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ROTATION OF THE HERCULES CLUSTER OF GALAXIES

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INTRODUCTION

Numerous attempts have been made to investigate the Hercules cluster of galaxies. This cluster is included in the first list of the clusters of galaxies published by Shapley [1]. Shapley listed two clusters in direction toward Hercules with the following galactic co-ordinates

$$\text{(1)} \quad \begin{array}{l} \text{cluster No. 14 } b^{I}=+43^\circ \text{ and } l^{I}=357^\circ \\ \text{cluster No. 15 } b^{I}=+43^\circ \text{ and } l^{I}=359^\circ \end{array}$$

with areas 2.17 and 1.37 sq. degr. respectively. Cluster No. 14 contains 370 members and cluster No. 15—256 members down to the plate limit of 17.4 apparent photographic magnitude. According to Shapley the distances to these clusters are equal to 23 Mpc (old scale).

According to the Lick counts of galaxies [2, 3] the Hercules cluster of galaxies is a multiple one and contains 2 large and 1 or 2 smaller condensations. The position of the Hercules cluster is determined as follows

$$\text{(2)} \quad \begin{array}{l} \alpha_{1950}=16^{h}02^{m} \\ \delta_{1950}=+17^\circ.0. \end{array}$$

The co-ordinates of the two main condensations are

$$\begin{array}{l} \alpha_{1950}=16^{h}03^{m} \\ \delta_{1950}=+17^\circ.8 \end{array} \quad \text{and} \quad \begin{array}{l} \alpha_{1950}=16^{h}01^{m} \\ \delta_{1950}=+16^\circ.2. \end{array}$$

Evidently, the first condensation (Shapley's cluster No. 15) is in fact the Hercules cluster of galaxies. The Lick counts of galaxies gives 1248 membership against a background of 60 galaxies [2]. The plate limit of the Lick counts of galaxies is $m_{lim}=18^{m}.4$ [2, 4, 5] (the new reduction gives about $m_{lim}=19^{m}$ [6, 7]) and then the probability to adopt a background galaxy instead of a cluster one down to m_{lim} for the central parts of the Hercules cluster is $p\leqslant 60/1248\approx 0.05$.

The main condensation of the Hercules cluster of galaxies has been listed by A b e l l [8] — No. 2151 in his Catalogue — with a position

$$\alpha_{1855} = 15^h 58^m.7 \quad \text{and} \quad l^I = 358^\circ.9$$
$$\delta_{1855} = +18^\circ 09' \qquad\qquad b^I = +44^\circ.4$$

or [9]

$$\alpha_{1950} = 16^h 02^m 48^s \qquad (3)$$
$$\delta_{1950} = +17^\circ 53'.$$

There are two additional clusters in the field examined — No. 2125 and No. 2147 (Abell), which are contained in the second condensation of the Lick counts.

Cluster No. 2151 has $m = 13^m.8$, $D = 1$ and $R = 2$. m is the magnitude of the tenth brightest cluster member, estimated by the step-scale technique and corrected for the effects of atmospheric extinction and general galactic obscuration. D is the distance (from 1 to 6); for $D = 1$ we have $z = 0.027$ and for $D = 2$ $z = 0.038$, respectively. R is the richness or the membership of the clusters. For $R = 1$, the number of galaxies, contained in a cluster, which is not more than 2 magnitudes fainter than the third brightest member, it is 30—40 and for $R = 2$, 80—129, respectively.

Clusters No. 2152 and No. 2147 have $m = 13^m.8$, $D = 1$ and $R = 1$.

A special study of the Hercules cluster of galaxies is published by G. R. and E. M. B u r b i d g e [10], where Figures 1—5 are reproduced from plates taken by W. Baade with the Hale 200-inch reflector. The Hercules cluster is an asymmetrical one and its north-south and east-west dimensions are about 1° and 40′, respectively. Out of 61 classified galaxies in [10], 69 per cent are spiral or irregular ones and 31 per cent elliptical or SO. This points to a very high proportion of spirals. A value of the cluster mass is obtained.

The Hercules cluster of galaxies is investigated by L o v a s i c h, M a y a l l, N e y m a n and S c o t t [11] in connection with the testing of the hypothesis for expansion, by E. and G. B u r b i d g e [12] and by N e y m a n and S c o t t [13].

The following center of the Hercules cluster of galaxies is adopted in [12]

$$\alpha_{1950} = 16^h 02^m.9, \qquad (4)$$
$$\delta_{1950} = +17^\circ 54'.$$

According to G. de V a u c o u l e u r s [14] this cluster is located at a distance of 72 Mpc with characteristics: mean radius of 0.85 Mpc, population of $\lg N_3 = 1.9$, total mass of $\lg N \mathfrak{M}_\odot = 13.58$, mean mass per galaxy $\lg \mathfrak{M} = 11.7$ and mean density of $\lg \varrho = -27.15\ \mathrm{g\,.\,cm^{-3}}$ (according to [10] with $H = 150\ \mathrm{km\,.\,sec^{-1}\,.\,Mpc^{-1}}$).

It is worth noting that A m b a r t s u m i a n and S h a c h b a z i a n [15] have established the presence of an intergalactic matter between two of the brightest cluster galaxies — IC 1182-84. The presence of peculiar and interacting systems in the Hercules cluster of galaxies may be retraced on the V o r o n t s o v-V e l y a m i n o v's Catalogue [16].

In the Zwicky's Catalogue [17] the Hercules cluster of galaxies is not defined as an isolated cluster. According to a note by Zwicky the cluster 1600.4+1925 (medium compact, population of 2859, near) contains the Hercules cluster as a condensation. Indeed, it is quite possible the Hercules cluster to be contained in a more extended cluster of galaxies, or in a second-order cluster [18].

A radio observation of the Hercules cluster is carried out by J. Heidman [19] (1430 MHz), where the isopleths of the Lick counts of galaxies are reproduced and a synthetic apparent luminosity function is constructed. This cluster is marked as Hercules-North (No. 2151 after Abell's Catalogue). A powerful radio emission of IC 1182 is registered. An analogic investigation (1445 MHz) is carried out by Fomalont and Rogstad [20].

The latest radioobservations [9] (234, 750 and 1414 MHz) are compared with a new count of galaxies in $5' \times 5'$ squares, which is carried out on an original 48" plate (approximated with weighted circular Gaussian).

OBSERVATIONAL MATERIAL

Center coordinates. In order to apply the method for determination of the rotation of the Hercules cluster of galaxies (this method and its application to the Coma cluster of galaxies is published in [21, 22]), it is necessary to determine the center co-ordinates and to treat the radial velocities.

The first difficulty is in connection with the differences among the available positions of the Hercules cluster center. All conclusions in the present paper are based on the assumption that the Hercules cluster (Hercules-North [19] or No. 2151 [8]) possesses a central part (nucleus), which is justified on the basis of the papers [2, 6, 9, 10, 19, 20]. If the Hercules cluster of galaxies is included as a condensation in a more extended cluster (according to [17]), whose investigation is impossible now, because of the absence of measured radial velocities, we may assume that at least for the nucleus, the rotation will not be essentially influenced by the neighbouring condensation (or clusters).

An inspection of the data up to now shows that the Hercules cluster of galaxies is comparatively isolated and the condensation according to [17] is substantially located in the interval

$$16^h00^m < \alpha_{1950} < 16^h05^m \qquad (5)$$
$$+17°15' < \delta_{1950} < +18°50'.$$

Indeed all published centers are located in a smaller interval, which is contained in (5).

The co-ordinates (1) are aproximate and must be rejected, as well as the co-ordinates which are determined in our investigation of clusters and of groups of clusters of galaxies [23] on the Lick counts. In the Catalogue [23] the co-ordinates of the Hercules cluster center are

$$l^I = 359°.3 \qquad (6)$$
$$l^I = +43°.0.$$

The cluster limits are

$$l_1^{\rm I}=358°.0 \qquad l_2^{\rm I}=359°.7$$
$$b_1^{\rm I}=+42°.6 \qquad b_2^{\rm I}=+43°.5.$$

Co-ordinates (2) (which are equivalent to (6)) are approximate too. More accurate co-ordinates are (3), but they may agree only with determinations (4) and [20]

$$\alpha_{1950}=16^{h}02^{m}58^{s}, \quad \delta_{1950}=+17°53'13''. \tag{7}$$

On the assumption that the center is symmetrical at least with respect to the outer isopleths, then the count [9] allows a new cluster center determination (which is not made in [9])

$$\alpha_{1950}=16^{h}03^{m}08^{s}, \quad \delta_{1950}=+17°55'20'' \tag{8}$$

in accordance with radioobservations [9] and [19].

As it is known there are no indications in favour of the affirmation that the cluster galaxies possess various centers (apparent) of clustering. Consequently, as far as the Zwicky catalogue may be examined as a homogeneous one up to $m_{\rm lim}=15^{m}.7$ [24], it is justified to assume that the weighted center of all galaxies contained in [17] on the assumption (5) must be located near the apparent center of the Hercules cluster. Thus we have a new determination for the cluster center

$$\alpha=\frac{1}{n}\sum_{n}\alpha_i, \quad \delta=\frac{1}{n}\sum_{n}\delta_i \tag{9}$$

which for 39 galaxies in the field (5) gives

$$\alpha_{1950}=16^{h}03^{m}13^{s}, \quad \delta_{1950}=+17°59'22''. \tag{10}$$

Analogic operation for 40 galaxies in the same field contained in the Catalogue [16] permits the determination of another center

$$\alpha_{1950}=16^{h}03^{m}19^{s}, \quad \delta_{1950}=+17°56'56''. \tag{11}$$

The co-ordinates (10) and (11) show an exceptional conformity.

