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ТОМ 29 ОКТЯБРЬ, 1988 ВЫПУСК 2

УДК: 524.45:520.824

TWO-COLOUR PHOTOMETRY OF CLUSTERS OF GALAXIES. III. A2256

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Received 10 May 1988

The results of two-colour photometry of rich cluster of galaxies A2256 in B and V colour system are presented. About 500 galaxies have been identified on the large scale plates of the 2.6-m telescope of the Byurakan Observatory up to approximately 21^m8 in B. The luminosity function is constructed in both B and V colours. It has a usual form with the characteristic break at $M_B^* = -19.0$ and $M_V^* = -19.9$. The projected radial distribution of the number of galaxies and of surface luminosity have a steep density gradient. The luminosity and colour segregation effects as well as the distribution of apparent ellipticities and position angles of the major axes of the galaxies have been investigated.

1. *Introduction.* A2256 is a rich and regular cluster of galaxies as Coma [1]. According to Abell [2] it has richness class 2 and distance group 3 (the cluster redshift $z = 0.0601$ [3]). The cluster belongs to the Bautz-Morgan intermediate type II—III [4]. Two brightest galaxies are located in the central region of the cluster (a close double NGC 6331 and a giant D [5]), therefore A2256 has the Rood-Sastry B type (binary) [6]. Zwicky has described the galaxy NGC 6331 as a triple system in halo [7]. Two of them form a close double galaxy with $z = 0.0562$ and the north-west neighbour is a radio galaxy with $z = 0.0570$ [8]. Another brighter member has been classified as D type galaxy by Dressler [9].

A2256 is one of the most powerful cluster X-ray sources among the presently known ($L_X \sim 8.2 \cdot 10^{44}$ erg s^{-1}) [10, 11]. The X-ray emission has been detected from an extended source whose angular size is about 16′ [12]. This corresponds to a linear extent approximately 1 Mpc (here and hereafter $H = 75$ km s^{-1} Mpc^{-1}). High resolution observations at the Einstein Observatory have shown the X-ray surface brightness distribution in A2256 to be relatively smooth and centrally enhanced, but not sharply peaked around a dominant galaxy at the center of the cluster [13]. According to [14] the cluster has a large velocity dispersion ($\sigma \sim 1274$ km s^{-1}), which is typical for high luminosity X-ray clusters of galaxies with a dense core and small fraction of spiral galaxies [13].

The region around the cluster center contains an unusual concentration of active galaxies [8]. These galaxies do not have strong optical spectroscopic pecularities, but they have been identified as discrete radio sources with complex radio morphology. Four of them have definite head-tail structure, and four are head-tail candidates [8, 15]. This is an anomalously large number in one cluster. Moreover, two diffuse radio emission regions (with a larger linear extent about 1 Mpc each) were found near the cluster center [8, 15]. This diffuse emission is partially polarized. It is supposed that the complexity of radio morphology in the cluster is due rather to unusual properties of the intracluster environment than to the activity of the individual galaxies [15].

In this study we continue the series of papers on two-colour photometry of the clusters of galaxies (Kalloghlian et al. [16], hereafter paper I, Egikian et al. [17], hereafter paper II). The results of B and V photometry of galaxies in rich cluster A2256 are presented. 486 galaxies have been identified on the large scale plates of the 2.6-m telescope of the Byurakan Observatory up to approximately 21^m8 in B and 21^m4 in V. The luminosity function is constructed both in B and V. The luminosity and colour segregation effects as well as the distribution of apparent ellipticities and position angles of the major axes of the galaxies have been investigated.

2. *Observations and reduction procedure.* The B, V photometry used in this study has been made on photographic plates taken in the prime focus of 2.6-m telescope of the Byurakan Observatory during two nights in August 1981. The plate-filter combinations are: Zu-21 + Soviet blue filter № 8 for B and Kodak 103a — D + Soviet yellow filter № 17 for V band. A colour system defined in this way is very near to the standard B, V system [18]. The plates have been scanned with the PDS microdensitometer of the Naples Observatory. Only one good quality plate in each colour band has been measured. The reduction procedure has been described in paper I.

As a result the X, Y rectangular coordinates, diameters, total B, V magnitudes, the corresponding $B-V$ colours of galaxies as well as their apparent ellipticities and position angles of the major axes have been determined.

