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The Cluster of Galaxies Abell 1413

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The cluster Abell 1413 at a redshift of 0.143 shows an effect which may be interpreted as a luminosity segregation, indicating that this property probably persists over look-back times of order 0.14 of the inverse of the Hubble constant. The cluster has the same richness as the Coma cluster but only about 60% as the radius, unless what appears to be the brightest member is really a foreground galaxy.

THE accumulation of data on clusters of galaxies will eventually not only provide answers to the problem of their nature and origin, but may also have relevance for the cosmological deceleration parameter. It has been suggested that a linear cluster parameter, such as the cluster radius, might serve as a standard meter stick at various redshifts (Peach and Beard 1969). There necessarily arises the question of evolution (Just 1959). Do the more distant clusters differ from the nearer ones in any of the various properties which have been discussed? Of particular interest are the following characteristics (Zwicky 1957; Rudnicki 1967 and references therein cited; Rood 1969; Noonan 1969; Philip 1970; Philip and Sanduleak 1970). Some clusters may have the brighter members more concentrated toward the center than the fainter members. There has been the suggestion by some investigators that the bluer members may be more concentrated than the redder members; however, in the Coma cluster there is a tendency for the fainter galaxies to be bluer. To what extent might distant clusters exhibit a luminosity segregation and perhaps a color segregation?

The cluster Abell 1413 satisfies the two criteria that it is distant and has an Abell richness greater than 2. Humason, Mayall, and Sandage (1956, abbreviated HMS) give a redshift of $z=0.1427$ (cluster 1153+2341 in their designation). In the Zwicky catalogue (Zwicky *et al.* 1961–68), the cluster, No. 127–32, is described as a compact, distant cluster. According to the Abell catalogue (Abell 1958), the cluster has richness 3 and photored magnitude of the tenth brightest member $17^{m}.1$.

The only previous study of the cluster is that of Sastry (1968), who found that the cluster members have a circularly symmetric distribution and that the brighter members are more concentrated than the fainter members. However, he restricted his counts to only the 21 brightest cluster members. The brightest member is a supergiant cD elliptical (Morgan and Lesh 1965).

I. THE COUNTS

The counts were made on plates obtained at the Palomar 48-inch Schmidt (Table I). Intercomparison of plates 6647 and 6648 allowed elimination of flaws. The distribution of galaxies was analyzed by grid counts, isopleths, and ring counts. However, when the grid counts were summed by strips, the background irregularities were found to be too great for the strip-count method to be reliable. For example, the location of the cluster center depends on the number of strips used.

Isopleths of plate 6645 were constructed by the following method. The density of galaxies at each lattice point of the grid (consisting of 49ʺ.3 squares) was estimated by counting the number of galaxies within a circular aperture of area 10^{-3} deg² centered at the lattice point. The resulting densities, in units of 10^3 gal/deg², were used for constructing smooth contours. The results are shown in Fig. 1. The cluster appears to be irregular in shape. However, the contours in the outer parts of the field suggest that the background itself is highly inhomogeneous.

The ring counts were made in circles with radii being multiples of 1′, centered 49ʺ.3 south of the brightest member at the densest point indicated by the isopleths. The results are given in Tables II and III, where $N(r)$ is the total number of galaxies counted on the plate within a ring of radius r. The counts were analyzed by the following method (Noonan 1961). Since $N(r)$ is the sum $N_C(r)+N_F(r)$, where $N_C(r)$ is the number of cluster galaxies within radius r and $N_F(r)$ is the number of field galaxies—the latter approximately equal to πnr^2 where n is the field density—, the plot of $N(r)$ versus r^2 should be approximately a straight line with slope πn beyond the value of r corresponding to the cluster radius. In this way, it is found that plate 6645 shows a cluster population (to the plate limit) of 340 galaxies, cluster radius 12′, and background density 4870 gal/deg². The uncertainty of ±3% in the background density introduces an uncertainty of approximately 8% in both the population and the radius. Comparison with plate 181 indicates that the inclusion of flaws in the counts of plate 6645 introduces an error of about 360 gal/deg², giving a corrected background density of 4510

TABLE I. Plate material.

