cluster. The brightest member of the group is IC 3475. Although having the general characteristics of known dwarfs, this type of dwarf galaxy does not seem to be represented in the local group. The contribution of the dwarfs to the luminosity function of the cluster is significant, and emphasizes the incompleteness of our knowledge of the cluster's contents; their contribution to the total mass of the cluster probably is small.

I. *Introduction.* A fundamental problem of extragalactic research is the determination of the luminosity function of galaxies. From a study of individual resolved galaxies in the local group and in the general field, and from residuals in the relationship between red shift and magnitude, Hubble (1936a) found a luminosity function approximating a normal error curve with a dispersion of 0.85 mag. and $\bar{M}_{pg} = -14.2$. At that time the presence of three dwarf, or relatively underluminous, galaxies in the local group, IC 1613, NGC 205 and 6822, seemed to Hubble (1936b) ". . . to be a unique feature of the group, and they detract from its significance as a fair sample of nebulae in general." The discovery since 1936 of nine new members of the local group, all dwarfs, makes the discrepancy with Hubble's normal luminosity function even more outstanding. Holmberg's (1950) work on the M81 and M101 groups confirmed that these two groups also show a luminosity function significantly different from Hubble's, with a surplus of dwarfs. The problem of the recognition of dwarfs is complicated by the fact that intrinsically faint galaxies tend to have their light much less concentrated toward the center than do the bright ones, and they are thus much less easily recorded photographically. For these reasons a re-examination of the problem of the recognition of dwarf galaxies outside the local group seemed worth while.

The area considered for re-examination is the Virgo region including the Virgo cluster of galaxies. On Hubble's (1936a) scale this cluster is at a distance of 2.2 mpc, corresponding to a distance modulus of $m - M = 26.7$ mag. While it appears certain that Hubble's pre-1952 distances are too small, a definitive redetermination of the distance to the Virgo cluster has not yet been completed. Therefore, for the sake of consistency with earlier work, Hubble's distance moduli have been used throughout this paper.

Although several brief references to the presence of dwarf galaxies in the Virgo cluster have appeared in the literature (Shapley 1938, 1951;

* *Lick Observatory Bulletin*, No. 540; portion of a thesis submitted in partial fulfillment of the requirements for the Ph.D. degree in astronomy, Graduate Division, University of California.

† Lick Observatory Fellow, 1950–52.

Shane 1950; Baade 1951, 1952), no detailed investigations seem to have been published. In these preliminary researches, the nearby dwarfs evidently were distinguished from more distant galaxies of normal luminosity on the basis only of physical appearance or of color. Relationships between these characteristics and absolute magnitude, however, do not yet seem to be sufficiently well established to permit any high degree of certainty of selection of dwarfs in this manner. The method of distance, and thus of absolute magnitude, estimation used in this investigation is the comparison of surface distributions. On a series of photographic plates that includes the greater part of the Virgo cluster and much of the surrounding region, a set of similarly appearing faint galaxies suspected of being dwarfs was picked out. The surface distribution of these faint objects in the Virgo region was found to be strikingly similar to that of the bright well-known galaxies that form the Virgo cluster; these objects are therefore considered to be associated in space with the bright Virgo cluster galaxies.

An important question is whether, if dwarf galaxies similar to those in the local group are in the Virgo cluster, they will show on photographs taken with the Lick 20-inch Carnegie astrograph. To help answer this question, Figure 1 has been prepared. The left-hand ordinate gives surface brightness in units of magnitudes per square second of arc. The abscissae give diameters at the distance of the Virgo cluster, on the lower scale in minutes of arc, and on the upper scale in kpc. If all images are considered as uniform circular disks, a reasonable assumption for many dwarfs, then lines of equal total apparent magnitude, *m*, may be drawn. Parallel to the *m* lines are lines of equal total absolute magnitude, *M*, computed from the adopted distance modulus of the cluster. According to Ross (1938), the photographic brightness of the night-sky background is about magnitude 22 per square second of arc, and, for large images, it is possible to detect those having a surface density as small as 0.01 of the sky background, or roughly equivalent to magnitude 27 per square second. The limiting stellar photographic magnitude of an average astrograph two-hour exposure on Eastman 103a-O emulsion is 19.3. The transition zone between small images, for which the limit of detection depends upon the total magnitude, and large images, for which the limit of detection depends on surface brightness, is essentially that given by Hubble (1932, see Fig. 1). When some representative local group objects are plotted in the coordinates of Figure 1, it is found that except perhaps for Sculptor-type systems, if dwarf galaxies similar to those in the local group are present in the Virgo cluster they should be detectable on the astrograph plates. There is no assurance, of course, that any dwarfs will be recognizable as such, because they may be indistinguishable from the more distant—and perhaps more numerous—background objects; but