15 galaxies with radial velocities are contained in the Catalogue of G. and A. de Vaucouleurs [25] in the same field (5) and according to (9) we have

$$\alpha_{1950}=16^{h}03^{m}16^{s}. \quad \delta_{1950}=+17°52'52''. \tag{12}$$

These co-ordinates must be rejected on account of the following: 1) very small sample, 2) a preference for the locations of the galaxies with known radial velocities (mostly in the south-west part of the cluster), and 3) systematic differences among declinations of the galaxies.

The positions of 15 galaxies listed in the Catalogues [16, 17, 25, 28] are plotted on Fig. 1. It is easy to determine

$$\delta_{Zw}-\delta_{V_{\rm auc}}=1'\!.0\div 1'\!.5.$$

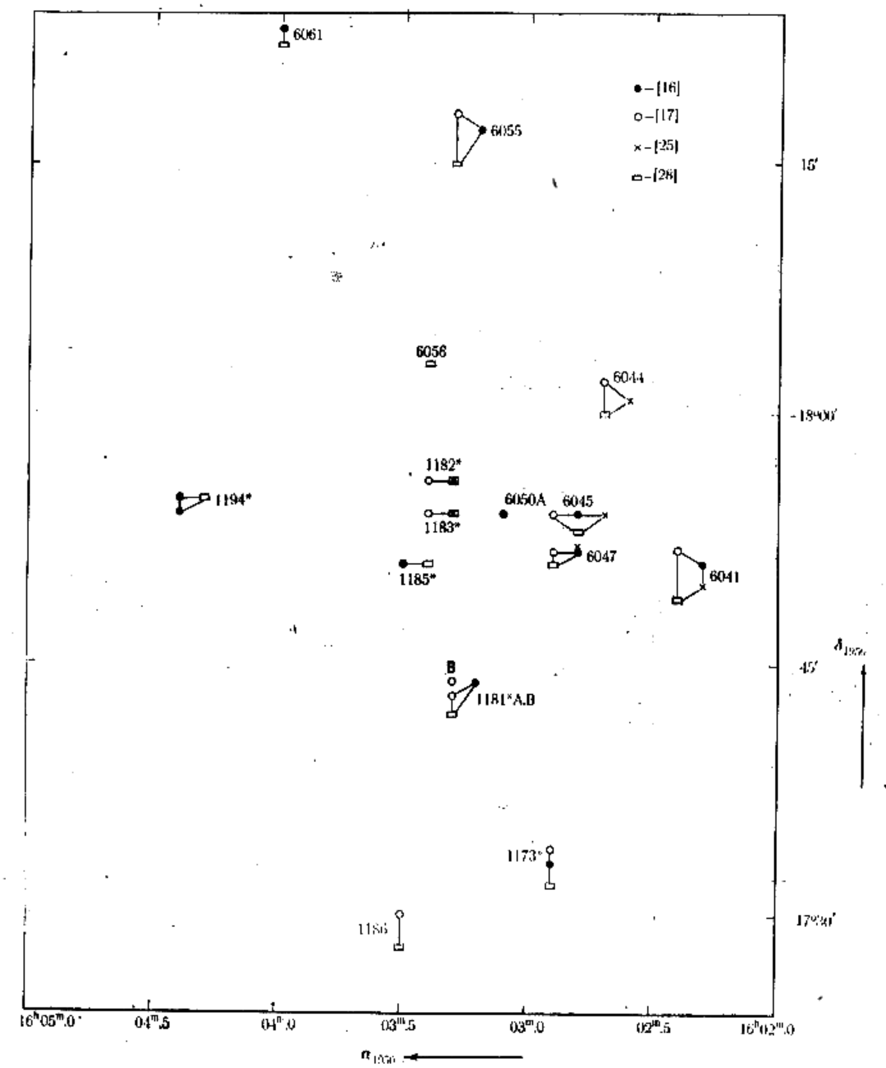


Fig. 1

The averaged of the three determinations (8), (10) and (11) gives

$$\alpha_{1950}=16^{\rm h}03^{\rm m}13^{\rm s}, \qquad (13)$$
$$\delta_{1950}=+17°57'12''.$$

A new determination of the Hercules cluster center was made on the basis of the counts of galaxies on print No. 83 of the Palomar Observatory Sky Survey [26], when in the field (5) the counting was repeated (at 1'.5×1'.5 squares). The treated cross-section or profiles (like these in [27]) allow the determination of a new cluster center

$$\alpha_{1950} = 16^h03^m.29 \qquad (14)$$

$$\delta_{1950} = +17°58'20''.$$

Radial velocities. Only two main sources for the radial velocities in the Hercules cluster of galaxies are published — the Catalogue HMS [28] and [10]. The radial velocities are measured for 16 galaxies, two of which form a double system.

The radial velocity data, together with the magnitudes from [17] are given on Table 1, which needs the following comments.

All velocities are corrected for solar motion (relative to the Local Group of galaxies) as in [28].

The velocity of the galaxies NGC 6045 is determined in [10] and [28], 10 058 and 9 943 km. sec.$^{-1}$, respectively. In [10] a mean velocity of 10 001 km. sec.$^{-1}$ is given, but in [25] the velocity is 10 034 km sec.$^{-1}$. The last value is adopted in the present paper.

The galaxy NGC 6041 also is listed in [10] and [28], 10 530 and 10 592 km sec^{-1} (in [10] is adopted the velocity 10 561 km sec^{-1}). We adopted V=10 578 km sec^{-1} according to [25].

For NGC 6047, IC 1181 A and B, IC 1173, IC 1186 and IC 1194 the differences between [10] and [25] are of 1 km sec^{-1} and for NGC 6061 they are 2 km sec^{-1}. The largest difference is between the velocities for NGC 6055. According to [10] the velocity is 11 314 km sec^{-1}, while according to [25] it is 11 487 km sec^{-1}. Since the authors of the Catalogue [25] have made a detailed analysis of the probable and systematic errors in the determination of the radial velocities and besides they have taken into consideration new observations it may be considered that the above mentioned Gatalogue is a homogeneous one. That is why a preference is given for the velocities in [25].

The velocity of IC 1182 is missing in [10] and [28], but it is included in [25].

Table 1

Galaxy	V, km sec^{-1}	m	Galaxy	V, km sec^{-1}	m
NGC 6047	9 592	$15^m.4$	IC 1181B	10 812	$15^m.4$
NGC 6045	10 034	14.8	IC 1173	10 962	15.6
NGC 6044	10 059	15.3	IC 1186	11 134	15.4
IC 1183	10 161	15.6	NGC 6050A	11 179	15.0
IC 1182	10 368	15.2	NGC 6061	11 294	15.0
IC 1181A	10 446	15.3	NGC 6055	11 487	15.4
IC 1185	10 575	15.1	IC 1194	11 766	15.5
NGC 6041	10 578	15.0	NGC 6056	11 781	—

All galaxies on Table 1 must be contained in [16] and in [17]. But in some cases the identification is quite uncertain, as it may be seen on

Fig. 1 — the differences among the positions of the galaxies according to the published catalogues are very large.

In order to make certain the identification at least of those galaxies with known radial velocites, an enlarged copy of the Hercules cluster from

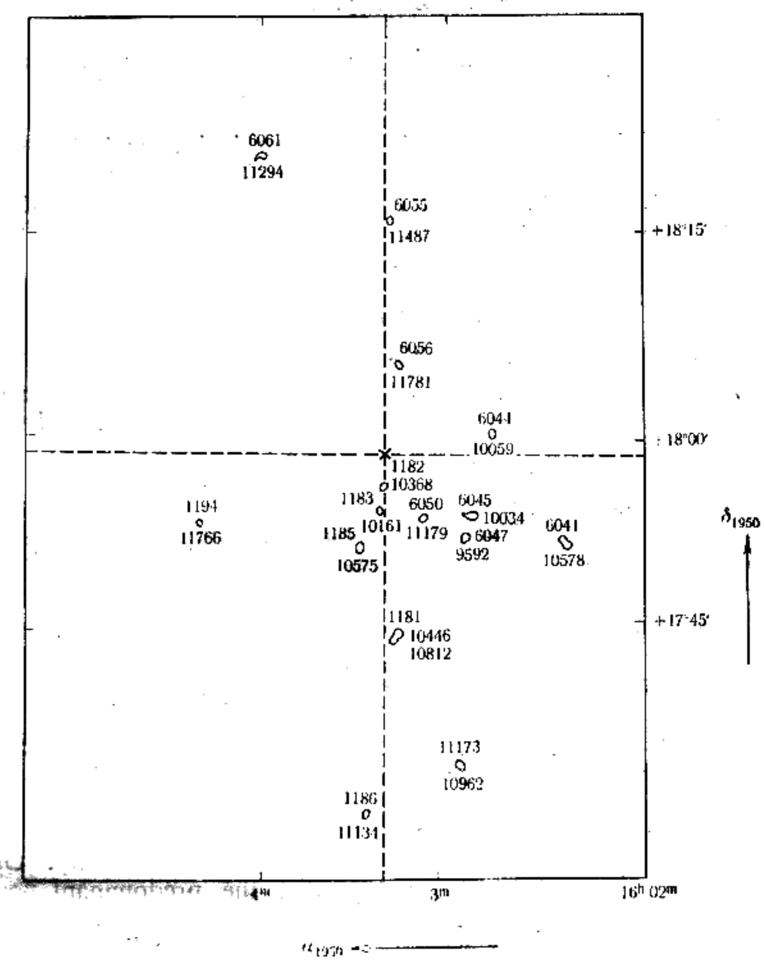


Fig. 2

the Palomar print was prepared. This copy was used together with the Figures in [10].