3. *Calibration*. The plates were calibrated with a 12-tube spot sensitometer. The absolute photometric calibration was accomplished by B, V surface photometry of the brightest cluster members (close double NGC 6331 and D galaxy), as well as by measuring the sky background surface brightness on the plates in B and V respectively. It should be noted that the double galaxy NGC 6331 and its north-west neighbour surrounded by a common envelope have been measured together. The plates with the extrafocal images of the stars in the open cluster NGC 7031 obtained at the same nights and in the same B, V colour system as the plates of A2256 have been used as photometric standards. The B, V photoelectric magnitudes of these stars given by Sandage have been taken from [19].

In order to check the zero-point of the magnitude scale, the g, r photoelectric magnitudes of the brightest cluster galaxy (NGC 6331 + + north-west component) in Gunn and Thuan photometric system [20] have been used. The data were taken from [21], where the SIT measurements of this galaxy are presented. After the g, r magnitude transformations to the standard B, V system using the colour equations

$$V = g - 0.37\,(B - V) + 0.14$$
$$B - V = (g - r) + 0.46$$

taken from [22, 23], we obtain for the brightest member $V = 14^{m}.33$ and $B = 15^{m}.34$ in aperture 53″. The comparison of these data with our measurements of the same galaxy magnitude in diameter 50″ ($V = 14^{m}.46$, $B = 15^{m}.47$) shows rather good agreement.

4. *Results*. The galaxy identification and their separation from stars have been conducted automatically (see paper I). Nevertheles, a visual inspection of the objects on the plates in both B and V has also been made as in two previous papers. As a result, 486 galaxies have been identified within the measured area of the cluster with sizes $35'.7 \times 35'.7$ ($\approx 0.35\ \square°$) up to the limiting magnitude about $21^{m}.8$ in B and $21^{m}.4$ in V. However, the sample limits of completeness are $20^{m}.1$ and $19^{m}.5$ and the numbers of galaxies till these magnitudes are 410 and 438 in B and V respectively. At the cluster distance modulus $m - M = 37.0$ the limits of completeness correspond to the absolute magnitudes $M_B = -16.9$ and $M_V = -17.5$. A2256 is at the galactic latitude $b^{II} = 31°.7$. The galactic absorption has been taken into account by Sandage's formulae [24] and amounts to $A_B = 0.12$ and $A_V = 0.08$.

The identification chart of 486 galaxies is presented in Fig. 1.

a) *The luminosity function.* The luminosity function of A2256 has been constructed within the measured area of the cluster both in B and V colour bands. The galaxy counts have been performed within $0^m.3$ in-