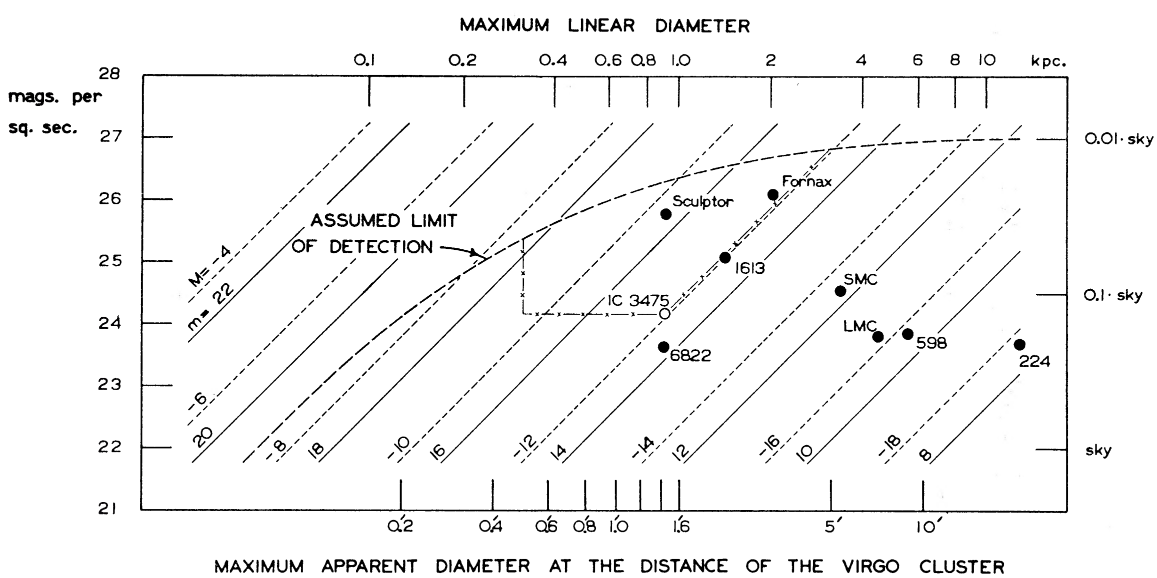

Figure 1. Relations between total magnitude, surface brightness, and diameter for dwarf and local group galaxies.

according to the old distance scale they should be visible on the plates.

II. *The Survey*. The collection of plates that forms the observational basis of this search for dwarf galaxies was originally part of a supernova patrol program initiated by Shane. While examining these plates, Shane noticed numerous nebulae with abnormally low surface brightnesses, yet with angular diameters of around one minute of arc. His suggestion that these might be the long-suspected dwarf members of the Virgo cluster led to the present work.

All observations were made with the photographically-corrected Ross lens of the 20-inch astrograph (Shane 1947), on 8 × 10 inch Eastman 103a-O plates exposed for two hours. The original 1946–47 supernova patrol plates included most of the Virgo cluster and some of the surrounding regions; additional plates were taken in 1951 to cover more of the area surrounding the Virgo cluster, so that a better comparison of the distribution of the supposed dwarfs could be made both inside and outside the Virgo cluster. The plates were surveyed by direct visual examination, and by high- and low-power magnification. Many large objects are visible only under low-power, and many small objects are visible only under high. In addition, because the objects dealt with here so closely resemble water spots and certain common emulsion defects, it was always considered necessary to check the findings on more than one photograph.

In the examination of these plates several types of nebulae were recognized which, upon further investigation, might prove to be dwarf galaxies. Some of these, listed in Table I, are discussed below:

(a) *Dwarf ellipticals*. This class of object has been well described by Baade (1944) in his paper on the local group. In the Virgo region, IC 3019 and object No. 1 in Table I show the low luminosity gradient that is so characteristic of the underluminous ellipticals in the local group.

(b) *Dwarf spirals*. Although the existence of these objects has not been established, the possibility of their existence may be inferred by analogy with the dwarf variants of normal ellipticals and irregulars. Examples of spirals in Virgo that have an outstandingly low surface brightness are IC 769 and NGC 4446. Another example of a spiral (not in Virgo) that falls in this category is NGC 7793; observations by Shapley and Mohr (1938) indicate, however, that this spiral probably is not dwarf.

(c) *Dwarf irregulars*. Object No. 8 in Table I is a good example of a system that looks somewhat similar to IC 1613 and to NGC 6822 of the local group.

(d) *IC 3475-type objects*. There seems to be no local group counterpart for these objects; the