Out of all galaxies in Table 1 only the galaxies NGC 6047, 6045, 6061, 6055 and IC 1185, 1173, 1194 and 1182 are identified in [17].

NGC 6044 must be IC 1172 in [17] with $m=15^m.3$. IC 1188 according to Zwicky is given by Vorontsov-Velyaminov [16] with $m=15^m.6$. In this case an erroneous identification in [17] is evident.

The double system IC 1181 A and B is double in [17], as in [16], but one of the components is denoted as IC 1178. In [17] one gives the total magnitude, so that one may accept $m=15^m.3$ for IC 1181 A and $m=15^m.4$ for IC 1181 B.

In [17] for NGC 6041 is given the total magnitude with IC 1170.

IC 1186 is not identified by Zwicky. The identification made by Vorontsov-Velyaminov is accepted.

In [17] NGC 6050 A is marked simply as NGC 6050 — a double spiral and the total magnitude with IC 1179 is given. In all probability IC 1179= NGC 6054.

The galaxy NGC 6056 is not listed either in [17] and [16], or in [29].

NGC or IC numbers of the identified galaxies together with their velocities from Table 1 are plotted on Fig. 2, where the positions of the galaxies are obtained on a copy of the Palomar Atlas Sky Survey (without using the data from any catalogues).

DETERMINATION OF THE ROTATION

Let us assume that the Hercules cluster of galaxies is rotating around an axis which is located perpendicularly to the line of sight. Then with respect to the cluster center the distribution of the mean radial velocities of the galaxies in sectors [21, 22] will not be accidental. The sector radial velocity distribution will have a maximum in this sector, corresponding to a moving away from the observer and a minimum in this sector, corresponding to an approachment. The average radial velocity of the galaxies situated in sectors coinciding with the rotation axis must be equal to that of the ctuster recession. The distribution of the average sector velocities may be expressed with $\bar{V}=\bar{V}_0+\Delta V\cos\alpha$ where $\bar{V}_0=(V_{max}+V_{min})/2$ is the average cluster recession velocity, $\Delta V=V_{max}-\bar{V}_0=\bar{V}_0-V_{min}$ and α is the angle measured from the equator of the cluster with a plane perpendicular to the line of sight.

Consequently, this case may be examined not only when the angle between the equatorial plane of the cluster and the line of sight is $i=0$ but for $0°<i<45°$, depending on the velocity dispersion. Besides the requirement the observed radial velocities must be related to the galaxies, their uniformly distribution over the whole cluster field is necessary. Otherwise the rotation may be established roughly, and the predominant position of the observed galaxies may influence the average recession velocity to such an extent that the latter may become non-representable.

In the particular case when the rotation axis is parallel to the line of sight, it is impossible to establish the rotation without using some other method.

Let us use only the breaking up of 30° sectors, since the number of objects (16) do not allow smaller sectors. In fact smaller sectors require an additional smoothing, which may provoke disagreeable effects.

Let the numbers of the sectors (1—12) around the adopted center increase in clockwise direction — NWSE.

Let us use Fig. 1, and while attaching the galaxies to various sectors, let us give [17] and [16] larger weights. Naturally, because of the smaller number of the objects, a smoothing by the running arithmetic mean by 3, 6 and 9 sectors is required.

(In all cases only the weighted arithmetic velocities are used.) The formation of running arithmetic means of 9 sectors (or 270°) is risky, since the range around the mean velocity decreases and, when there is nonhomogeneity in the galaxy distribution in sectors, it moves the maxima sectors and the minima ones.

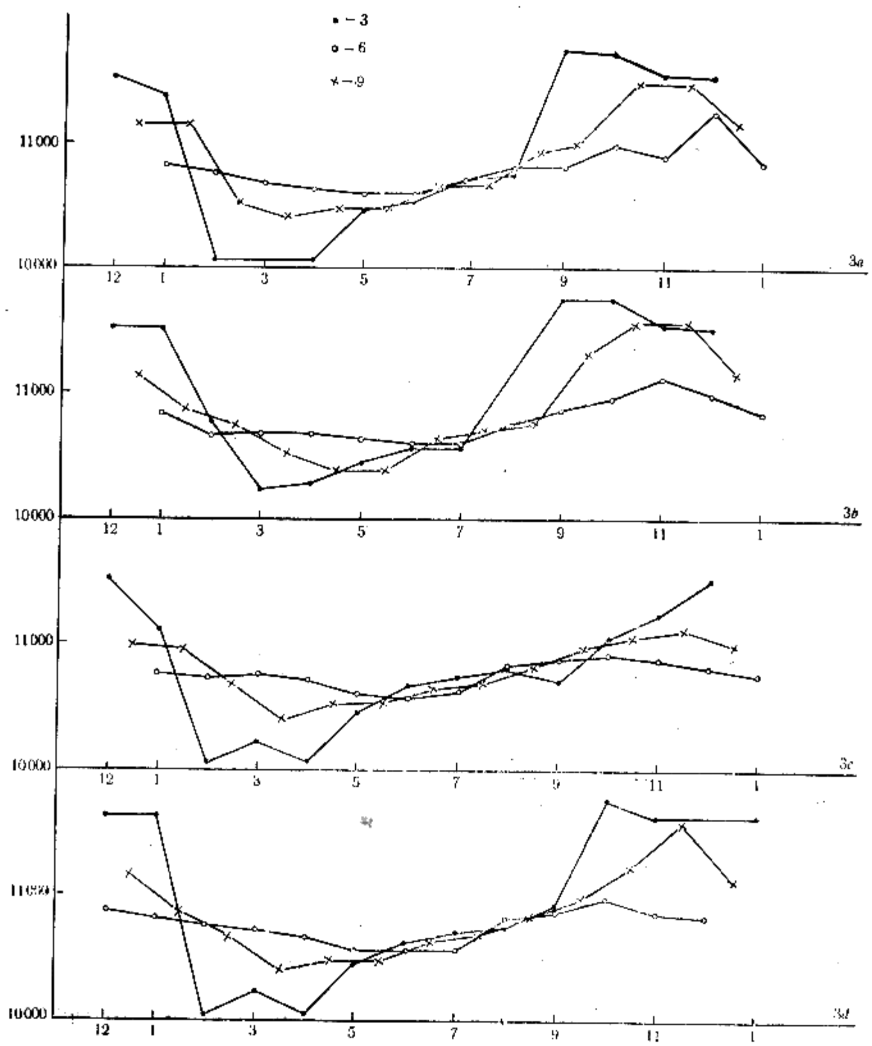


Fig. 3

The separate results are:

1. Center (10) — Fig. 3a. All three curves indicate a rotation. The position of the equatorial plan of the 3- and 6-sector running corresponds roughly to the sectors No. 4. and No. 10, i. e. the rotational axis has a

positional angle of $P=330°$ (in the opposite direction — NESW; as a positional angle).

2. Center (11) — Fig. 3b. According to the 6-sector running $P \approx 315°$.

3. Center (8) — Fig. 3c. $P \approx 300°$.

4. Average centre (13) — Fig. 3d. The rotational effect is very well expressed, but the determination of the axis position is uncertain.

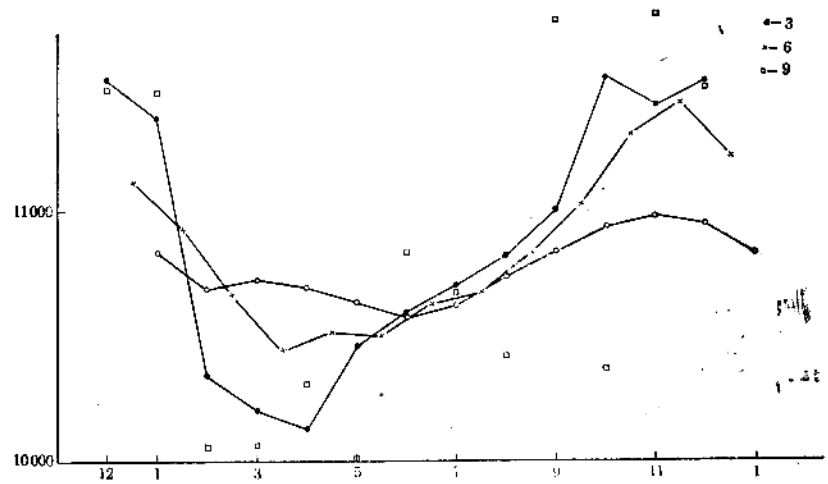


Fig. 4

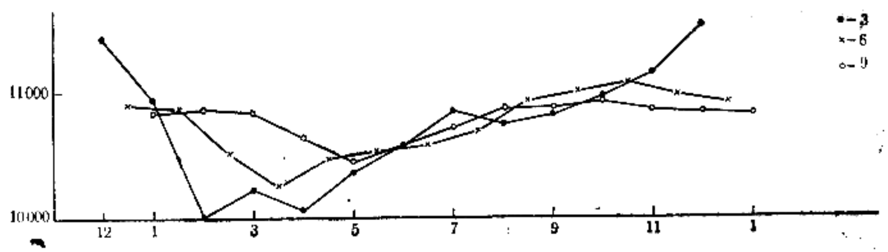


Fig. 5

5. An analogous result may be derived by the consistent averaging of the first three cases — Fig. 4 and then $P \approx 315°$.