Plate No.	Emulsion	Filter	Exposure time	Telescope	Observer	Color
6645	IIIa-J	Wr4	2^h	48-inch Schmidt	Noonan	blue
6646	IIIa-J	Wr4	1^h	48-inch Schmidt	Noonan	blue
6647	103a-E	RG-1	1^h	48-inch Schmidt	Noonan	red
6648	103a-E	RG-1	1^h	48-inch Schmidt	Noonan	red
181	103a-O	···	40^m	200-inch Hale	Humason	blue

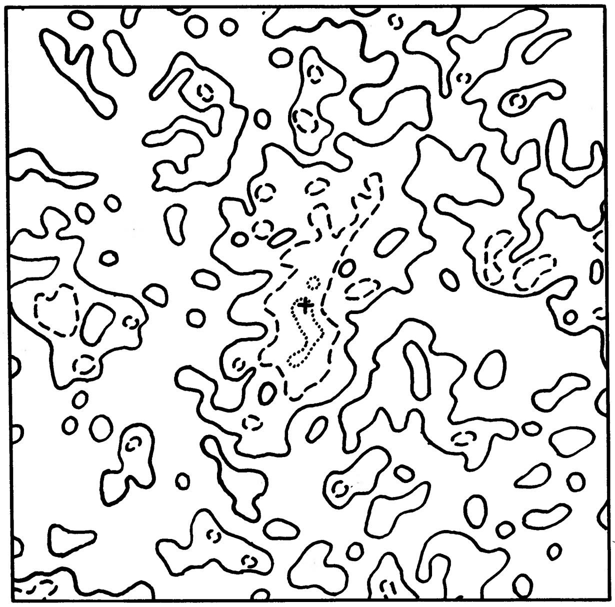

FIG. 1. Isopleths for plate 6645. The *cross* indicates the position of the brightest member (No. 1 in plate I-11 of HMS). The contours represent various densities as follows: *continuous*, 5 gal/deg^2; *dashed*, 10 gal/deg^2; *dotted*, 20 gal/deg^2. North is at the top, and east is to the left.

gal/deg^2 for plate 6645. (The inclusion of flaws with uniform density will not affect conclusions regarding the cluster.) For plates 6647-8, the corresponding quantities are: cluster population 120 to the plate limit; cluster radius 12′; and background density 882 gal/deg^2. These quantities are uncertain by 11%, 12%, and 7%, respectively.

Comparison of plates 6646 and 6647-8 is shown in Table IV for those grid cells on plate 6646 unobstructed by scratches. The counts represent the net difference between the blue plate and the red plates. For example,

TABLE II. Ring counts of plate 6645.

r (′)	$N(r)$	r (′)	$N(r)$
1	27	15	1261
2	70	16	1413
3	128	17	1560
4	208	18	1705
5	282	19	1862
6	369	20	2022
7	450	21	2198
8	527	22	2401
9	622	23	2614
10	736	24	2814
11	842	25	3032
12	951	26	3225
13	1056	27	3437
14	1186	28	3649

TABLE III. Ring counts of plates 6647-8.

r (′)	$N(r)$	r (′)	$N(r)$
1	13	9	174
2	22	12	233
3	42	15	286
4	68	18	365
5	101	21	461
6	123	24	583
7	136	27	683
8	153		

the cell with +8 has five galaxies on plates 6647-8 and 13 galaxies on plate 6646. There is a tendency for the cluster galaxies to be bluer than the field galaxies. This effect is probably due to cosmological reddening of the more distant field galaxies. Unfortunately, the plate material is insufficient for any conclusion regarding color segregation of cluster members.

The normalized ring counts for plates 6645 and 6647-8 are shown in Fig. 2. The abscissa is the radius r on the plane of the sky from the center of the ring counts, and the ordinate is the fraction $F(r)$ of cluster members within a given radius. The cluster members on plates 6647-8 are more concentrated toward the cluster center than those on plate 6645. Thus there is some kind of segregation. However, it is not clear whether the segregation is in luminosity or color or both. If there is no color segregation, then the brighter members are more concentrated than the fainter members. If there is no luminosity segregation, then the redder members are more concentrated than the bluer members, contrary to the results noted earlier.

The irregular appearance of the cluster in Fig. 1 may be due to the irregular background. The subtraction of circularly symmetric counts corresponding to the ring counts (Fig. 3) removes obvious evidence of the cluster's presence. The background fluctuations appear intuitively to be distributed over the entire field. The point is that the irregularities in the cluster contours in Fig. 1 *may* be due to the background rather than the cluster itself.

The 200-inch plate was also counted in rings to a radius of 6′. A plot of $N'(r)/N_C(r)$ versus $r^2/N_C(r)$, where $N'(r)$ is the number of *all* galaxies on the 200-inch plate within radius r, and $N_C(r)$ is the number of *cluster* galaxies on plate 6645 within radius r, approximated a straight line, consistent with the possibility that the *cluster* galaxies have the same distribution on both plates (Noonan 1961). The line approximated by the data has ordinate intercept 1.5, indicating that the cluster population on plate 181 is 50% greater than that on plate 6645, and a slope corresponding to a field density of 1.09×10^4 gal/deg^2. Although this density could include flaws, it is of the same general magnitude as found in studies of 200-inch plates of two other clusters (Noonan 1971a).