TABLE I. MISCELLANEOUS DWARF-LIKE OBJECTS IN VIRGO

Object	R. A. (1950.0)	Decl. (1950.0)	Remarks
(a) *Dwarf ellipticals*			
IC 3019	$12^h 06^m 8$	+14° 17′	Probable
1	12 16.1	18 00	Probable
(b) *Dwarf spirals*			
IC 769	12 10.1	12 25	Probable
NGC 4446	12 25.6	14 11	Probable
2	12 30.3	3 39	Possible
3	12 31.3	3 50	Possible
(c) *Dwarf irregulars*			
4	12 09.7	18 23	Possible, very small
5	12 11.3	5 37	Possible, late-type
6	12 27.3	8 12	Possible dwarf irreg. or spiral, 5′SE of NGC 4472
NGC 4523	12 31.3	15 26	Possible irreg. or spiral, dwarf?
IC 3522	12 32.3	15 30	Possible dwarf irreg. or edge-on spiral
7	12 39.6	11 44	Possible dwarf irreg. or two spirals, 9′W of NGC 4638
8	12 56.1	14 29	Probable, late-type, 11′W of NGC 4866
(d) *Possible IC 3475-type objects* (borderline)			
9	12 06.1	15 23	Similar to IC 3710, small and faint
10	12 07.1	20 19	Star superposed
11	12 12.4	9 51	Has faint extended envelope
12	12 14.5	10 17	Long (class a3), no central condensation
13	12 20.1	8 12	Trace of nucleus
14	12 22.6	7 00	Long, similar to No. 12
15	12 23.6	12 51	Bright, with central condensation, 8′SE of NGC 4388
16	12 25.6	10 39	Irreg., trace of stellar nucleus
17	12 32.7	14 16	Irreg., 28′W of NGC 4571
18	12 34.9	12 39	Long, similar to No. 12, 27′SE of NGC 4552
19	12 36.3	10 06	Trace of structure, 25′NE of NGC 4578
20	12 41.3	12 06	Similar to IC 3710, 15′N of NGC 4647/9
IC 3710	12 41.6	12 24	Trace of structure, delta-shaped
21	12 50.4	14 40	Somewhat small
22	12 55.7	+15 07	Central condensation, faint extensions

brightest example of the class is IC 3475 in Virgo. These objects are considered as possible dwarfs because of their general resemblance to known dwarfs rather than because of any resemblance to a particular type, as was the case with the dwarf ellipticals and irregulars. There is no trace of any small central nucleus or arm structure, and, compared with normal spirals and ellipticals, there is relatively slight concentration of light to the center, if any. Their outlines are circular or elliptical, not irregular; they have an extremely low surface brightness. The apparent photographic magnitude of IC 3475, according to unpublished work by Hubble, is between $14\frac{1}{2}$ and 15; it appears circular on the astrograph plates, and has an apparent diameter of 1'.4. The faintest of these objects are at the limit of detection on the plates, and they do not seem to be especially numerous—but this inference may be subjective. IC 3475 is plotted in Figure 1, where it falls among the local-group dwarfs. Plate I shows photographs of this object. In the preparation of the lower part of Plate I, the contrast has been so much increased that the

TABLE II. IC 3475-TYPE OBJECTS IN THE VIRGO REGION

Object	R. A. (1950.0)	Decl. (1950.0)	Class	Max. Diam.	Remarks
23	$12^h 10^m.4$	$+5°39'$	b 6	0'.7	Poor example
24	12 11.7	16 15	a 8	1.1	Somewhat irreg.
25	12 13.1	15 17	c 7	0.8	Bright, 27'E of NGC 4192
26	12 13.6	8 40	a 9	0.6	Fan-shaped, good example
27	12 13.7	15 51	a 9	0.7	Faint
28	12 15.3	5 18	a 8	0.5	Poor example
29	12 17.0	14 17	b 10	0.9	Good example, 27'S of NGC 4254
30	12 17.8	14 59	a 7	0.7	Good example, 16'SE of NGC 4262
31	12 18.3	15 17	a 7	0.9	21'E of NGC 4262
32	12 18.9	15 54	a 7	0.5	23'W of NGC 4321
33	12 19.2	15 22	b 7	0.7	28'N of NGC 4298
34	12 19.6	16 05	b 10	0.6	11'W of NGC 4321
35	12 19.9	15 45	a 9	0.8	22'S of NGC 4321
36	12 20.0	17 19	a 9	0.9	Good example, faint, 26'NW of NGC 4340
37	12 20.3	5 33	b 10	0.5	Small, 5'W of NGC 4324
38	12 20.4	8 37	a 8	0.8	
39	12 20.4	15 47	b 6	0.9	Star superposed, 19'S of NGC 4321
40	12 21.3	15 24	b 10	0.6	Small
41	12 22.3	9 46	b 9	0.6	29'W of NGC 4417
42	12 22.4	13 24	a 9	0.7	14'N of NGC 4374
43	12 23.4	9 15	b 10	1.0	Excellent example
44	12 23.7	15 12	a 7	0.8	12'SW of NGC 4419
45	12 24.3	11 51	b 9	0.6	Star superposed, 29'N of NGC 4429
46	12 24.9	9 53	b 6	1.0	Good example but faint, 10'E of NGC 4417
47	12 26.0	9 21	b 7	0.8	Hint of structure, or irreg., 21'NW of NGC 4469
1225	12 26.5	9 43	b 7	0.6	Hint of structure, borderline, in Ames's catalog, *Ann. Harv. Coll. Obs.* **88**, No. 1, 1930, 26'SE of NGC 4442
IC 3418	12 27.2	11 41	c 6	1.2	Hint of structure, borderline, star superposed
48	12 27.6	10 27	b 9	0.9	Faint
49	12 27.9	15 59	a 6	0.8	Poor example
50	12 28.4	13 30	a 9	0.6	19'SE of NGC 4473
51	12 28.9	14 06	b 6	0.9	22'NE of NGC 4477
52	12 29.1	11 08	a 8	0.9	21'S of NGC 4503
53	12 29.2	11 18	a 10	0.5	12'SW of NGC 4503
54	12 30.0	12 11	a 6	0.9	
IC 3475	12 30.2	13 03	c 9	1.4	Prototype, conspicuous
55	12 31.8	16 20	a 9	0.9	Good example
56	12 32.1	12 01	a 8	0.7	Faint, 30'NW of NGC 4564
57	12 33.2	9 54	a 7	0.7	Somewhat irreg., 27'W of NGC 4578
58	12 33.4	7 53	a 8	0.5	23'NW of NGC 4570
59	12 34.0	13 53	a 9	0.8	26'N of NGC 4569
60	12 39.1	16 05	a 7	0.8	
61	12 39.2	11 32	a 9	0.8	Hint of structure, borderline, 19'SW of NGC 4638
62	12 39.4	13 21	a 7	1.1	Good example, 19'SW of NGC 4639
63	12 40.2	7 37	a 9	0.8	Good example, 18'E of NGC 4612
64	12 41.7	10 00	a 7	0.7	Good example
IC 3720	12 42.2	12 21	b 6	1.1	
65	12 42.5	12 38	a 8	0.8	Faint
66	12 53.9	+15 20	a 8	1.1	Fan-shaped