6. Center from [20] — Fig. 5. An approximate determination of the axis position gives $315° < P < 345°$.

The results up to here are in favour of the affirmation that the Hercules cluster of galaxies is rotating around an axis, but the position of the axis may be only roughly determined. It is clear that the possible causes for the rough position of the rotation axis are two — the approximate galaxy co-ordinates and rough cluster center co-ordinates. That is why let us use Fig. 2.

7. Center (14) — Fig. 6. Sectors are plotted on a copy of the Palomar Sky Survey print. Evidently, optical defects cannot influence the galaxy co-ordinate from Fig. 2 with an error larger than 1′ (the accuracy of the published catalogues). The joint examination of the extremes and null points

(with respect to the mean velocity) allow the determination of the positional axis angle $P \approx 300°$. Consequently, the equatorial plane passes over the sectors No. 5—6 and. No. 11—12.

The fact, that determination 7. is in accordance with all determinations 1.—6. shows that for the study of the Hercules cluster rotation, the accurate position of the center is of no importance.

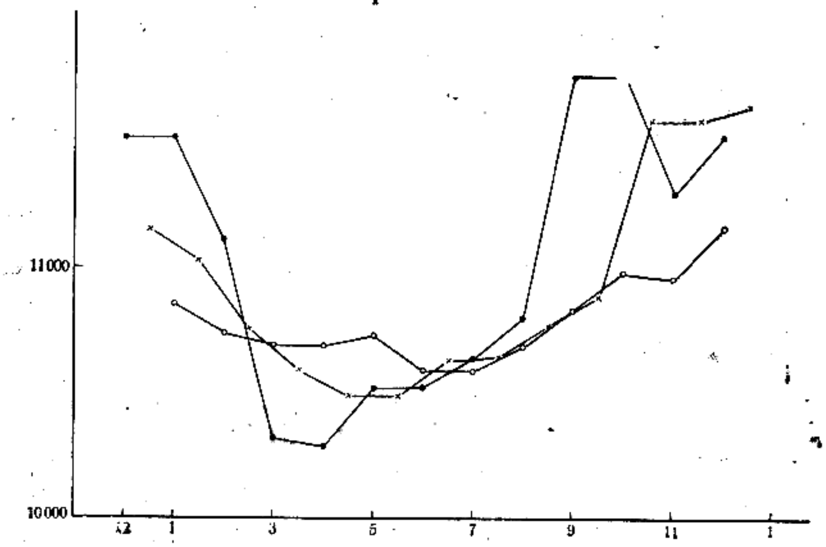


Fig. 6

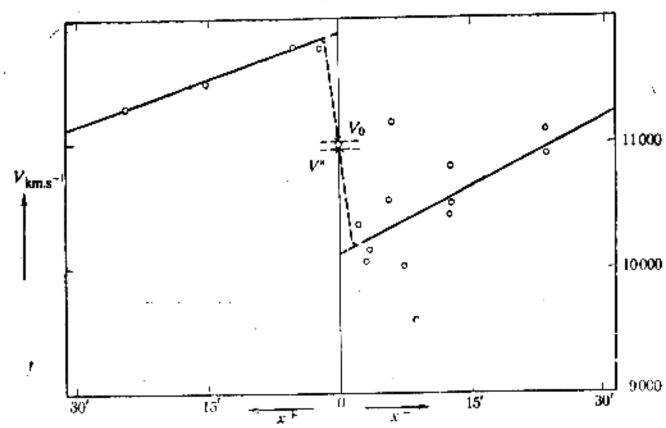


Fig. 7

The above mentioned considerations show that while in the range of $V_{max} > \bar{V}_0$ (sectors No. 9—2) 12 radial velocities are determined and therefore the mean velocity of recession of the Hercules cluster of galaxies $\bar{V}_0 = \frac{1}{n} \sum_n V_i = 10\,764$ km sec^{-1} is not representable, and the determined distance has to bɜ corrected.

An attempt may be made on the basis of the positional angle of the rotational axis ($P=300°$) for at least a rough determination of the rotational law of the Hercules cluster.

The rotational axis is marked on Fig. 2 as p_1p_2. Let k_1k_2 (Fig. 2) be the projection of the equatorial plane on the celestial sphere on the assumption that $i=0$.

Let us project the positions of galaxies with known radial velocities on k_1k_2 and let us construct Fig. 7, on which the mean radial velocity $\bar{V}_0$ is noted. As it may be expected, on the left side (NE) galaxies with large radial velocities (NGC 6061, 6065, 6056 and IC 1194) are located and on the right side (SW) — those with smaller radial velocities. Only two galaxies are deviating from the supposed rotational curve (NGC 6047 and 6050A).

Obviously, in the near vicinity of the cluster center, the observed radial velocities are changing proportionally to the distance to the center. As far as the direction to the cluster center is between the galaxies IC 1194 and IC 1182, it must be expected that the central part of the cluster should be rotating as a solid body — with angular velocity $\omega=\text{const}$. The extreme points of the rotational curve must be located (Fig. 7) around IC 1194 on the hand, and IC 1182, NGC 6044 and IC 1183 on the other. Although known radial velocities in this interval are not available, the position of $\bar{V}_0$ gives grounds to admit a rotation of a solid body.

Fig. 7 shows that there is a complete analogy with the rotation of galaxies — for instance [30—35], in which the investigations of the velocity dispersion are not smaller than the dispersion in the examined case.

The positions of the galaxies NGC 6061, 6065, 6056 and IC 1194 in the plane xV (Fig. 7) permit the determination of a linear relation between x — the distance from the rotational axis in minutes of arc and V — in km sec^{-1}, after the least-mean squares method

(15) $$V^+=11\,859.8-23.15\,x^+$$

for $x^+>1'\div3'$.

All remaining galaxies present an analogous relation

(16) $$V^-=10\,127.9+36.03\,x^-$$

for $x^->1'\div3'$.

The average velocity of the cluster recession may be determined as $[V^+(x^+=0)+V^-(x^-=0)]/2=10\,993.9$ km sec^{-1}. The last value is roughly corrected for the non-homogeneity in the distribution of the galaxies with known radial velocities. On the other hand the average velocity of recession may be obtained as an arithmetic mean (grouped) of the mean velocities of the two groups (NGC 6056 and IC 1194) and (IC 1182, NGC 6044, IC 1183 and IC 1185) which are symmetrically located around the axis p_1p_2. Thus $V_{gr}=11\,032.1$ km sec^{-1}.

Let us assume the latter value ($V_{gr}=11\,032$ km sec^{-1} with a probable error of ±10 km sec^{-1}) as a representable one. This velocity differs considerably from the adopted one in [10] $V=10\,775$ km sec^{-1} and from that given in [28] $V=10\,400$ km sec^{-1}.

As it is known, the Hubble constant H is not determined at present. Usually one accepts [36—41] that

$50 \text{ km sec}^{-1} \text{ Mpc}^{-1} < H < 150 \text{ km sec}^{-1} \text{ Mpc}^{-1}$.

Recently Sandage [42] drew the conclusion that the more probable value of H is $H=75.3^{+19}_{-15}$ km sec^{-1} Mpc^{-1} (this value is in agreement with some of the previous results), and it is possible to decrease this value up to $H_2=55^{+14}_{-11}$ km sec^{-1} Mpc.$^{-1}$ Consequently with these constants, the distance to the Hercules cluster of galaxies will be $R_1=146.5$ Mpc and $R_2=200.6$ Mpc respectively and the following two distance moduli may be derived

$$m-M_1=35^m.83$$

$$m-M_2=36^m.51.$$

Thus a galaxy with $m=15^m.0$ will have $M_1=-20^m.83$ and $M_2=-21^m.51$. One has to admit, that the second modulus gives an extremely large luminosity.

Note. In the present paper no corrections are made in the determinations of the galaxy magnitudes. The most important corrections are due to 1. the K-effect, 2. the galactic absorption and 3. the metagalactic absorption.

1. From the adduced Tables for various types of galaxies in [28] it becomes obvious, that the K-correction changes linearly for small red shifts and for $z=0.03$ we have $K=0^m.15$. This value is in agreement with [11]. $K=0^m.155$ for $V=10\,000$ km sec^{-1}. The range of the radial velocities in the Hercules cluster of galaxies is about 2.10^3 km sec^{-1} and therefore the differential K-effect is negligible.

2. The correction determination for the galactic absorption cannot be certain, because of the fact that various values are obtained for the galactic polar obscuration — from $0^m.25$ up to $0^m.50$ [5, 44—46]. If we adopt the recent values, then the obscuration should be $0^m.50$ cosec$b$ and for the Hercules cluster of galaxies the mean galactic obscuration will be about $\Delta m=0^m.70$.