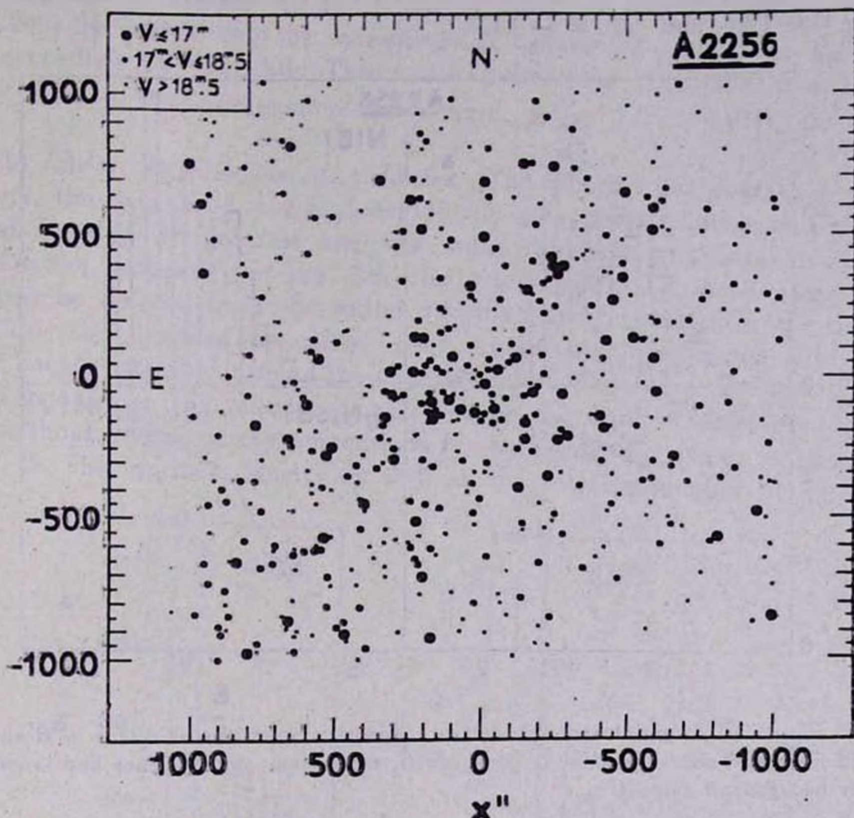

Fig. 1. Identification chart of galaxies in A2256.

tervals. The differential and logarithmic cumulative luminosity functions with and without corrections for background galaxies are presented in Fig. 2. The vertical dotted lines show the sample limits of completeness. As in paper I and II the corrections for background galaxies were made according to [25], where the faint galaxy counts up to 24 mag. are given. From these data the number of background galaxies within the measured area up to the completeness limit of our sample has proved to be equal to 99 and 141 in B and V respectively.

As one can see from Fig. 2 the luminosity function of galaxies in the measured area of the cluster A2256 does not differ from the typical form primarily suggested by Abell [26]. The differential luminosity function has a marked local maximum at about $B^* = 18^m.0$ and $V^* = 17^m.1$, that leads to the characteristic break in the logarithmic cumulative luminosity function at the same magnitudes. After corrections for galactic absorption these values correspond to the absolute magnitudes $M_B^* = -19.0$ and $M_V^* = -19.9$.

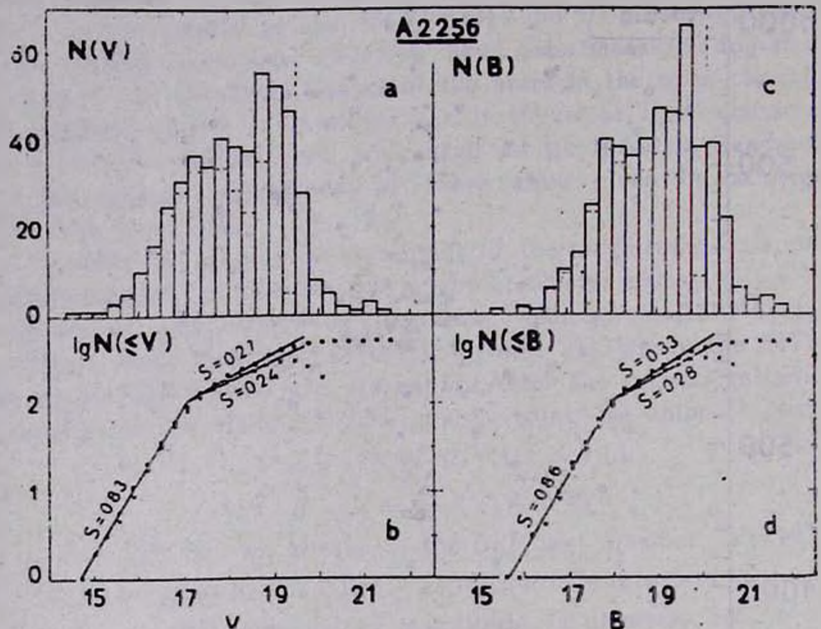

Fig. 2. Differential and cumulative luminosity functions of A2256 in B and V. Solid lines and circles — without background correction, dotted lines and crosses — after background correction.

Thus, the logarithmic cumulative luminosity function is represented by two intersecting straight lines, whose slopes in B and V are equal to 0.86 and 0.83 at the bright end and 0.28 and 0.24 at the faint end of the curves corrected for background galaxies. Such a steepness of the bright end is typical for the clusters with dominant galaxies [27, 28].

