Physical Chain of Galaxies in the Virgo Cluster and Its Dynamic Instability

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GALAXIES with NGC numbers 4374 (M84), 4406 (M86), 4435, 4438, 4458, 4461, 4473, and 4477, all in Virgo cluster, form a slightly bent chain extending over about $1\frac{1}{2}°$ (see Fig. 1). These galaxies are located in a ring bounded by circles centered at $\alpha=12^h\ 22^m.9$, $\delta=+14°\ 28'$, with radii of 74′ and 80′, respectively. The chain occupies only one-seventh of this ring, with an area of about one square degree. The question arises whether the formation of this chain in the Virgo cluster is the result of chance projection of galaxies.

In order to clarify this question, consider a circular region, say R, about the chain, with radius of 7°, representing the densest part of the Virgo cluster. According to the Shapley-Ames catalogue, this region contains 88 galaxies brighter than 13 mag. Table I gives the distribution of these galaxies according to types. As indicated in Table II, almost all the galaxies forming the chain are of types E or S0, the exception being NGC 4438, which is of type Sap. For this reason, in contemplating the question posed, it may be appropriate to consider 39 galaxies belong to types E and S0. However, in order to be cautious, we are adding to this number the galaxies of types Sa and one-third of galaxies which are not assigned to any type. As a result, the number of galaxies in the region R which could participate in the formation of the chain becomes 52.

Table I. Distribution of galaxies in the region R according to types.

Type	E	S0	Sa	Sb	Sc		S		Total
Number	31	8	9	8	20	2	7	3	88

The contemplated chain could be placed in a square of one radius on the side. The ring which formed about the chain admits the presence in the square of three galaxies because through any three points it is always possible to draw a circle. For this reason, in order to calculate the probability of a chance formation of the chain, it is necessary to multiply the possible number of chance formation of triplets (located in area of 1 square degree) by the probability that some other five galaxies will be located, by chance, in the same domain. The probability of a chance formation of such triplet of galaxies out of N galaxies available in a domain of area of S square degrees is

$$P_1=NC_{N-1}^2(1/S)^3. \quad (1)$$

The number of such groups will be obtained by multiplying P_1 by S, that is, $M=SP_1$. Further, the probability that, by chance, there will be five more galaxies located in the domain of any such group, the domain of area equal to one-seventh square degree, will be

$$P_2=C_{N-3}^5(1/7S)^5(1-1/7S)^{N-8}. \quad (2)$$

For this reason the probability of chance formation of the chain is determined by

$$P=MP_1P_2. \quad (3)$$

The order of magnitude of this probability is 6×10^{-9}.

It is obvious that this small probability practically excludes the possibility that the chain of galaxies considered was formed by chance.

In this way I arrived at the conclusion that the chain of galaxies in the Virgo cluster is not a chance grouping but a real physical system. If this is true, in which there will hardly be any doubt, then this system must be a linear system. If this conclusion corresponds to reality, then the chain must be an exceptionally young system. The reason is that, in spite of considerable dispersion of radial velocities of particular members, the observed deviations from the linear structure are exceedingly small.

The corrected radial velocities of components of the

Table II. Eight galaxies forming the chain in the Virgo cluster.

NGC	α_{1950}	δ_{1950}	Type	m_{pg}	V_r'	V_r	k
4374	12^h22^m6	+13°10′	S0	10.2	+880	+54	0.91
4406	23.7	13	E3	10.1	−452	−1278	1.00
4435	25.1	21	SB0	11.8	+796	−30	0.21
4438	25.2	17	Sap	11.0	−105	−931	0.36
4458	26.4	31	E0	13.0[a]	+309	−517	0.07
4461	26.5	28	S0	12.0	+1813	+987	0.17
4473	27.3	42	E5	11.3	+2173	+1347	0.33
4477	27.5	55	SB0	11.8	+1195	+369	0.21

[a] The magnitude of the galaxy NGC 4458 was determined by the author.

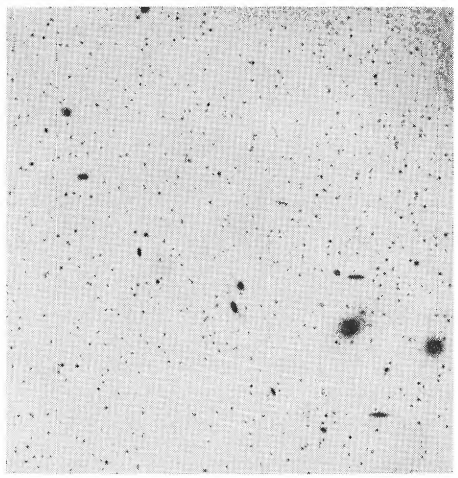

Fig. 1.

chain given in the 6th column of Table I are taken from Humason *et al.* (1956). They vary over a substantial range from −452 to 2173 km/sec, and the radial velocities with respect to the center of gravity of the system vary from −1278 to 1347 km/sec (see column 7 of Table II). The dispersion of the radial velocities is 902 km/sec.