3. As far as the metagalactic obscuration is concerned up to now there are no acceptable values.

In the final reckoning, the first two corections change the absolute magnitudes of the brightest Hercules cluster galaxies, and thus we shall have $M_1=-21^m.7$ and $M_2=-22^m.4$.

As it may be seen on Fig. 7, the nucleus of the Hercules cluster of galaxies has an angular diameter of 2.10^5 pc (at a distance of R_1 1′ corresponds to a linear distance of 42.6×10^3 pc), and at R_2 — 58.4×10^3 pc. These quite small dimensions of the nucleus are really amazing, since in this cluster galaxies with angular dimensions of 1′ may be observed! Consequently, the Hercules cluster nucleus is strongly localized.

At a linear velocity of rotation $V_t=800$ km sec^{-1} (Fig. 7) at a distance of 2′ away from the axis, a period rotation of the cluster nucleus of about $T=7.7\times10^8$ years may be derived.

The diameter of the Hercules cluster along its equatorial plane is about 60′ and the corresponding dimensions at H_1 and H_2 are $D_{max1}=2.56$ Mpc and $D_{max2}=3.50$ Mpc respectively. At a distance of 30′ away from the cluster axis, the radial velocities are approaching the velocity of recession for the whole cluster.

The distance determination to the Hercules cluster of galaxies permits us to obtain the uncorrected alsolute magnitudes, as well as the linear dimensions of the cluster of galaxies — Table 2. The first column presents the co-ordinates according to Zwicky [17], the second one — the NGC or IC (with*) number, the third one — the corresponding Vorontsov-Velyaminov's [16] number — field 3—41. In the next columns are given the

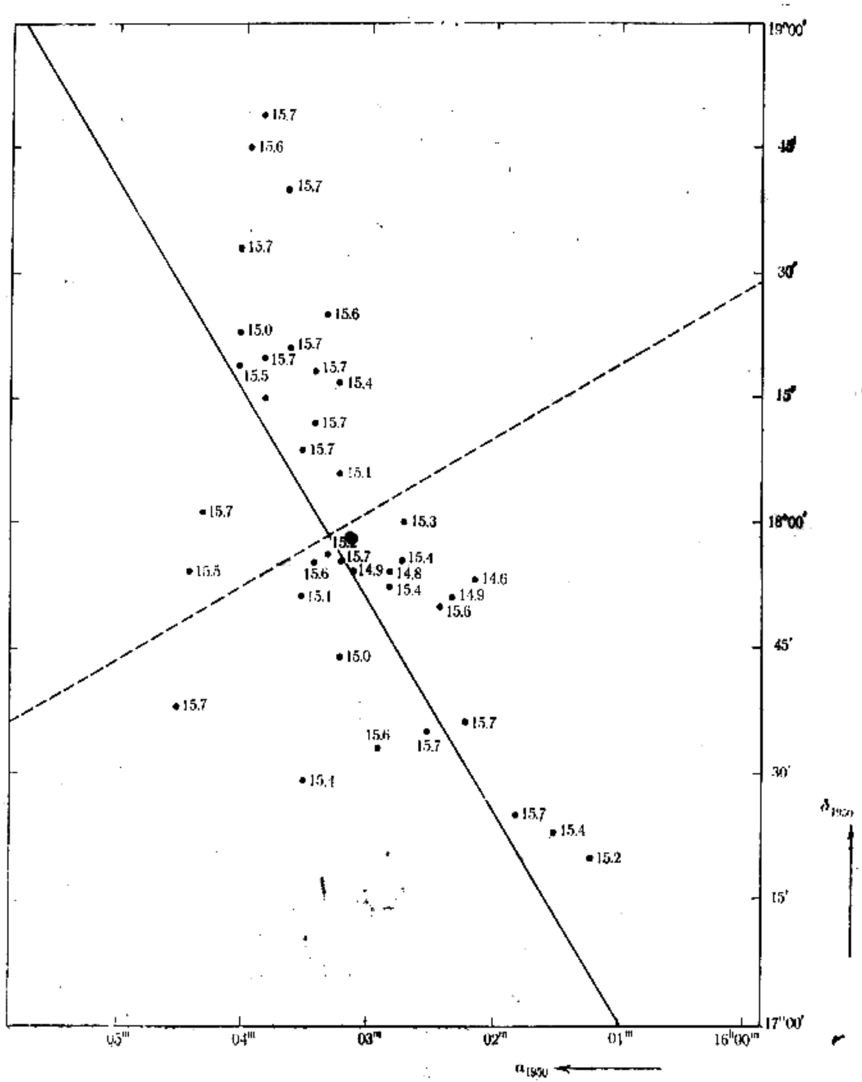
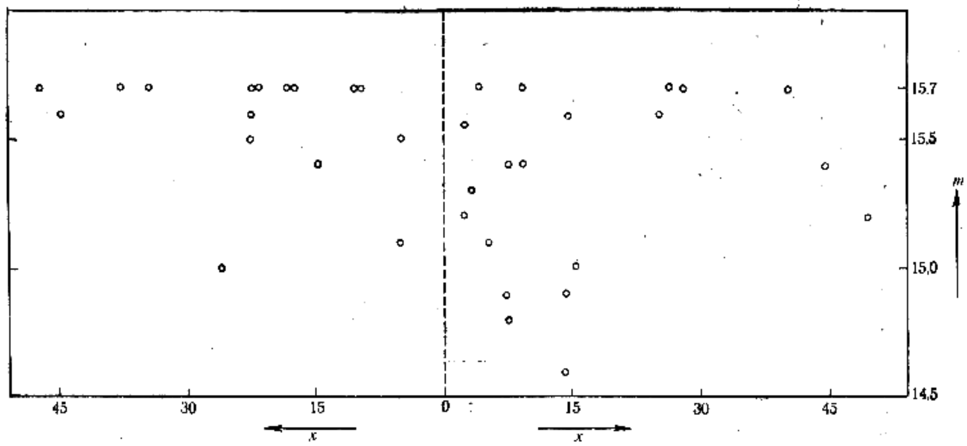
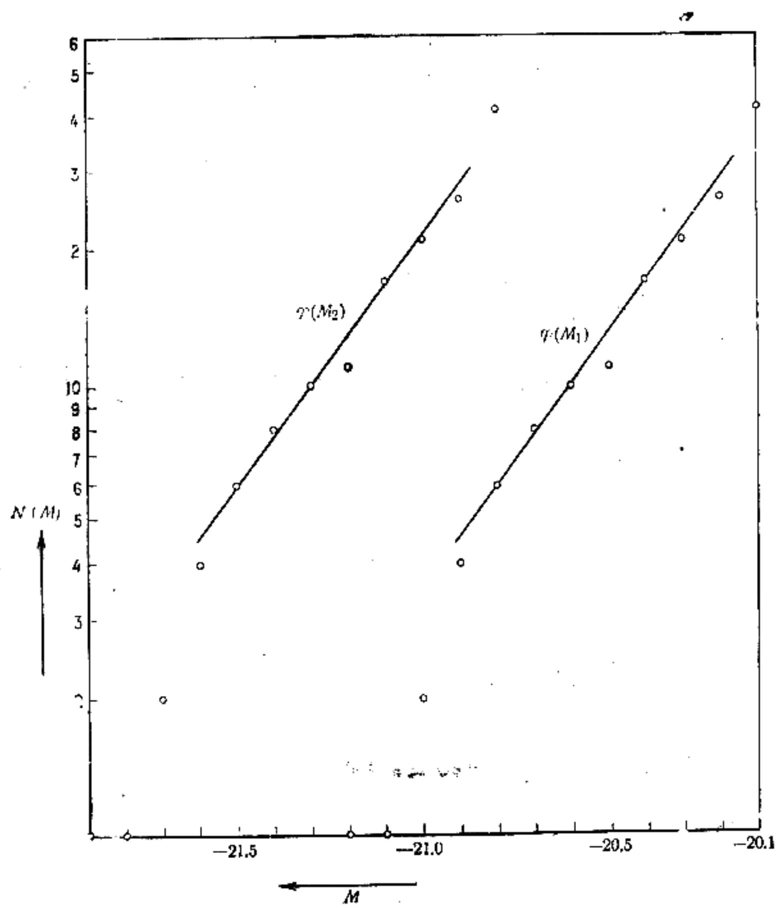