The cluster A2256 has been studied by Dressler in [1], where the luminosity function of galaxies is given in F band. The difference in colour systems and the lack of direct data make the comparison of the results of both studies difficult. Nevertheless, using Dressler's luminosity function graph we determined the values of slopes which are equal to about 0.78 and 0.29 respectively for the bright and faint ends of the curve corrected for background galaxies. These values are in good agreement with our data. The absolute magnitude of the point of break estimated from the same graph is equal to -21.8 in F band. After reduction to the same distance scale and transformation to the standard V colour system by the equations given in [29] we have $M_V^* = -20.0$ by subtracting the cosmological correction applied by Dressler according to [24, 30]. This value practically coincides with the value $M_V^* = -19.9$ obtained in the present study.

b) *Radial distribution of galaxies.* The central concentration of clusters, the degree of compactness of the galaxy distribution and the central density of galaxies are the significant characteristics which describe the properties of the rich clusters [31, 32]. All these parameters may be defined from the radial distribution of galaxies in the clusters. For this purpose the galaxy counts have been performed with a set of concentric rings around the cluster center. The radial distribution of 438 galaxies in the measured area up to the limit of completeness in V without and with the corrections for background galaxies is given in Fig. 3. The surface density as well as the relative number of gala-

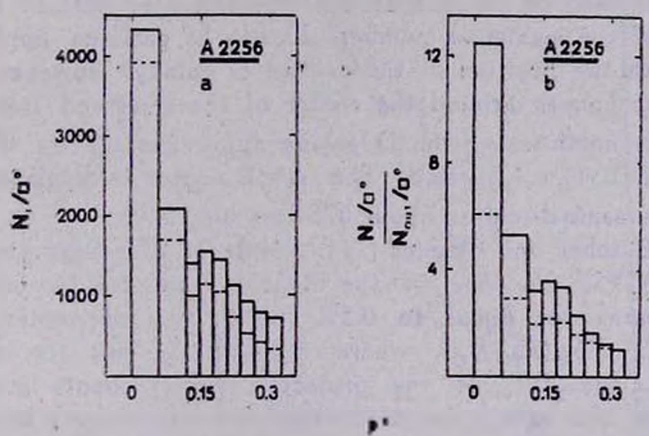

Fig. 3. Radial distribution of 438 galaxies with $V < 19^m.5$. On the ordinate axis are plotted: a) the surface number density of galaxies per square degree, dashed lines—after background correction; b) the relative number of galaxies per $1\Box^\circ$, solid lines—after background correction.

xies per square degree are plotted as a function of distance from the cluster center. The number density of galaxies in the outmost ring is taken as unity. The background corrections in each ring have been made according to [25] in one magnitude interval.

As one can see from this figure (see Fig. 3b) the radial distribution has a steep gradient. At the distance of 0.3 from the cluster center the number density of galaxies falls about 12 times in respect to the central density. This distance corresponds approximately to 0.6 r_a, where r_a is the Abell radius of the cluster defined by $5.15 \cdot 10^5/cz$ arcmin. The central surface number density of galaxies in the radius of about 3.6 is 4300 galaxies per square degree without background corrections (see Fig. 3a). The value of this parameter defined for the A2256 by Baier and Mai in [33] within a central circle of radius 3.12 is approximately equal to 4200 galaxies per square degree. We note that in [33] the limiting magnitude of the galaxy counts roughly corresponds to our limit of completeness in V band. On the other hand the galaxy counts performed by Bahcall [34] in the region of cluster A2256 have a limiting magnitude for about two magnitudes brighter and the central density is defined in a circle of radius 1.12. If the data in the same areas up to the same limiting magnitudes are compared, the agreement between the data obtained in [34] and the present study becomes fairly good.

It should also be noted that the cluster center defined in [33, 34] as position of the maximum number density of galaxies approximately coincides with the position of the central D galaxy. However, we have performed the counts around the center of the measured area which is shifted to the north-west from D galaxy approximately by 0^m5 in right ascension and $1'$ in declination. The Abell center is displaced from D galaxy in the same direction about 0^m5 in α and $5'$ in δ.

In the Butcher and Oemler [31] sample of 23 nearby rich clusters of galaxies A2256 has one of the highest values for the central concentration parameter equal to 0.59 ± 0.04. This parameter in [31] is defined by $C = \log(R_{60}/R_{20})$, where R_{60} and R_{20} are the radii which contain 60% and 20% of the projected galaxy counts respectively. Unfortunately, this cannot be determined from our counts because they do not cover the whole cluster but extend only to 0.6 Abell radius. In White's [32] classification scheme the studied cluster has intermediate type (I) by both central density of galaxies and the degree of compactness. By definition the latter means that the bulk of the brighter cluster galaxies are within 0.5—0.75 Abell radius.