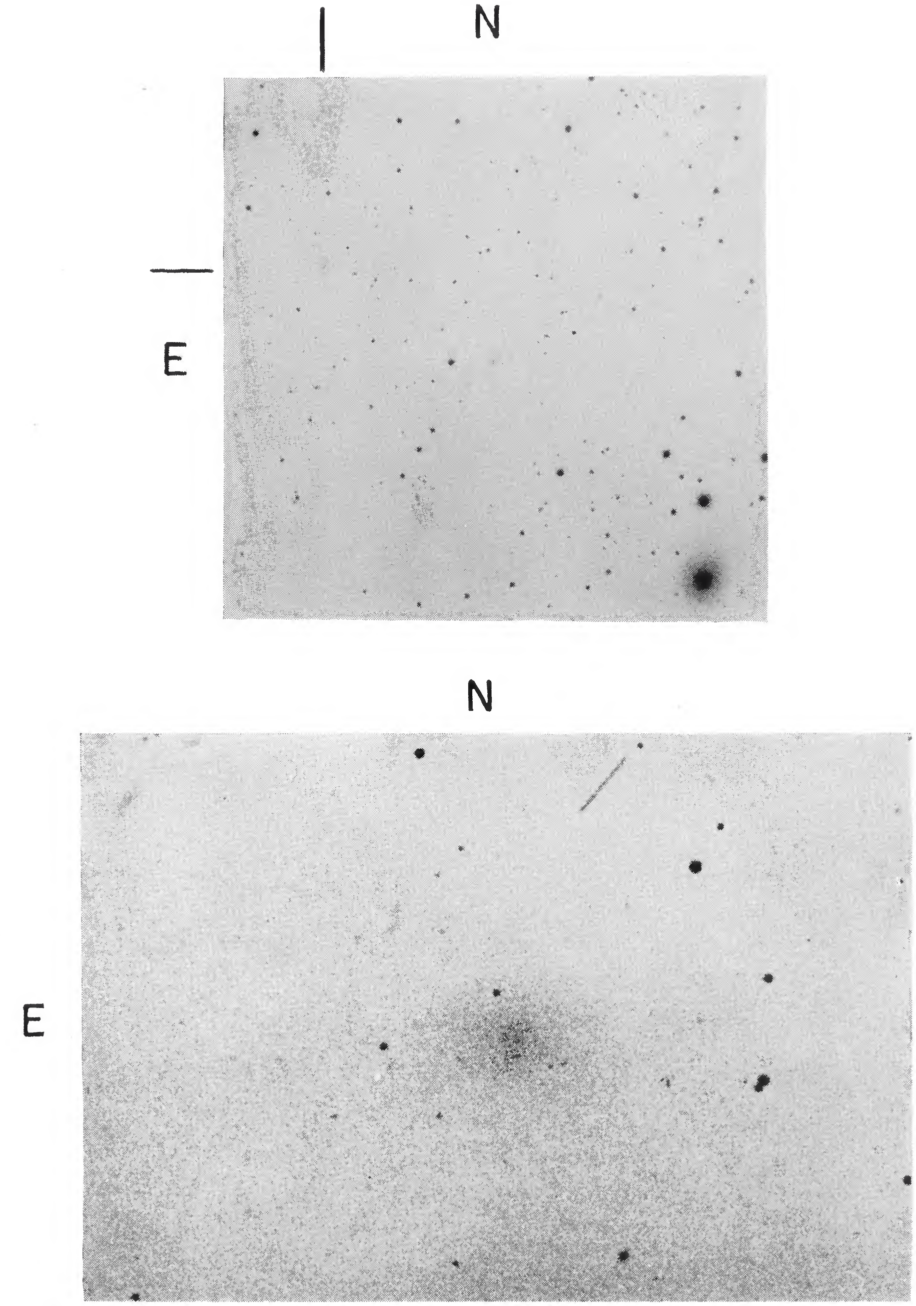

Plate I. IC 3475 photographed in blue light with (above) the Lick 20-inch astrograph, and (below) the Mount Wilson 100-inch reflector. The upper area is 40 minutes of arc square, the lower 5′ by 7′. The bright galaxy in the southwest corner of the upper part is NGC 4486 (M87).

grain of the plate is conspicuous; this effect should not be mistaken for stellar resolution, which is completely lacking in this photograph. M. F. Walker (unpublished) has measured the color of IC 3475 with the 60-inch reflector at Mount Wilson, finding $B - V = +0.8$ mag.