Fig. 8



45
30
15
0
15
30
45
x
x
15,7
15,5
15,0
14,5
m

Fig. 9



$\varphi(M_2)$
$\varphi(M_1)$
N (M)
−21,5
−21,0
−20,5
−20,1
M

Fig. 10

Table 2

α_{1950}	δ_{1950}	NGC ; IC*	№	m	M_1	M_2	$d_1^1 \times d_2^1 \times 10^3$ pc	$D_1^1 \times D_2^1 \times 10^3$ pc	$d_1^2 \times d_2^2 \times 10^3$ pc	$D_1^2 \times D_2^2 \times 10^3$ pc	Notes
1	2	3	4	5	6	7	8	9	10	11	12
$16^h01^m.2$	+17°20′	6034	62	$15^m.2$	$-20^m.6$	$-21^m.3$	12.8×10.7	42.6×42.6	17.5×14.6	58.3×58.3	
16 01.5	+17 23		63	15.4	−20.4	−21.1	12.8× 6.4	29.8×14.9	17.5× 8.8	40.8×20.4	
16 01.8	+17 25		67	15.7	−20.1	−20.8	8.5× 8.5	17.0×17.0	11.7×11.7	23.3×23.3	1
16 02.1	+17 53	6040 ; 6039—40	73	14.6	−21.2?	−21.9?	8.5× 8.5	25.6×25.6	11.7×11.7	35.0×35.0	2
16 02.2	+17 52	=1710*	74				25.6× 8.5	51.1×25.6	35.0×11.7	70.0×35.0	
16 02.2	+17 36		72	15.7	−20.1	−20.8	17.0× 6.4	25.6×17.0	23.3× 8.8	35.0×23.3	
16 02.3	+17 51	6041+1170* ; 6041	78	14.9	−20.9	−21.6	12.8×12.8	51.1×51.1	17.5×17.5	70.0×70.0	3
16 02.4	+17 50	6042	79	15.6	−20.2	−20.9	10.7×10.7	25.6×25.6	14.6×14.6	35.0×35.0	4
16 02.5	+17 35		80	15.7	−20.1	−20.8	12.8× 9.8	29.8×19.2	17.5×13.4	40.8×26.3	
16 02.7	+17 55	6043	86	15.4	−20.4	−21.1		17.0× 8.5		23.3×11.7	5
16 02.7	+18 00	1172* ; 6044 ?		15.3	−20.5	−21.2					x
16 02.7	+18 02	6044	84	15.5	−20.3	−21.0		17.0×17.0		23.3×23.3	6
16 02.8	+17 52	6047	87	15.4	−20.4	−21.1	12.8×12.8	38.4×38.4	17.5×17.5	52.5×52.5	
16 02.8	+17 54	6045	88	14.8	−21.0	−21.7	21.3× 6.4	51.1× 8.5	29.2× 8.8	70.0×11.7	7
16 02.9	+17 33	1173*	89	15.6	−20.2	−20.9	12.8× 6.4	42.6×21.3	17.5× 8.8	58.3×29.2	
16 03.1	+17 54	6050+1179* ; 6050	92	14.9	−20.9?	−21.6?	14.9×10.7	34.1×21.3	20.4×14.6	46.7×29.2	8
16 03.15	+17 54	6050	93				8.5× 8.5	21.3×17.0	11.7×11.7	29.2×23.3	9
16 03.2	+17 44	1178*+1181*+1178*	97	15.0	−20.8?	−21.5?	10.7×10.7	29.8×29.8	14.6×14.6	40.8×40.8	10
16 03.3	+17 43	1181*	98				6.4× 6.4	25.6×25.6	8.8× 8.8	35.0×35.0	x
16 03.2	+17 55	6054 ; 6054=1179*	99	15.7	−20.1	−20.8	12.8× 6.4	32.0×19.2	17.5× 8.8	43.8×26.3	x
16 03.2	+18 03		96	15.5	−20.3	−21.0	17.0× 8.5	29.8× 8.5	23.3×11.7	40.8×11.7	11
16 03.2	+18 06	1176*	100	15.1	−20.7	−21.4	17.0× 8.5	34.1×17.0	23.3×11.7	46.7×23.3	
16 03.2	+18 17	6055	101	15.4	−20.4	−21.1	17.0×17.0	51.1×51.1	23.3×23.3	70.0×70.0	12
16 03.3	+17 56	1182*	104	15.2	−20.6	−21.3	10.7×10.7	21.3×21.3	14.6×14.6	29.2×29.2	13
16 03.3	+18 25		107	15.6	−20.2	−20.9	12.8× 8.5	21.3×17.0	17.5×11.7	29.2×23.3	
16 03.4	+17 55	1184* ; 1183*	103	15.6	−20.2	−20.9	8.5× 8.5	19.2×19.2	11.7×11.7	26.3×26.3	x
16 03.4	+18 03	6056									14
16 03.4	+18 12		105	15.7	−20.1	−20.8	8.5× 8.5	19.2× 8.5	11.7×11.7	26.3×11.7	
16 03.4	+18 18	6057	106	15.7	−20.1	−20.8	8.5× 8.5	21.3×21.3	11.7×11.7	29.2×29.2	15
16 03.5	+17 29	1186*	111	15.4	−20.4	−21.1	21.3×17.0	29.8×19.2	29.2×23.3	40.8×26.3	16
16 03.5	+17 51	1185*	110	15.1	−20.7	−21.4	17.0×12.8		23.3×17.5		
16 03.5	+18 09		112	15.7	−20.1	−20.8	12.8×10.7	21.3×19.2	17.5×14.6	29.2×26.3	17
16 03.6	+18 21		113	15.7	−20.1	−20.8	19.2× 6.4	51.1×17.0	26.4× 8.8	70.0×23.3	
16 03.6	+18 40			15.7	−20.1	−20.8					18

1	2	3	4	5	6	7	8	9	10	11	12
16 03.8	+18 15		114	15.7	−20.1	−20.8		17.0×17.0		23.3×23.3	19
16 03.8	+18 20		115	15.7	−20.1	−20.8	29.6×17.0	46.9×17.0	35.0×23.3	64.2×23.3	
16 03.8	+18 49		116	15.7	−20.1	−20.8	12.8× 4.3	25.6×12.8	17.5× 5.8	35.0×17.5	20
16 03.9	+18 45		117	15.6	−20.2	−20.9	8.5× 8.5	17.0×17.0	11.7×11.7	23.3×23.3	21
16 04.0	+18 19	1189*	119	15.5	−20.3	−21.0	6.4× 6.4	21.3×12.8	8.8× 8.8	29.2×17.5	
16 04.0	+18 23	6061	118	15.0	−20.8	−21.5	17.0×12.8	42.6×34.1	23.3×17.5	58.3×46.7	22
16 04.0	+18 33		120	15.7	−20.1	−20.8	12.8× 8.5	27.7×19.2	17.5×11.7	37.9×26.3	
16 04.3	+18 01			15.7	−20.1	−20.8					
16 04.4	+17 19	1195*	126	15.4	−20.4	−21.1		21.3×14.9		29.2×20.4	23
16 04.4	+17 54	1194*	128	15.5	−20.3	−21.0	10.7×10.7	17.0×17.0	14.6×14.6	23.3×23.3	
16 04.5	+17 38			15.7	−20.1	−20.8					

Notes to Table 2

x — cf. the text about the identification of the galaxies with known r dial velocities.
1. Compact system (Z.)
2. Double system (Z.). Interacting system (in contact with No. 74 —V—V).
3. x. Triple system (Z). Doubt for interaction (V—V), galaxy with a halo.
4. Compact system (Z).
5. x. Interacting double system (V—V).
6. m according to (V—V).
7. Double or triple system (V—V).
8. Together with No. 93 in contact (V—V). Double spirals in contact (Z).
9. x. In contact with No. 93.
10. x. Double system (Z).
11. m according to V—V.
12. NGC 6055 or NGC 6053 ? (Vaub.). Double ? (V—V).
13. x. Double system with jet (Z). Evidently, IC 1182—1184 is investigated by the Ambartsumian-Shachbazian system. but in [10] is erroneously identified as IC 1181. The connection between IC 1182 and IC 1184 is missing according to Z. Interacting (Triple ?) system (V—V).
14. Co-ordinates according to Vauc., without any other data. Non-identified by Z. and V—V.
15. Compact (Z) and possible double system (V—V).
16. The co-ordinates are according to V—V.
17. Possible double system (V—V).
18. Very compact (Z.).
19. Diffuse (Z.).
20. Possible double system (V—V).
21. Very compact (Z).
22. Possible double system (V—V).
23. Compact system (V—V).

absolute magnitudes for H_1 and H_2. They are followed by the dimensions of the nuclei and the outer parts of the galaxies for both H_1 and H_2. For their calculations one uses exclusively the angular diameters derived by Vorontsov-Velyaminov [16].

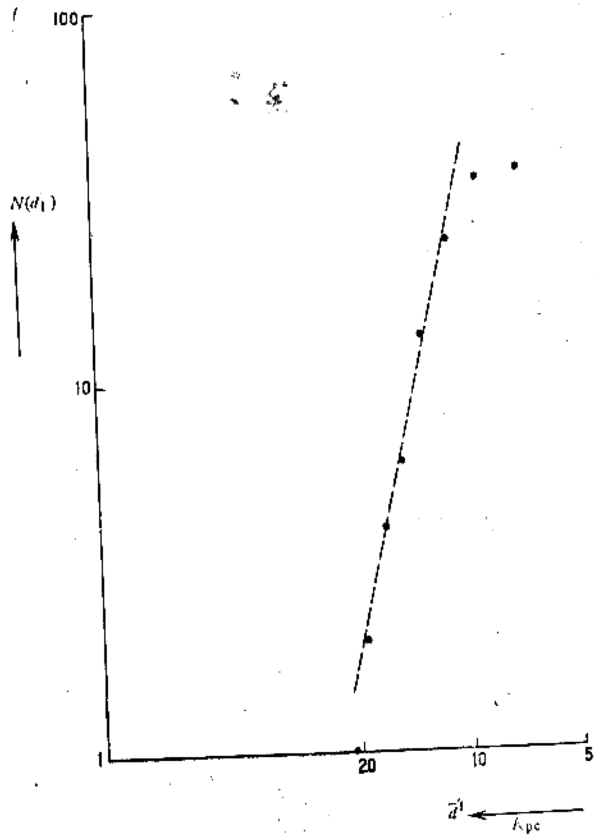


Fig. 11

Fig. 8 presents the galaxy positions together with the corresponding apparent magnitudes from Table 2. When projected on the axis k_1k_2 a distribution of magnitudes along the distance on the axis may be obtained — Fig. 9 — which shows a small correlation of m from x.