The high central concentration and the steep number density gradients are usually typical to the rich, regular clusters with a dominant galaxy and low spiral fraction.

c) *Surface luminosity density.* The shape of the surface-brightness profile of clusters is also correlated with the galactic content [29, 35]. The dependence of the surface luminosity density of galaxies in A2256 on the distance from the cluster center is given in Fig. 4 (by analogy

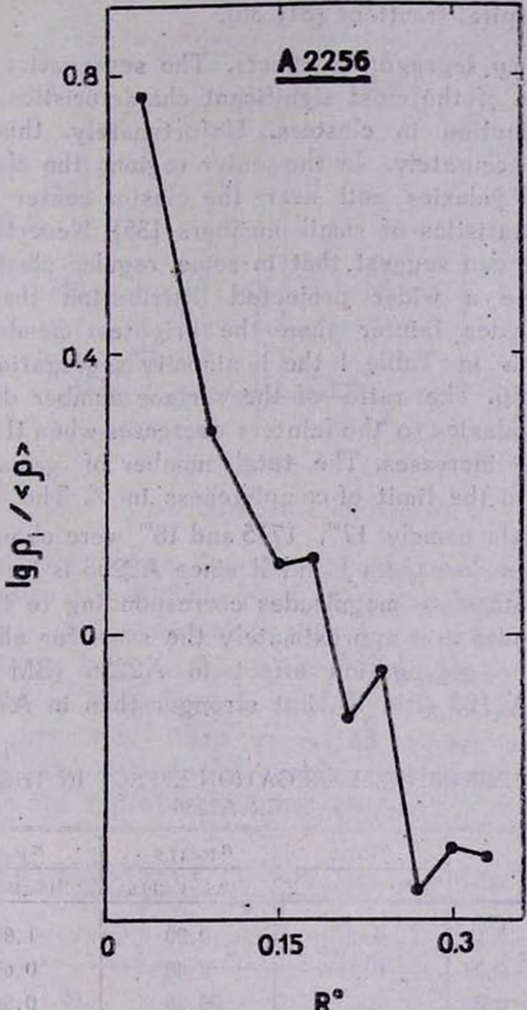

Fig. 4. Surface luminosity density distribution in the cluster. The logarithm of the luminosity densities in the rings relative to the mean for the measured area of the cluster as a function of the radius.

of that for A1213 in paper II). As one can see from this figure the surface luminosity density falls rather quickly along the radius with some fluctuations. Already at the distance of 0.6 Abell radius the surface density of luminosity as well as the number density of galaxies falls about 12 times in respect to the central one. Consequently, this distribution has also a rather steep gradient in agreement with the statement that spiral — poor and cD clusters have steeper density gradients than irregular clusters [29, 35]. A2256 is among the clusters with abnormally low spiral fractions [31, 36].

d) *Luminosity segregation effects.* The segregation of galaxies by luminosity is one of the most significant characteristics connected with the galaxy distribution in clusters. Unfortunately, this effect is difficult to measure accurately. In the outer regions the cluster counts are affected by field galaxies and near the cluster center the accuracy is limited by the statistics of small numbers [35]. Nevertheless, from various studies one can suggest that in some regular clusters the fainter galaxies may have a wider projected distribution than the brighters (for 2—3 magnitudes fainter than the brightest member). As one can see from the data in Table 1 the luminosity segregation effect is also observed in A2256. The ratio of the surface number densities of relatively brighter galaxies to the fainters decreases when the distance from the cluster center increases. The total number of galaxies used in this table is 438 up to the limit of completeness in V. The border values of magnitude intervals namely 17^m, $17^m_.5$ and 18^m were chosen for one magnitude fainter than in papers I and II since A2256 is farther than A1185 and A1213. The absolute magnitudes corresponding to the three border apparent magnitudes are approximately the same for all three clusters. We note that the segregation effect in A2256 (BM type II—III) is weaker than in A1185 (BM II), but stronger than in A1213 (BM III-E).