(e) *Sculptor-type systems.* No large class of objects was found that closely resembles these objects in the local group. The larger of the IC 3475-type nebulae seem to be consistently too regular in outline to be classifiable as Sculptor types, but the outlines of some of the fainter and smaller objects thought to be of the IC 3475 type are not so easily discernible. This negative observation lends support to Sandage's (1954) tentative conclusion that, although "the problem is far from settled," distances to galaxies beyond the local group are likely to be from two to four times as far away as Hubble's distance scale would indicate. At the true distance of the Virgo cluster the apparent magnitudes of Sculptor-type systems may be between 1.5 and 3.0 mag. fainter than shown in Figure 1, which is based entirely on Hubble's distance scale. Thus they are probably beyond the limit of detection for this search. A. G. Wilson, in unpublished work on plates taken with the more powerful Palomar 48-inch Schmidt, has picked out numerous faint objects

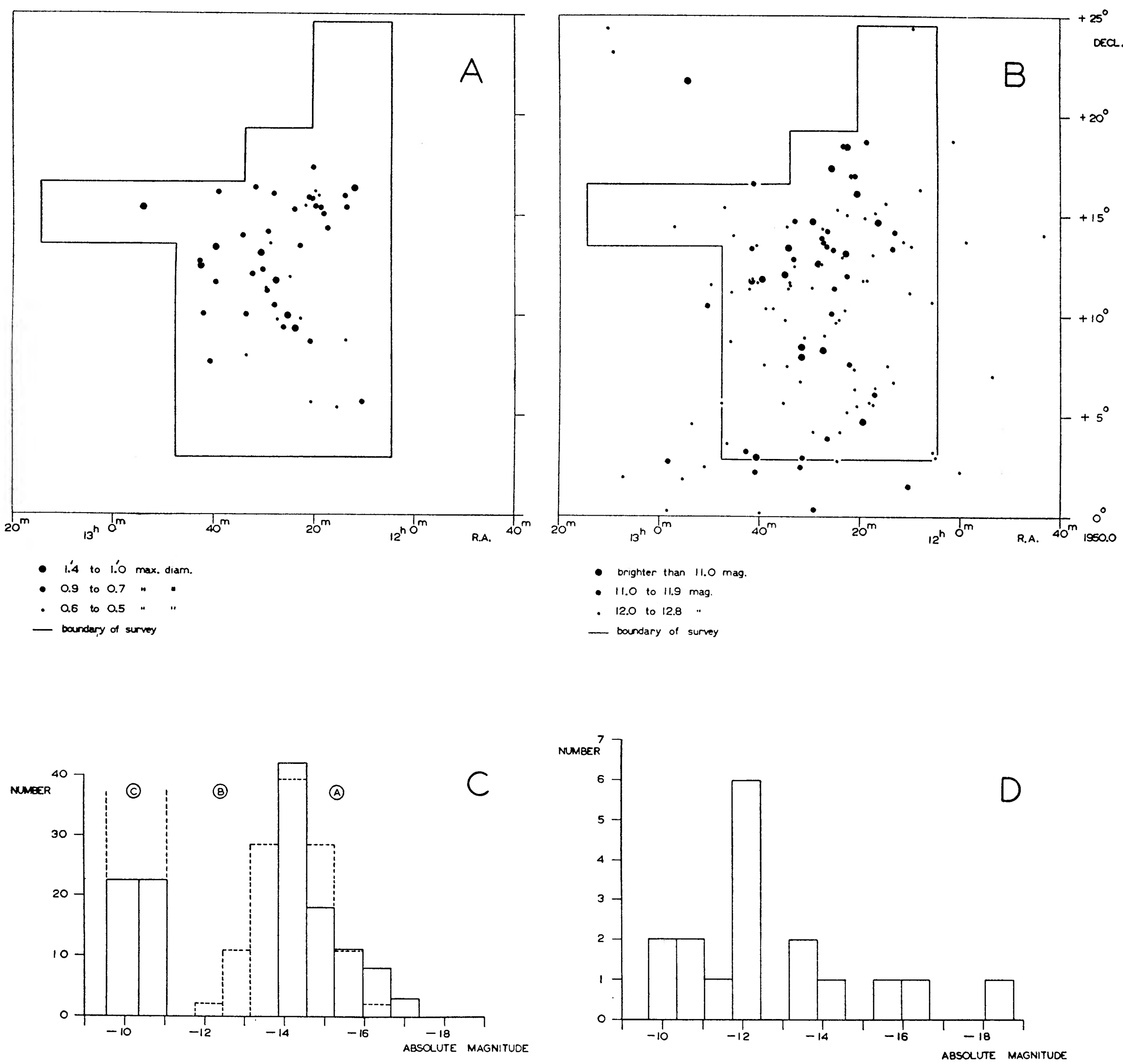

Figure 2. Distribution of (A) IC 3475-type nebulae in the Virgo region, and (B) brighter galaxies in the Virgo cluster. Luminosity distributions of dwarf and bright galaxies in (C) the Virgo cluster and (D) the local group.

that he considers as probable Sculptor-type dwarf galaxies in the Virgo cluster.