TABLE IV. Difference between counts on plates 6646 and 6647-8. The numbers are the counts, in 2′.47-sq cells, of galaxies on plate 6646 minus galaxies on plates 6647-8. The x marks the location of the brightest member; north is at the top and east is to the left. Plate 6646 unfortunately came out with bad scratches, leaving only patches in usable condition.

	0	0	0											
		0	−2						0					
		−1	−3	+1							0	0		
			0	0							0			
			0	0							0			
			0	0	0	+2								
			0	+3		+8								
							x							
		+2	+3	+2	+3			+3						
	−2	−3												
0	−1	−1								0			+2	−2
			0						+2	0	0	−1	0	0
									0	0	0		0	−2

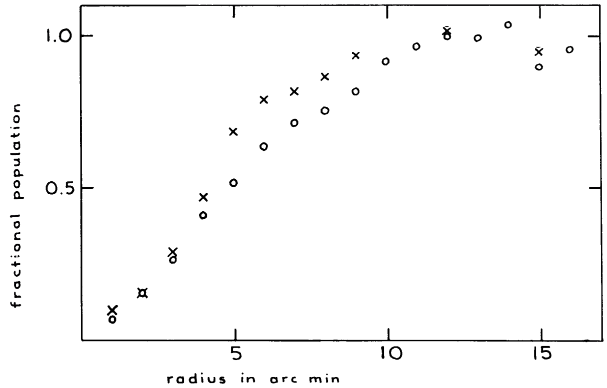

FIG. 2. Normalized integrated ring counts as functions of radius. The ordinate is the fraction of cluster members within projected circle of given radius (as in Fig. 3 of Noonan 1961a for the Coma cluster). The symbols represent the two plates as follows: 6645 *circles*, 6647-8 *x's*.

II. THE BRIGHTEST CLUSTER MEMBER

The writer's measurement (measured to the outermost luminosity detected by the eye on the plate) of the major diameter of the brightest member on plate 6645 is 0.69 mm (compared with Sastry's 0.45 mm) which, at a distance of 428 Mpc (Hubble constant 100 km sec^{-1} Mpc^{-1}), corresponds to 96 kpc. The diameter of the core is 0.22 mm or 30 kpc. The writer's ellipticity (0.38 halo, 0.46 core) is greater than Sastry's (0.30).

The knot designated 1A by HMS is visible only on the 200-inch plate. It lies within the halo of the supergiant.

According to Peach (1969) the galaxy has a visual magnitude of $15^{m}.6$ to the 25-mag-per-sq-arc-sec isophote, after correction for galactic absorption and the K correction. We will assume that Peach's galactic-absorption correction is $0^{m}3$, and all K corrections will be taken from Oke and Sandage (1968) as needed. Magnitudes will be denoted by the subscript notation of an earlier study (Noonan 1971a); e.g., V_{25} is the apparent visual magnitude within the 25-mag-per-sq-arc-sec isophote, and P_t is the total apparent photographic magnitude. The latter is defined by the concepts in HMS, Abell and Mihalas (1966), and the Zwicky catalogue (Zwicky *et al.* 1961–68). Parentheses are added to designate the cluster member to which the magnitude refers. Thus $V_{25}(1)$ is the apparent visual magnitude of the first brightest cluster member to the 25-mag-per-sq-arc-sec isophote. We have $V_{25}(1)=16.2$ uncorrected for galactic absorption or the K correction. From the color index $B-V=1.43$ (Oke and Sandage 1968) and the relation $B-P=0.11$ (Allen 1963, p. 197), we find $P_{25}(1)=17.5$. The correction to total magnitude is of the order of 0.2 mag (Noonan 1971a); then $P_t(1)=17.3$. Finally, use of the color index $P-R=2.4$ for the Oke–Sandage giant elliptical gives $R_t(1)=14.9$.

III. LIMITING MAGNITUDES

The field correction in Abell's catalogue ranged up to 30% of the uncorrected cluster count, while the fraction here is 45%. Abell's estimate of the background may be too low in this case. A fraction of 30% field galaxies within a radius of 12′ would have given a cluster population of about 160 to the limit of plates 6647-8. From the Abell richness of 3, there are 130 to 200 cluster members to a limiting magnitude of $R_t(L)=R_t(3)+2.0$ (L in parentheses refers to galaxies at the plate limit). Therefore, the limiting magnitude of plates 6647-8 is approximately two magnitudes fainter than $R_t(3)$. The latter is between $R_t(1)=14.9$ and $R_t(10)=17.1$.

Inspection of the plates gives the impression that the nine brightest galaxies after the first do not differ greatly in brightness. It is therefore estimated that $R_t(3)$, to within several tenths of a magnitude, is $16^{m}.5$.