Table 1

LUMINOSITY SEGREGATION EFFECT IN THE CLUSTER A2256

Ring	$\frac{n_{V<17}}{n_{17<V<19.5}}$	$\frac{n_{V<17.5}}{n_{17.5<V<19.5}}$	$\frac{n_{V<18}}{n_{18<V<19.5}}$
0—0.12	0.30	0.80	1.39
0.12—0.24	0.24	0.48	0.69
0.24—0.33	0.09	0.28	0.56

e) *Colour distribution and segregation.* In Fig. 5 the integral colour distribution is given for the incomplete sample of 442 galaxies. The remaining 44 galaxies out of 486 are not taken into account because of incorrect magnitudes due to contamination by a neighbouring star or galaxy. No correction for the field galaxies has been applied.

As one can see from Fig. 5 the colour indices vary in a wide range from $-0^m.2$ to $+2^m.4$. However, about 70 % of the galaxies have colour indices within a broad maximum with mean value $(\overline{B-V}) \sim 0^m.9$.

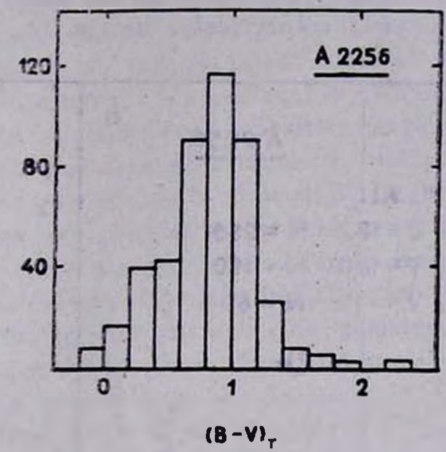

Fig. 5. Colour distribution of galaxies.

It has been shown above (see section 4d) that some luminosity segregation is present in A2256. From the data of Table 2 a colour segregation effect is also observed in this cluster. The relative number of less redder galaxies having $(B-V) < 0^m.7$ increases with distance from the cluster center. This effect as well as the luminosity segregation in A2256 are less pronounced than in A1185 but are stronger than in A1213 (see papers I and II) with probable agreement with their morphological types in the BM classification scheme.

Table 2

COLOUR SEGREGATION EFFECT IN THE CLUSTER A2256

Ring	$n_{B-V<0.7}$	$n_{B-V>0.7}$	$\frac{n_{B-V<0.7}}{n_{B-V>0.7}}$	$\frac{n_{B-V<0.7}}{N}$
0—0°.12	24	90	0.27	0.21
0.12—0.24	52	130	0.40	0.29
0.24—0.33	68	78	0.87	0.47

It should also be noted that the luminosity and colour segregation effects are apparently inherent to the X-ray clusters of galaxies. As indicated in [36, 37] the ratio of the surface densities of spirals to S0's increases with distance from the center of rich clusters associated with strong X-ray emitters. Particularly, this is also true for A2256 [36].

f) *The distribution of apparent ellipticities and position angles.* We consider the distribution of the apparent ellipticities and position angles of the major axes of galaxies brighter than $18^m.7$, 18^m and 17^m in *V* band. The number of galaxies up to these limiting values is equal to 286, 190 and 69, respectively. In Fig. 6a, the number of ga-