Calculations show that, with this dispersion, the linear structure of a system would be totally destroyed during 10^8 years.

It is clear that a chain, as such, cannot be a stable system to any reasonable degree, quite irrespective of the sign of its total energy. Independently from this circumstance, the sign of the total energy of systems is of considerable interest for many reasons. Therefore, we attempted to determine this sign from the data given in Table II.

Assume that the total energy is equal to 0, that is,

$$T+U=0, \tag{4}$$

where T and U represent, respectively, the kinetic and the potential energy of the system. Assuming that the components of this system and their space velocities are randomly distributed, we may put $V_i^2 \cong 3V_{ri}^2$ and $r_{ij} \cong \frac{1}{2}\pi\rho_{ij}$, where the V_{ri} are the radial velocities of the components and ρ_{ij} the projections of the linear distances between the components on the plane perpendicular to the line of sight. Then we shall have

$$\frac{3}{2}\sum_i \mathfrak{M}_i V_{ri}^2 - \frac{2}{\pi}\sum_{ij}\frac{\mathfrak{M}_i\mathfrak{M}_j}{\rho_{ij}} = 0. \tag{5}$$

As already noticed, the galaxies forming the chain belong to the types E and S0, with the exception of one which is of type Sap. For this reason, the mass-luminosity ratio may be assumed constant. Then the relative values of the masses may be obtained from the luminosities of the galaxies.

On the assumption that the distance of the Virgo cluster is 15 Mpc (on the new distance scale) and using the apparent magnitudes of Table II [these are averages of the data of Holmberg (1958) and Pettit (1954)], the luminosities of the galaxies were determined and then their masses. The latter are expressed in terms of the mass of the brightest galaxy of the system, namely NGC 4406. Denoting the latter mass by $\mathfrak{M}$ and substituting in (5) $\mathfrak{M}_i = k_i\mathfrak{M}$ and $\mathfrak{M}_j = k_j\mathfrak{M}$, we obtain

$$\mathfrak{M} = \frac{3\pi}{4G}\sum_i k_i V_{ri}^2 \left(\sum_{i,j}\frac{k_i k_j}{\rho_{ij}}\right)^{-1}. \tag{6}$$

The values of the quantities V_{ri} and k_i are given in the two last columns of Table II and the values of the ρ_{ij} were obtained using the above estimate of the distance of the Virgo cluster and the angular separations of the members of the chain. These were measured on a photograph taken with the 21-inch Schmidt telescope of the Burakan observatory.

Using formula (6) the mass of NGC 4406 was calculated to be $4\times10^{13}\ \mathfrak{M}_\odot$. In turn, this figure determines the luminosity ratio of the galaxy, equal to 10^3.

The values of the mass and of the mass-luminosity ratio so obtained appear inordinately large: They exceed the known maximal values of these quantities by $1\frac{1}{2}$ to 2 orders of magnitude. It is true that the values obtained depend to a certain extent on the adopted Hubble constant and on the projection factor used in the calculation of the space velocity from the radial velocity. However, if we replace the adopted values by 100 km/sec per megaparsec and by 2, respectively, then the values obtained for the mass and for the mass-luminosity ratio will be diminished only in the ratio of two to one.

It may be appropriate to mention that, if galaxy NGC 4473, with the greatest relative radial velocity of the system, is excluded from the calculations, on the assumption that it is not a physical member of the chain, this does not alter the general situation.

While the assumption that the total energy of the system is equal to zero leads to very unusual conclusions, the alternative assumption that the total energy is negative would lead to even greater estimates of the mass and of the mass-luminosity ratio. As a result, we arrive at an inescapable conclusion that the total energy of the system must be positive.

The indicated chain of galaxies may be taken as an outstanding example confirming the Ambartsumian hypothesis (1958) that among multiple galaxies and among groups of galaxies there are unstable systems having positive energy.

REFERENCES

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DISCUSSION

SCOTT asked whether a search had been made for chains in other parts of the Virgo cluster or elsewhere. MARKARIAN replied that he had found no others in the Virgo cluster, but that there are several other examples of chains in Vorontsov-Velyaminov's catalogue, although there is doubt that some of them are dynamical systems. Of course, projection can lose some of the chainlike character. SCOTT then asked whether one should not compute the probability of at least one chance chain in the larger area (with many more galaxies involved and thus a much larger value of N). On the other hand, DE VAUCOULEURS pointed out that the 3° *core* of the Virgo cluster, where this chain is located, is much more densely populated with E and S0 galaxies than the larger area of 7° square over which Markarian took, in effect, an *average* density to compute the probability of a chance chain. MARKARIAN answered that any smaller

area leaves out some of the denser parts of the cluster. As a result, if one narrows the area S containing the chain, the increase in the probability in question will be negligible.