The mean absolute magnitudes of all galaxies on Table 2 are $\bar{M}_1 = -20^m.36$ and $\bar{M}_2 = -21^m.06$ with mean square errors (equal) $\pm 0^m.046$.

The non-normalized absolute luminosity functions for the galaxies on Table 2 are given on Fig. 10 — $\varphi(M_1)$ and $\varphi(M_2)$. Only a rough normalization may be made, since it is not clear to which zone of the celestial sphere the galaxies should be related — in other words, the cluster field is unknown. Let us note that the normalization shifts linearly along the lg $N(M)$ the non-normalized functions. The highest point of $\varphi(M)$ shows that Zwicky's Catalogue is non-homogeneous for the limiting magnitude (at least for the examined field). The above mentioned catalogue presents the galaxies with $m < 15^m.7$ (if based on $\varphi(M)$, the error in the limiting magnitudes is of the order of $0^m.1 \div 0^m.2$, which is in agreement with [24]). The initial points of $\varphi(M)$ are uncertain, since the influence of the double galaxies (No. No. 73—74, 92—93 and 97—98 according to Vorontsov-Velyaminov) is considerable.

After a definition, in an obvious static Euclidean Universe, the diameter function of the galaxies $N(d)$ is given with

(17) $$N(d) = 4\pi \int_0^\infty \varphi(D) r^2 dr$$

where $N(d)$ is the number of galaxies with angular diameters larger than a given d, and $\varphi(D)$ is the number of galaxies in an unit volume, with linear diameters, larger than D. With the transformation $r = \frac{D}{d}$ we obtain

(18) $$N(d) = 4\pi d^{-3} \int_0^\infty \varphi(D) D^2 dD = N_1 d^{-3}$$

where N_1 is the number of galaxies on the celestial sphere with angular diameters larger than 1 radian.

Table 2 gives some reasons to draw certain conclusions about $\varphi(D)$ or about $N(d)$, although a normalization cannot be made.

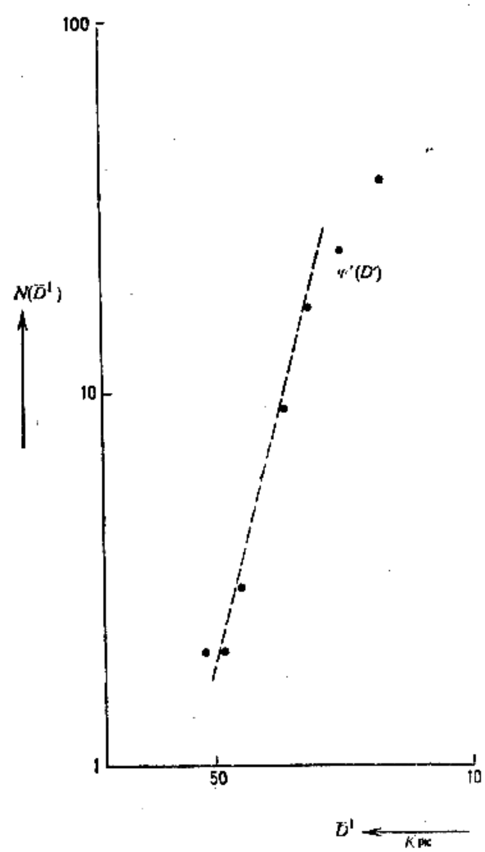


Fig. 12

Let us use the average dimensions of the nuclei and galaxies, determined only for R_1 (the results for R_2 are analogical). For the average dimensions we have $\bar{d}' = \frac{d'_1 + d'_2}{2}$ and $\bar{D}' = \frac{D'_1 + D'_2}{2}$, where d_1 and d_2 are the diameters of the nuclei, and D_1 and D_2 those of the galaxies, calculated from Table 2. The functions $N(d')$ and $N(D')$ are plotted on Fig. 11 and Fig. 12, respectively. It is obvious that the slope of these functions is larger, than the required one (18). Moreover, the two functions are not very different in range, which shows that the nucleus diameter function may be used effectively (since the outer galaxy diameters cannot be derived more accurately).

At the distance R_1 to the Hercules cluster of galaxies, the average nucleus diameter is $d' = 11.5 \times 10^3$ pc and the average outer diameter is

$D' = 25.5 \times 10^3$ pc. Respectively for R_2 we have $d^2 = 15.8 \times 10^3$ pc and $D^2 = 34.9 \times 10^3$ pc.

Between the average nuclei and the galaxy diameters, on the one hand, and the absolute magnitudes, on the other, there is a certain statistical relation —

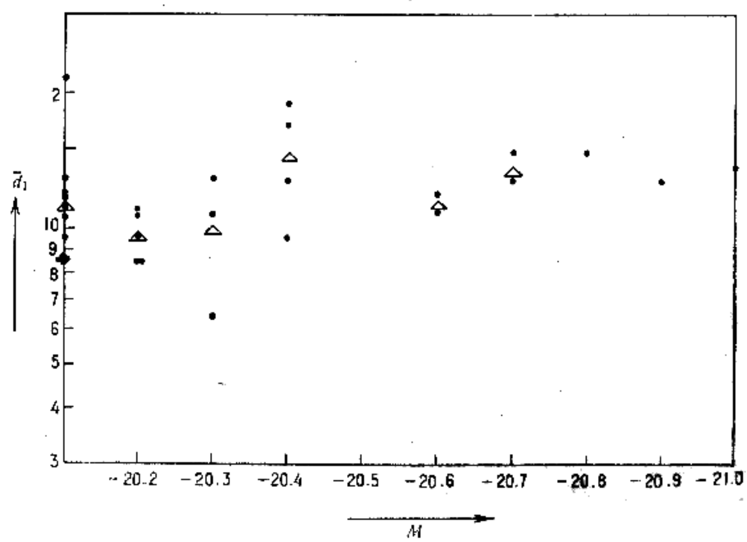


Fig. 13

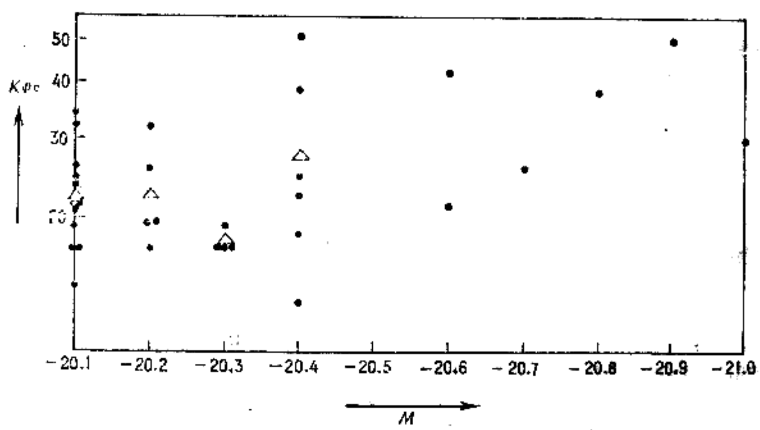


Fig. 14

Fig. 13 and Fig. 14, for R_1. The average diameters for the given absolute magnitudes are plotted (with Δ) on the latter Figures.

Our previous paper [47] pointed out that in the Coma cluster of galaxies the flattenings of the nuclei are larger than those of the galaxies and besides these flattenings decrease with the distance to the cluster center.

Let us mark with ε_n and ε_s the flattening of the nuclei and of the galaxies, which for the field (5) can be calculated directly from the Catalogue [16]. From all cluster objects $\varepsilon_n = 0.763$ and $\varepsilon_s = 0.745$. In a circle with a radius of 22′:5 around the cluster center (Fig. 8) the sphericities are $\varepsilon_n = 0.826 \pm 0.059$ and $\varepsilon_s = 0.849 \pm 0.060$ but outside the circle $\varepsilon_n = 0.682 \pm 0.059$ and $\varepsilon_s = 0.659 \pm 0.056$.

Therefore, the second peculiarity of the Coma cluster is valid also for

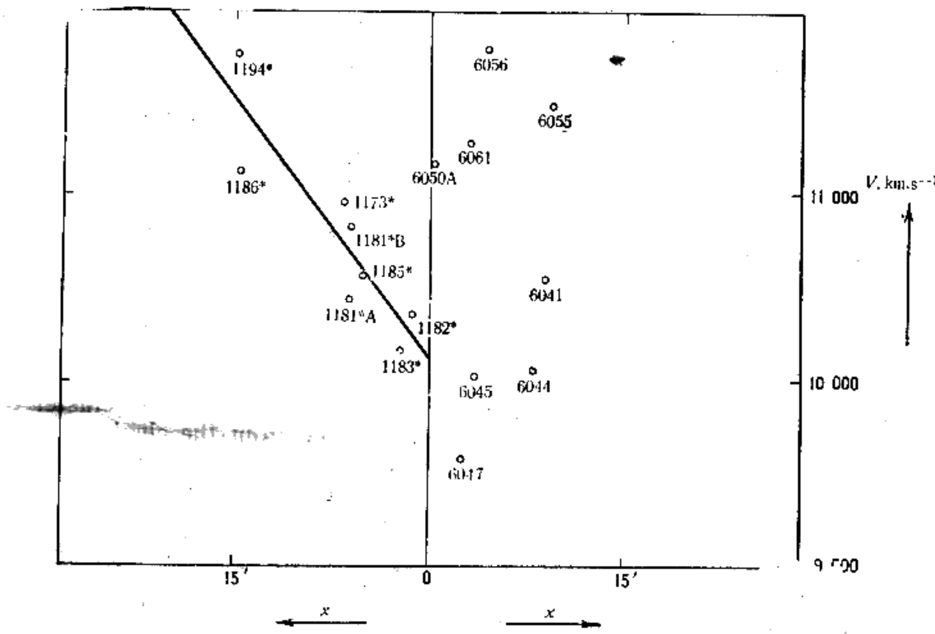


Fig. 15

the Hercules cluster of galaxies — in the cluster center more spheroidal galaxies predominate, than in the periphery.