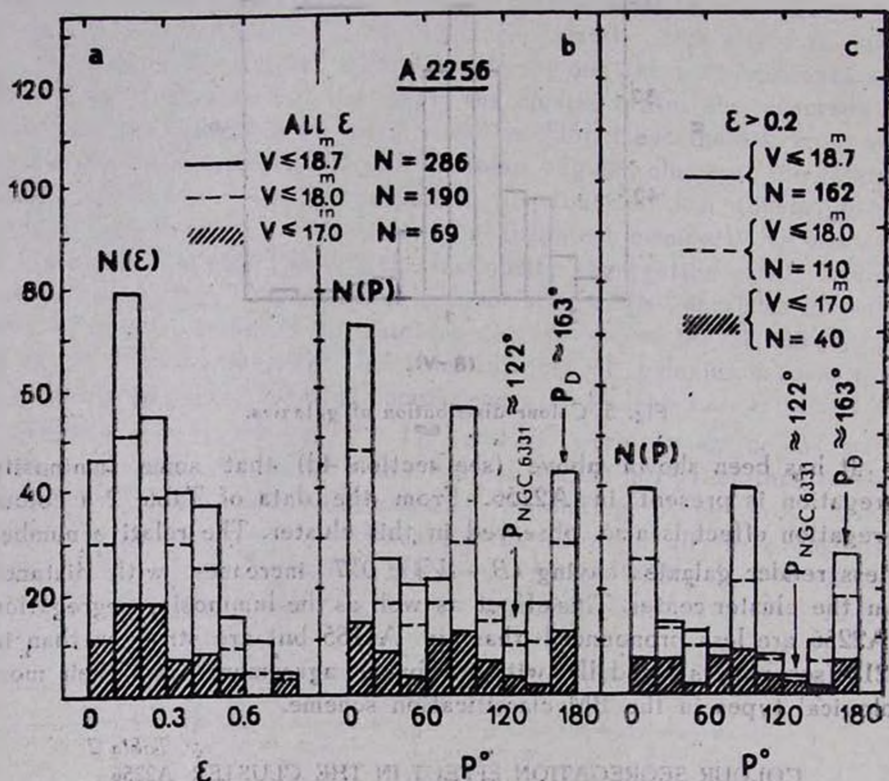

Fig. 6. a) Distribution of apparent ellipticities; b) distribution of position angles for all galaxies with measured ellipticities; c) the same for galaxies with ellipticities larger than 0.2.

laxies within intervals of ellipticity $\Delta\varepsilon = 0.1$ as a function of the apparent ellipticities $\varepsilon = (a - b)/a$ is plotted. This relation is approximately the same for all three samples. From the histogram in Fig. 6a the ratio of the number of galaxies with $\varepsilon > 0.2$ to those with $\varepsilon \leqslant 0.2$ is equal to

$$\frac{N(\varepsilon > 0.2)}{N(\varepsilon \leqslant 0.2)} = \frac{161}{125}, \quad \frac{109}{81} \text{ and } \frac{40}{29}$$

for galaxies brighter than $18^m.7$, 18^m and 17^m, respectively. These limiting values correspond to the absolute magnitudes approximately -18.3, -19 and -20 in V. Consequently, there are many flattened galaxies both in bright and intermediate brightness populations by analogy with the Perseus cluster [38, 39]. As it was mentioned above, the overwhelming majority of the galaxies in cluster A2256 are ellipticals and lenticulars, while only a few per cent of galaxies are spirals [31, 36].

In Fig. 6b the distribution of position angles of the major axes of all galaxies with measured ellipticities is plotted and in Fig. 6c the same is plotted for galaxies with ellipticities larger than 0.2. As in the case of distribution of ellipticity the shape of this relation does not change considerably for samples with different limiting magnitudes. The three maxima which are clearly seen in both plots (Fig. 6b and c) seem to be real since the greater part of the galaxies in all three samples have position angles within those three intervals though rounder galaxies with uncertain orientations are included in Fig. 6b rather than in Fig. 6c. The position angle of the brightest D galaxy equal to approximately 163° coincides with one of these maxima. About 40 % of the galaxies with $\varepsilon > 0.2$ up to the limiting magnitude $V = 18^m.7$ have an alignment in the direction of elongation of the central D galaxy. As one can see from the data of Table 3 this phenomenon does not apparently depend on the brightness of galaxies while the percentage of galaxies with alignment in the direction perpendicular to the elongation of the D galaxy increases with the decrease of brightness. On the contrary, among galaxies with other orientations the number of brighter objects is significantly higher than that of the fainter. Thus the brighter cluster galaxies do not show any preferential alignment.