Of the various kinds of suspected dwarfs described above, only those of the IC 3475 type were found to be suitable for further study. On the astrograph plates, it is generally not possible to distinguish between the small supposed dwarf ellipticals and spirals, diameter $<1'$, or between these objects and distant normal ones. The suspected dwarf irregulars, though easily recognizable, do not appear in sufficient numbers to permit a useful study of their distribution to be made. Objects of the IC 3475 type, however, are relatively numerous, and because of their size and characteristic appearance, they are considered unlikely to be confused with background objects—provided, of course, that they prove to be truly dwarf in character. This last statement constitutes an hypothesis whose test is one of the principal subjects of this study. The survey, therefore, was exclusively devoted to the identification of IC 3475-type nebulae.

From approximately 1000 objects in the Virgo region that might be considered as barely probable IC 3475 types, the 48 objects listed in Table II were finally chosen as good examples of highly probable, or almost certain, IC 3475-type galaxies. These objects all look very much the same, but they range from the round, slightly concentrated IC 3475, to the somewhat oval, completely structureless and barely detectable No. 46 in Table II. It is difficult to describe adequately all of the numerous, almost subjective criteria for the acceptance of an object for inclusion in Table II; these criteria may be learned by a comparison of the borderline, possible IC 3475-type objects listed in Table I, with the borderline and poorer examples of the highly probable IC 3475-type objects in Table II. The classification is Shapley's (1927) and the angular diameters are from direct comparison with a graduated scale. The area covered by the survey and a plot of the positions of these objects is shown in Figure 2 (A).

In order to estimate the completeness and homogeneity of this survey, and to compare it in detail with previous surveys for dwarfs, a region ($\alpha = 12^h18^m5$ to 12^h32^m0 and $\delta = +7°25'$ to $+11°00'$, 1950.0) containing a large sample of many types of both bright and faint galaxies was chosen for special study; in addition, a pair of plates exposed in blue and red light with the Palomar 48-inch Schmidt, was examined. All these comparisons indicated that this survey is reasonably complete and homogeneous to the limit of detection indicated by the dashed line in Figure 1.

III. *Properties of the IC 3475-type Objects in the Virgo Region.* To facilitate comparison of the surface distribution of objects suspected of being dwarf galaxies with that of the bright objects constituting the Virgo cluster, Figure 2 has been prepared. All galaxies from $\alpha = 11^h40^m0$ to 13^h20^m0 and from $\delta = 0°00'$ to $+25°00'$ (1950.0) in the Shapley-Ames catalog (1932) with $m_{pg} \leqslant 12.8$ mag., and with known positive radial velocities from Humason and Mayall's unpublished work, were plotted. For purposes of comparison, these objects are taken to constitute the Virgo cluster.

Figure 2 (A) shows that the distribution of the IC 3475-type nebulae is not random over the surveyed area; moreover, comparison of Figure 2 (A) with 2 (B) of the Virgo cluster shows that the distribution of the IC 3475-type nebulae over the Virgo region is essentially the same as the distribution of the well-known bright galaxies forming the Virgo cluster. The similarity of the two areal distributions is so striking that it is natural to conclude that the spatial distributions are likewise the same. For a region so close to the north galactic pole, the effects of interstellar material on the apparent distribution of nearby galaxies probably are negligible. Therefore a distance of 2.2 mpc, or a modulus of $m - M = 26.7$ mag., on Hubble's scale, of the Virgo cluster, is adopted for this group of IC 3475-type objects. An assumed extent in the line of sight of 0.5 mpc for the Virgo cluster will not materially affect the luminosities and linear diameters of the IC 3475-type nebulae as discussed below. If Hubble's estimate that IC 3475 is between $14\frac{1}{2}$ and 15 mag. is adopted, and if this object is assumed to represent the brightest object of its class in total magnitude and surface birghtness, and if $0'.5$ is taken as the lower limit in angular diameter of this survey, the objects listed in Table II may be enclosed within the dash-cross line in Figure 1. The average apparent magnitude is thus estimated to be around $15\frac{1}{2}$ to 16, which corresponds in the Virgo cluster to $M \sim -11$. On this basis, the IC 3475-type objects are considered to be dwarf galaxies in the Virgo cluster.

The strongest concentration of bright galaxies is around 12^h26^m, $+13°.5$, whereas the largest clump of IC 3475-types is at 12^h20^m, $+15°.0$ (1950.0). If the distribution of only the giant members of the Virgo cluster, $m \leqslant 10.9$ mag. or $M \leqslant -15.8$, is compared with that of the IC 3475-type objects, there appears to be no significant difference in the character of the association from that found when all the bright nebulae are taken together. The same result is true for both ellipticals and spirals in the Virgo cluster. The effect is, in part, a consequence of the apparently random "mixing" of all types of bright objects in the Virgo cluster, and also of the small number of objects under examination. For a different interpretation of the distribution of bright objects in the Virgo cluster, see Zwicky (1942).

Since the dwarf character of these objects appears to be probable from their areal distribution, it therefore seems that (1) less central concentration of light goes with fainter absolute magnitude, and also that (2) dwarfs tend to cluster, in so far as these IC 3475-type dwarfs are concerned.