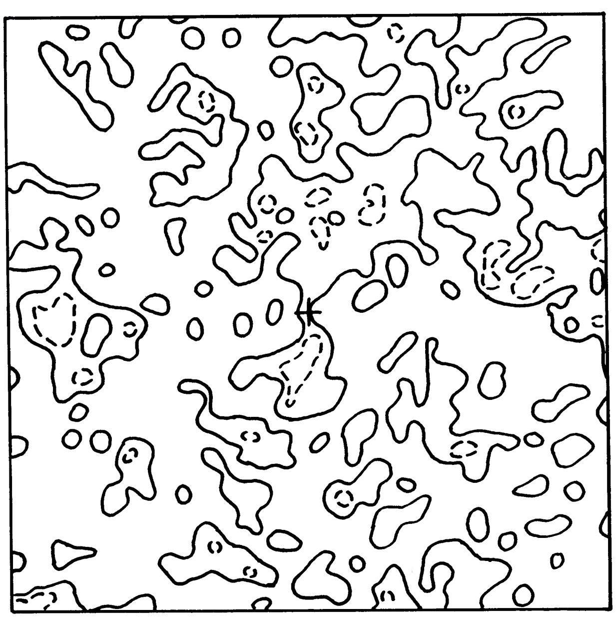

FIG. 3. Same as Fig. 1 but with circularly symmetric cluster counts removed.

Then the limit for plates 6647-8 is $R_t(L)\approx 18^{\mathrm{m}}.5$. This limit is expected to be brighter than the nominal value of $20^{\mathrm{m}}.0$ for the Palomar Sky Survey red prints because the nominal limit refers to stars rather than galaxies.

Another indication of the limiting magnitude comes from the interpolation formula

$$\log n = 0.6m - C, \tag{1}$$

where n is the field density in galaxies per square degree to limiting magnitude m, and C is a constant [Noonan 1971a, Fig. 6; Eq. (1) is being used only as an approximate interpolation device]. For the values of C in the fields of the Coma and Corona Borealis clusters with the field density on plate 6645, Eq. (1) gives $m\approx 22^{\mathrm{m}}$.

Another use of Eq. (1) is based on the reddening of field galaxies. If $P_t(L)$ and $R_t(L)$ are the limiting magnitudes of plates 6645 and 6647-8, respectively, then the difference is given by

$$P_t(L) - R_t(L) = c + \Delta m, \tag{2}$$

where c is the effective color index of field galaxies (Noonan 1971b) and Δm is the magnitude difference, inferred from Eq. (1), between the plates. For the values of n quoted earlier, $\Delta m = 1^{\mathrm{m}}.2$. The unreddened color index is $1^{\mathrm{m}}.8$ (Oke and Sandage 1968), and the reddening due to redshift is $3.6z$ (Oke and Sandage 1968; Noonan 1971b) which, for $z\approx 0.12$ to 0.16, is ~ 0.5. Equation (2) gives $P_t(L)-R_t(L)\approx 3^{\mathrm{m}}.5$, which, for $R_t(L)=18^{\mathrm{m}}.5$, leads to $P_t(L)\approx 22$ for plate 6645. The limiting magnitudes of $R_t(L)\approx 19^{\mathrm{m}}$ and $P_t(L)\approx 22^{\mathrm{m}}$ suggested here for plates 6647-8 and 6645, respectively, must be regarded with the utmost caution, since only photoelectric data can provide reliable magnitudes.

Regardless of the magnitudes, we can find the ratio of the slopes of the luminosity functions of the cluster and field galaxies from a comparison of plates 6645 and 181. If $N(P_t)$ is the cluster population and $n(P_t)$ is the field density to a limiting magnitude P_t, then the ratio of slopes is

$$u = \frac{d \log N(P_t)/dP_t}{d \log n(P_t)/dP_t} \approx \frac{\Delta \log N}{\Delta \log n}.$$

For plates 6645 and 181, the differences in $\log N$ and $\log n$ are $\Delta \log N \approx 0.18$ and $\Delta \log n \approx 0.38$, giving $u\approx 0.47$. Such a value is to be expected if the cluster logarithmic luminosity function $\log N(P_t)$ has a slope of 0.2 to 0.3 (Abell 1965; Zwicky 1957) and the field-galaxy logarithmic count density $\log n(P_t)$ has slope ~ 0.6 [Eq. (1)].

IV. DISCUSSION AND CONCLUSIONS

Abell 1413 exhibits segregation, but insufficient data was obtained to determine whether the segregation is in color or in luminosity. If the cluster has no color segregation, then there is a luminosity segregation, with the brighter members more concentrated than the fainter members.

Further redshifts would resolve the question of whether the cD galaxy, which is here denoted the brightest cluster member, is really a cluster member or a foreground galaxy. In the first case, the cluster is about as rich as the Coma cluster, but its radius would be only 60% of Coma's radius. In the second case, the cluster, if it had the same radius as Coma, would have redshift ~ 0.23 and a richness greater than Coma.

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