According to [48] the square of the real sphericity for the Hercules cluster galaxies is 0.71. It leads to a real sphericity 0.84 — a value, which is considerably different from the above mentioned one. The difference may be explained as a result of the small sample, used in [48] — 10 galaxies only.

Let us repeat the determination of the real sphericities, following the method of Agekian and Soomsina [48]. 6 new values can be obtained for x-squares of real sphericities:

$$\text{for all galaxies} \begin{cases} \text{nuclei} & x_n = 0.373 \\ \text{galaxies} & x_s = 0.333 \end{cases}$$

$$\text{in the circle} \begin{cases} \text{nuclei} & x_n = 0.523 \\ \text{galaxies} & x_s = 0.581 \end{cases}$$

$$\text{outside the circle} \begin{cases} \text{nuclei} & x_n = 0.198 \\ \text{galaxies} & x_s = 0.151 \end{cases}$$

The cited in [48] value of the square of the real sphericity is 0.56 and it does not differ essentially only for the corresponding values within the circle. The disagreement with [48] can be explained with the considerable gradient in the radial change of the real sphericity. This conclusion is stronger than the one in [47].

Fig. 7 was obtained by a projection of the galaxy positions on k_1k_2. Let us now make an analogous operation, but let the projection be on the p_1p_2 — the rotational axis — Fig. 15. The distances from the equatorial plane (the rotational axis is supposed to be perpendicular to the line of sight) are plotted along the abscissa in minutes of the arc. If only rotational effects exist, then the points on Fig. 15 must be distributed randomly.

And indeed, as far as the right side is concerned, this obviously is fulfilled. But for the sectors No. 6 — No. 11, on the left side there is a well expressed linear relation for 8 galaxies located in this zone. The least-mean squares method gives for this relation

$$V=10\,123.9+91.20x \tag{19}$$

where x is in minutes of arc.

The relation (19) shows that the south part of the Hercules cluster of galaxies is expanding proportionally to the distance from the cluster center.

As it can easily be derived up to the angular distance of 15′ from the cluster center, the expansion is done according to the law $V_s=hx$, where h is a constant like the Hubble one and has a rough value of $h=1820$ km sec^{-1} . Mpc^{-1}.

The relation $V_s=hx$ shows that the Hercules cluster of galaxies is a non-stationary one. As far as the second condensation in Hercules is located to the south of the Hercules cluster of galaxies, one may assume a development of a gravitational non-stability with a characteristic time of the order of

$$T=\frac{1}{h}\approx 5.4\times 10^8 \text{ years,} \tag{20}$$

i. e. of the order of one rotation of the cluster nucleus.

Table 3

Galaxy	V_{cor}	Galaxy	V_{cor}
IC 1182	10 200	IC 1181B	10 581
NGC 6044	10 231	NGC 6041	10 591
IC 1183	10 252	IC 1186	10 972
IC 1185	10 324	IC 1173	10 983
NGC 6050A	10 344	NGC 6061	11 291
NGC 6045	10 396	NGC 6055	11 503
NGC 6047	10 447	NGC 6056	11 734
IC 1181A	10 581	IC 1194	11 800

The present results permit a new determination of the velocity dispersion for the cluster investigated and a correction of the relation m — V.

According to [10] the average recession velocity of the Hercules cluster of galaxies is 10 775 km sec^{-1} with a dispersion of 631 km sec^{-1} (this is cited erroneously dispersion by Godfredsen [49] as 670 km sec^{-1}.) Velocities from Table 1 give an average velocity of $V=10\,764$ km sec^{-1} with a dispersion of 644 km sec^{-1}.

As Fig. 7 points out all galaxies from Table 1 are located in ranges, for which the expressions (15) and (16) are defined. Thus, all radial veloci-

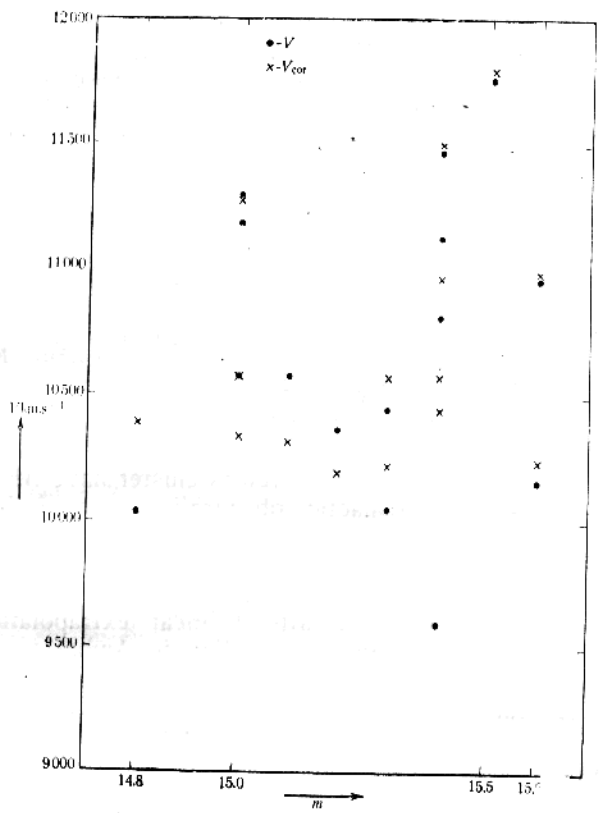


Fig. 16

ties can be corrected for the rotational effect. The corresponding velocities are given on Table 3. The new average velocity of recession is the same — 10 764 km sec^{-1} with a dispersion of 530 km sec^{-1}.

The accepted above average velocity of recession, which is corrected for non-homogeneity of the observed radial velocities, $V_{gr.}=11\,032$ km sec^{-1} gives us a new dispersion, more representative for all remaining velocities, after the correction of the rotational effects — 594 km sec^{-1}.

The relation $m-V$ according to Table 1 is given on Fig. 16. With an asterisk are marked the new, corrected for rotation, velocities. Thus the derived relation is different from the relations in [11] and [13].

DISCUSSION

The present paper deals with some questions connected with the rotation of the Hercules cluster of galaxies.

All known radial velocities of the Hercules cluster galaxies are treated here. A new cluster center is deduced on the basis of the galaxy counts on a print of the Palomar Sky Survey. The final results of the treatment lead to the conclusion that the Hercules cluster of galaxies is rotating around an axis with a positional angle of $P=300°$. The cluster nucleus has an angular diameter of $3'-4'$ and it rotates as a solid body, $\omega=$const. The outer part of these clusters presents another rotational law — (15) and (16). The rotating curve is constructed up to 15′ angular distance from the cluster center. An analogous investigation permits to make a conclusion that the south cluster part is expanding according to the Hubble law with new constant h. Thus, the assumptions of many authors (in the first place — Ambartsumian and his school) that at least some of the clusters of galaxies are non-stationary receive a quantitative confirmation. In our case the expansion may be due to a gravitational influence from a near by located cluster of galaxies, but the fact that the expansion follows ($V=hr$) demonstrates once more the basic character of the Hubble law.

A new value of the velocity of recession is derived. With respect to two values of H some characteristics are calculated for the whole cluster, as well as for the individual galaxies with $m \leq 15^m.7$. With $H=75.3$ km sec^{-1} Mpc^{-1} the brightest galaxies of the Hercules cluster have $M=-21^m.7$, while the correction for the metagalactic obscuration may influence M with $0^m.3 \div 0^m.5$.

The rotational period of the Hercules nucleus is of the order of 7.7×10^8 years and it is 1.4 times larger than the characteristic time of the cluster (5.4×10^8 years), which is obtained after a linear extrapolation in the past. As it is known, at a now-stationary according to Ambartsumian, there must be a rough correspondence between these two intervals.

The corrected radial velocities of the galaxies give a new dispersion, which permits a new evaluation of the cluster mass.

The present paper shows that our methods for the determination of the cluster rotation [21, 22] are applied to clusters with a quite small number of known radial velocities.

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ВРАЩЕНИЕ СКОПЛЕНИЯ ГАЛАКТИК ГЕРКУЛЕСА

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(Резюме)

Рассматриваются некоторые вопросы, связанные с вращением скопления галактик Геркулеса. Обработаны все опубликованные лучевые скорости членов этого скопления. Приведено новое определение центра. Исследовано вращение, где определен позиционный угол оси вращения и закон вращения. Предполагается вероятность расширения по Хабблу части скопления Геркулеса. Вычислено ряд характеристик галактик этого скопления, которые приведены в табл. 2.