Table 3

THE DEPENDENCE OF ALIGNMENT OF THE GALAXIES ON INTEGRAL MAGNITUDE

ΔV	Along alignment of D galaxy $n=67$	Perpendicular to the alignment of D galaxy $n=40$	Others $n=55$
$<17^m.1$	27 %	23 %	51 %
17.1–18.0	40 %	32 %	27 %
18.0–18.7	33 %	45 %	22 %

As it is known the greater part of clusters of galaxies have a marked ellipticity [40]. The alignment of clusters in the direction of elongation of dominant galaxies, is an interesting feature of their structure [40, 41]. A2256 has not a circular symmetry. According to [42] the region of the cluster with 0.5 Mpc average radius has ellipticity $0.60 \pm \pm 0.10$ at position angle $145° \pm 6°$. Moreover, in Baier's and Mai's study [33] A2256 is well isolated and shows an elongation in the direction from south-east to north-west up to 30 per cent confidence level. Using the map of isopleths for the region of A2256 given in this work it is possible to estimate roughly the cluster's ellipticity and position angle at which it is elongated. Those appear approximately equal to 0.54 and 150°, respectively. The position angle of the cluster alignment apparently coincides within the accuracy of the measurements with that of the central D galaxy. It is interesting to note that the extended X-ray source associated with A2256 is also elongated with an ellipticity equal to 1.7 ± 0.1 [13]. The latter is defined as the ratio of the maximum and minimum extents of the X-ray emission region. By analogy with the optical definition of ellipticity the inverse value is equal to 0.59.

5. *Summary*. a) The luminosity function of the cluster A2256 has Abell's typical form with the characteristic break at $M_B^* = -19.0$ and $M_V^* = -19.9$ in B and V respectively. The bright end of the logarithmic cumulative luminosity function rises rather steeply. Such a steepness is usually typical for the rich, regular clusters having a dominant galaxy [27, 28]. The slope of the bright end is equal to 0.83 in V. The same value for Coma cluster derived by Abell in [42] is equal to 0.85 in the same colour system. Such a good agreement apparently may be explained by the fact that both clusters belong to the same richness class (R = 2) and have the same structural types. In Rood's and Sastry's classification system both clusters belong to the B type (binary).

b) The radial distribution of either surface density of galaxies or their luminosities has a steep gradient. At the distance of 0.6 Abell radius, the surface density of luminosity as well as the number density of galaxies fall about 12 times in respect to the central density. The high central concentration and the steep density gradient (of the number of galaxies or surface luminosity) are usually typical to the cD and spiral-poor clusters [29, 41]. The transition from cD to the spiral-rich clusters is accompanied by decreasing these parameters. A2256 is among clusters which have anomalously low spiral fraction [31, 36].

c) Some luminosity and colour segregation effect is present in the cluster. These effects in A2256 are observed to be not as strong as in A1185 but are stronger than in A1213. Apparently, there is a certain correlation between the segregation evidence and the cluster BM morphological types, namely II, II—III and III-E for A1185, A2256 and A1213, respectively. According to [29, 41] some luminosity segregation is present only in the cD and spiral-poor clusters. No evidence for segregation effects in irregular, spiral-rich clusters has been observed.

d) As follows from distribution of the apparent ellipticities of galaxies there are many flattened galaxies among the bright and intermediate brightness populations of the cluster A2256.

The position angle of the brightest D galaxy apparently coincides with the accuracy of the measurements with the position angle at which the cluster, according to [33, 40], is elongated in the direction from the south-east to the north-west. A number of galaxies with $\varepsilon > 0.2$ up to $V = 18\overset{m}{.}7$ evidently have the same alignment. This phenomenon however does not depend on the apparent magnitude of galaxies. Moreover, the brighter cluster galaxies do not show any preferential alignment.

A. T. K. is grateful to the staff of the Rome and Naples Observatories for their hospitality and to the CNR of Italy for financial support.

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ДВУХЦВЕТНАЯ ФОТОМЕТРИЯ СКОПЛЕНИЙ ГАЛАКТИК. III. A 2256

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Приводятся результаты двухцветной фотометрии богатого скопления галактик A 2256 в цветовой системе B, V. На крупномасштабных снимках 2.6-м телескопа Бюраканской обсерватории отождествлено около 500 галактик до $21\overset{m}{.}8$ в B цвете. Построена функция светимости в B и V. Она имеет обычную эйбелловскую форму с характерным изломом при $M_B^* = -19.0$ и $M_V^* = -19.9$ в B и V соответственно. Радиальное распределение числа галактик и поверхностной светимости имеет большой градиент плотности. Исследуются эффекты сегрегации галактик по яркости и цвету. Рассматривается также распределение галактик скопления по их видимым эллиптичностям и позиционным углам больших осей.

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