Besides the positions of the IC 3475-type objects, Table II gives the concentration class, form, and maximum diameter for each nebula. The images are all so similar and so faint that little else of significance can be used to describe them individually. Angular diameters range from 0:5 to 1:4, with a modal and average frequency at 0:8. These values correspond, at the unrevised distance of the Virgo cluster, to linear diameters 0.3 to 0.9 kpc. These diameters are approximately one-half those of dwarfs in the local group. If the assumed distance to the Virgo cluster were doubled, then the IC 3475-type dwarfs would become more comparable in size to local group dwarfs. There is also an indication that the more elliptical objects have larger angular diameters, but this result could be a consequence of observational selection and may have little physical significance.

In order to find the contribution of the IC 3475-type dwarfs to the luminosity function, their frequency has been compared with that of the brighter galaxies in the Virgo cluster, as shown in Figure 2 (C). From the available apparent magnitudes of the brighter galaxies, and with Hubble's modulus of 26.7 mag., the distribution of absolute magnitudes of bright galaxies, shown by the solid lines in region A of Figure 2 (C), has been derived. The high-luminosity side of Hubble's normal luminosity function has been fitted to these brighter nebulae; the distribution of luminosities thus predicted from the normal function is shown by the dashed lines in regions A and B of Figure 2 (C). The contribution of the IC 3475-type galaxies to the luminosity function of the Virgo cluster is represented by the solid lines in region C. For comparison, the luminosity distribution in the local group is shown in Figure 2 (D). It should be emphasized that both luminosity distributions shown in Figures 2 (C) and (D) are incomplete. A comparison of these incomplete luminosity distributions for the Virgo cluster and for the local group suggests that there may be many unrecognized Virgo cluster members with absolute magnitudes between $M = -10$ and -14, corresponding to regions B and C. The data of this survey should not be taken as suggesting a bimodal luminosity function.

If the results of this survey are representative, even though the total number of dwarfs probably is significantly greater than that of bright galaxies, it seems unlikely to be so by a large factor. Estimates of the relative masses of galaxies (Holmberg 1952) suggest that the dwarfs may be much less massive than the giants, enough less, perhaps, that the mass contributing to the density of the Virgo cluster may be largely concentrated in the relatively few giant galaxies. These are speculative conclusions, of course, and they apply at best only to recognized types of galaxies; they do not, for example, take into account unknown types of intergalactic objects or material.

IV. *Acknowledgments.* I wish to thank Dr. C. D. Shane, Director, for the use of the facilities at the Lick Observatory, and especially for the use of the special series of astrograph photographs; also Dr. N. U. Mayall for the use of his unpublished notes and observations of galaxies. In addition, I wish to record my appreciation to Doctors G. H. Herbig, H. F. Weaver, and E. P. Hubble for many stimulating discussions.

REFERENCES

Baade, W. 1944, *Ap. J.* **100**, 147; *Contr. Mt. W. Obs.* No. 697.
——. 1951, *Pub. Obs. Univ. Mich.* **10**, 9; note reference to C. D. Shane's work.
——. 1952, *Ap. J.* **115**, 288 in a remark concerning IC 783 to NGC 4328.
Holmberg, E. 1950, *Medd. Lunds Astr. Obs.* Ser. II, No. 128.
——. 1952, *ibid.* Ser. I, No. 180.
Hubble, E. P. 1932, *Ap. J.* **76**, 112; *Contr. Mt. W. Obs.* No. 453.
——. 1936a, *ibid.* **84**, 158; *Contr. Mt. W. Obs.* No. 548 and 549.
——. 1936b, *The Realm of the Nebulae* (New Haven: Yale University Press), p. 149.
Ross, F. E. 1938, *Ap. J.* **88**, 548, 551.
Sandage, A. R. 1954, *A. J.* **59**, 180.
Shane, C. D. 1947, *Pub. A. S. P.* **59**, 182.
——. 1950, *ibid.* **62**, 42.

Shapley, H. 1927, *Bull. Astr. Obs. Harvard* No. 849.
——. 1938, *Nature* **142**, 716.
——. 1951, *Pub. Obs. Univ. Mich.* **10**, 81.
Shapley, H., and Ames, A. 1932, *Ann. Harv. Coll. Obs.* **88**, No. 2.
Shapley, H., and Mohr, J. 1938, *Bull. Astr. Obs. Harvard* No. 907.
Wilson, A. G. 1951, *Yearb. Carneg. Instn. Washington* No. 50, 1950–1951, p. 20.
Zwicky, F. 1942, *Ap. J.* **95**, 555.

Department of Astronomy,
University of Southern California,
Los Angeles, Calif.,
1955 *May.*

PARALLAX AND MASS–RATIO OF 85 PEGASI

FROM PHOTOGRAPHS TAKEN WITH THE 24–INCH SPROUL REFRACTOR

By ARNE A. WYLLER

Abstract. Measures on 178 plates with 559 exposures taken with the 24-inch Sproul refractor on 80 nights, representing a total weight of 150, give $+0\overset{''}{.}088 \pm 0\overset{''}{.}005$ for the relative parallax and $+0\overset{''}{.}353 \pm 0\overset{''}{.}005$ for the semi-axis major of the photocentric orbit. The adopted value for the absolute parallax, $+0\overset{''}{.}080 \pm 0\overset{''}{.}003$, leads to the masses .82$\odot$ and .80$\odot$, for the primary and secondary component, respectively.