SCOTT went on to say that in her study with Shane and Swanson (*Astrophys. J.* **119**, 91, 1954) a synthetic $6°\times6°$ field was constructed by distributing clusters at random and galaxies within each cluster according to a trivariate normal distribution as in the model of spatial distribution derived from Lick plates (Neyman, Scott, and Shane, *Astrophys. J.* **117**, 92, 1953). Many curious configurations, including straight and circular chains of galaxies of nearly the same magnitude, were found on this plot, the arrangement of almost all of these galaxies being due to fortuitous lining up of clusters one behind the other. This is empirical evidence of the strong effect of projection, and casts doubt on any conclusion that such configurations are physical systems.

MARKARIAN replied that the chain considered by him is entirely composed of bright galaxies. Because the Scott-Shane-Swanson experiment referred essentially to faint galaxies, the conclusions drawn from this experiment cannot be applied to the chain he studied. SCOTT answered that this is not the case—each galaxy in each cluster was treated individually and its exact position and magnitude determined synthetically. We can fix our attention on bright galaxies or on nearby galaxies or on what we please. The reader can visualize the superimposing *five* plots typified by Figs. 2(a) and 2(b) in the publication. This distance is reduced to 20 million parsecs by ignoring the smallest dots, etc. In any one plot there are already some chance configurations; with five their number is multiplied.

NEYMAN admitted an intuitive feeling that the 8 galaxies in Fig. 1, possibly combined with a few others, are the debris of some larger structure akin to a spiral arm. Nevertheless, he found the probability argument used to support the asserted physical connection among the eight galaxies not very convincing. The argument is as follows: We observe a configuration of objects on a photograph; arbitrarily, we select a feature of this configuration, and then compute the probability that such a feature will be created by chance. We find that this probability is small and conclude that the particular configuration is not due to chance.

Of course, this kind of reasoning is very common and has been used for ages; he does not mean to single out Dr. Markarian. In fact, the weakness of the reasoning was noticed some 50 years ago when it was the subject of a discussion between Joseph Bertrand and Emile Borel. They agreed that in general the conclusion is unfounded for at least one reason: Whatever the observed configuration of objects, it is always possible to invent a characteristic of this configuration such that the probability of obtaining it by chance will be as small as desired. In other words, among points distributed by chance on a plane one inevitably obtains configurations some features of which are extremely improbable. Thus, probability of a particular observed feature does not constitute convincing ground for denying the chance mechanism underlying the distribution of points.

Bertrand's pessimistic conclusion was that no probability argument could be useful in testing hypotheses. Borel disagreed; according to his intuition, probability theory could be used for testing hypotheses provided that certain precautions are observed. Two of these precautions are (1) that the test criterion be chosen *before* observations are started and (2) that the test criterion be a function of the observable variables "en quelque sorte remarquable." Borel did not indicate the exact meaning of this phrase, but in the late 1920's it served as a starting point for the modern theory of testing statistical hypotheses.

The phrase "fonction en quelque sorte remarquable" can be given a very precise meaning. Heuristically it is that function of the observable random variables for which: (i) the probability of rejecting the hypothesis tested (say H) when it is true be small and (ii) that the probability be greater of rejecting the hypothesis tested when it is false. In order to determine a test criterion of this sort it is necessary to know the hypotheses, h_1, h_2, $\cdots$, that may be true when H is false. In other words, it is necessary to know all the ways in which H might be false.

With reference to the present case, H is that the 52 galaxies are distributed over the area S with "statistical uniformity," that is, with a probability density which is constant over S, each galaxy being independent from the others. The hypotheses h_1, h_2, $\cdots$ (alternatives to H) are covered by the statement "the eight galaxies constitute a physical system." At first sight this appears meaningful, but not under closer examination. To be entirely meaningful, the description of the alternative(s) must be sufficient to calculate the probability of any preassigned configuration of galaxies considered. If we merely say that eight of them form a physical system, this is not enough for the calculation of probabilities.

MARKARIAN agreed that, by itself, small probability of the chance occurrence of a given chain of galaxies cannot be regarded as a proof that it is a physical system. However, many other groups of galaxies (pairs, clusters) are being treated as physical systems without adequate proof. In the present case, the small probability of the chain being formed by chance speaks strongly in favor of the hypothesis that the chain is a physical system.