Introduction. The system of 85 Pegasi = ADS 17175, $23^h56^m\!.9$, $+26°33'$ (1900), is a visual binary with a period of 26.27 years and a semi-axis major $0\overset{''}{.}83$ (Hall 1949). The combined visual magnitude is 5.75 and the spectrum of the primary component is G2V (Johnson and Morgan 1953).

The star has been photographed with the 24-inch Sproul refractor since 1912. The first Sproul parallax series includes material from 1912 through 1914. From 1934 on, the star has been photographed every year, although the plates taken in 1953 had to be rejected because of inferior quality. The first Sproul determination of parallax and mass-ratio was made by van de Kamp (1938) based on 54 plates. Since then the

TABLE I. OBSERVING DATA, MEASURED POSITIONS AND RESIDUALS

Epoch	Date	H.A. min.	No. of pl.	No. of exp.	Obs.	P_α	P_δ	Q_α	Q_δ	X unit .0001 mm	Y unit .0001 mm	v_x unit .0001 mm	v_y unit .0001 mm	p
1912.558	July 22	-20	1	2	B	+.80	+.55	-.73	+.11	+4 5267	+2 2463	+45	-27	1
1912.571	July 27	-19	1	3	M	+.76	+.56	-.73	+.11	5221	2495	-5	+11	1
1912.579	July 30	-27	1	3	B	+.73	+.57	-.74	+.11	5216	2476	-9	-4	1
1912.803	Oct. 20	-12	1	2	M	-.43	+.23	-.76	+.16	5281	2337	+16	-20	1
1912.882	Nov. 18	-39	1	3	B	-.76	-.05	-.76	+.18	5279	2317	-5	+11	1
1912.885	Nov. 19	-15	1	3	M	-.77	-.06	-.76	+.18	+4 5259	+2 2293	-25	-11	1
1913.789	Oct. 15	-3	1	3	P	-.35	+.28	-.80	+.35	5681	1883	-5	+3	1
1913.792	Oct. 16	+3	1	3	M	-.37	+.27	-.80	+.35	5671	1847	-16	-31	1
1913.808	Oct. 22	+2	1	3	P	-.45	+.22	-.80	+.35	5703	1881	+13	+14	1
1913.893	Nov. 22	+43	1	3	M	-.79	-.09	-.80	+.37	5712	1781	+1	-31	1
1913.945	Dec. 11	-25	1	3	M	-.89	-.27	-.80	+.38	+4 5747	+2 1761	+19	-17	1
1914.548	July 19	-22	1	2	S	+.83	+.53	-.78	+.48	6129	1567	+56	+47	1
1914.573	July 28	+1	1	3	S	+.75	+.56	-.78	+.48	6049	1521	-31	+13	1
1914.575	July 29	-32	1	3	S	+.75	+.56	-.78	+.48	6075	1556	-6	+49	1
1914.581	July 31	+23	1	2	M	+.73	+.57	-.78	+.48	6094	1507	+12	+2	1
1914.622	Aug. 15	+40	1	3	P	+.56	+.58	-.78	+.49	+4 6155	+2 1494	+62	+9	1
1914.625	Aug. 16	+21	1	2	P	+.54	+.58	-.78	+.49	6063	1486	-30	+2	1
1928.864	Nov. 11	-33	1	2	P	-.69	+.02	+.98	+.24	+5 2479	+1 3942	-34	-36	1
1928.897	Nov. 23	+35	1	2	P	-.80	-.10	+.98	+.23	2537	3960	+15	+8	1
1928.921	Dec. 2	+18	1	2	P	-.86	-.19	+.99	+.23	2492	3921	-39	-15	1
1928.932	Dec. 6	+30	2	4	K	-.87	-.22	+.99	+.23	+5 2541	+1 3907	+6	-22	2
1929.614	Aug. 13	-60	1	2	P	+.59	+.58	+1.00	+.14	2934	3601	+34	+8	1
1929.639	Aug. 22	-4	1	2	P	+.48	+.58	+1.01	+.13	2955	3579	+47	+1	1
1929.653	Aug. 27	-35	1	2	P	+.41	+.57	+1.01	+.13	2927	3581	+16	+10	1
1929.849	Nov. 6	-18	1	2	P	-.64	+.07	+1.01	+.10	2915	3461	-31	+21	1
1929.863	Nov. 11	+55	1	2	W	-.69	+.02	+1.01	+.10	+5 2913	+1 3488	-37	+59	1
1930.633	Aug. 20	-25	1	2	W	+.51	+.58	+1.00	-.01	3326	3027	-11	-6	1
1930.644	Aug. 24	-38	2	4	W	+.45	+.57	+1.00	-.01	3335	3023	-3	-4	2
1930.868	Nov. 13	-18	2	4	K	-.71	+.01	+.99	-.04	3373	2867	-6	-11	2
1930.922	Dec. 3	-8	2	4	P	-.86	-.19	+.99	-.05	3411	2834	+16	-5	2