SOME REMARKS ON COMPACT GROUPS OF COMPACT GALAXIES

V. A. Ambartsumyan, H. C. Arp, A. A. Hoag,
and L. V. Mirzoyan*

The questions connected with the study of groups of compact galaxies discovered at the Byurakan Astrophysical Observatory are discussed. The definition of compactness and the sufficient conditions of compactness of faint galaxies are given. It is shown that all galaxies fainter than $17^{m}.5$ and brighter than $18^{m}.5$ on the red prints of the Palomar Sky Survey having saturated images are compact. A total of 12 groups of compact galaxies are described by the direct photographs obtained with large resolution in the primary focuses of the 200-inch telescope of the Palomar Observatory and of the 4-m telescope of the Kitt Peak National Observatory. The reproductions of these photographs are presented. New data of observations confirm the real existence of the new type systems of galaxies named the compact groups of compact galaxies. The composition of compact groups of compact galaxies is rather various. In the observed compact groups together with starlike and compact galaxies there are normal looking galaxies having sharp nuclei and faint outer parts. Most of the members of these groups have symmetric and almost starlike images. Among the observed groups a few spiral galaxies are found, and irregular galaxies are practically absent. The appearance of the compact groups of compact galaxies are also various, sometimes without any signs of concentration.

Introduction

At the beginning of 1973 Robinson and Wampler [1] published the results of their important study of the cluster Shakhbazyan 1 discovered at the Byurakan Astrophysical Observatory in 1957 [2]. Using the spectrograms obtained with the Image-Dissector Scanner and the new spectrograph attached to the Cassegrain focus of 3-m telescope of the Lick Observatory they have shown that this cluster is a very distant (z = 0.116) group of galaxies possessing extremely unusual properties.

As it turned out the cluster Shakhbazyan 1 has small dimensions and the component galaxies are very compact and luminous. Besides, the first observations of the radial velocities in the cluster have shown very small dispersion, even smaller than the errors of the measurements [1].

Owing to its unusual properties the cluster Shakhbazyan 1 has been described by one of the authors (H. C. A.), Burbidge and Jones [3] as a unique one.

The survey of the maps of the Palomar Sky Atlas has confirmed that it con-

*Visiting Astronomer at Palomar and Kitt Peak National Observatories under the Exchange Program between the Academy of Sciences of the USSR and the National Academy of Sciences of the USA.

†Operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

Byurakan Astrophysical Observatory. Hale Observatories. Kitt Peak National Observatory. Published from Astrofizika, Vol. 11, No. 2, pp. 193-206, April-June, 1975. Original article submitted March 4, 1975.

tains no group of galaxies which is equal to or exceeds Shakhbazyan 1 simultaneously in richness, in compactness of the group, and in compactness of its members. However, Shakhbazyan et al. [4-6] have decided to approach the question of existence of similar groups from a different position. They tried to consider the group Shakhbazyan 1 as an extreme representative of a broad class of isolated groups of compact galaxies which generally satisfy somewhat relaxed conditions as regards to richness and compactness of the group. One can even allow the presence of some noncompacts in the group together with compact galaxies.

This approach has led to the discovery [4-6] of about 150 groups of compact galaxies the majority of which contain between 5 and 15 members. There is no doubt that the total number of such groups on the whole sky must be larger than 1000. With regard to their structure, these groups, as systems, are sometimes more compact than Shakhbazyan 1 but are more often less compact. Very often these groups have elongated forms or even represent mostly curvilinear chains of compact galaxies.

The majority of these groups consist of faint objects between 17th and 19th red magnitudes. Since the compactness of their member galaxies is the most important characteristic of these groups, it is necessary to consider the definition of compactness as well as the possibility of distinguishing the compact galaxies from other objects of the same magnitude.

The Definition of Compactness

Until now the question of the most useful definition of compactness has not been discussed in any detail. In compiling his catalog of compact galaxies Zwicky [7], who first undertook their study, stated that their most important property is high surface brightness. He has proposed tentatively to define the compacts as galaxies having surface brightness higher than 20th magnitude per square second of arc.

The "Reference Catalog" of de Vaucouleurs and de Vaucouleurs [8] contains surface brightnesses of 1393 bright galaxies in B including the galaxies of Shapley-Ames Catalog. The statistics of these values shows that among them only 57 are of surface brightness higher than $21\overset{m}{.}4$ per square second of arc ($\square''$), only 10 higher than $21\overset{m}{.}0$ per $\square''$ and only in one case is surface brightness higher than $20\overset{m}{.}0$ per $\square''$.

Thus taking only galaxies which have in B surface brightness higher than $21\overset{m}{.}4$ per square second of arc we select about 4% of galaxies which surpass all others in surface brightness.

Then the probability that when choosing at random 10 galaxies we shall have among them four objects with such high surface brightness will be

$$\frac{10!}{4!\,6!}\left(\frac{1}{25}\right)^4 \simeq \frac{1}{1875}.$$

Similarly, the probability of random presence of three compact objects in a group of seven galaxies is practically negligible.

Thus if in the groups of Shakhbazyan's lists [4-6] the surface brightness of three or four objects exceeds the above-stated level, this will mean that there is a special tendency of clustering among the distant compact galaxies which must have some important significance.

Now for the majority of galaxies the surface brightness in B of the order of $21\overset{m}{.}4$ per $\square''$ corresponds approximately to 20^m per $\square''$ in the red.

From the above considerations it follows that for our purposes it is appropriate to apply 20^m per $\square''$ in the red as a very suitable limiting value for the selection of groups of compact galaxies. This is also in accordance with Zwicky's suggestion. For comparison let us estimate the surface brightness corresponding to the density of Palomar Sky Survey red prints at which saturation occurs.

We can obtain this estimate taking into account that the images of 20^m stars are of very low density and only the stars of about $18\overset{m}{.}5$ are seen as sufficiently saturated dots. Now the smallest stellar images on those prints have diameters of the order of 3" or less. This means that true saturated images correspond to the surface brightness

$$m = 18.5 + 2.5 \lg \pi r_0^2 = 20.6,$$

where r_0 = 1.5. It follows that the true saturated image density corresponds to the surface brightness $20^m.6$ per □".

Thus the galaxies that have surface brightnesses lower than the minimal surface brightness of compacts but higher than $20^m.6$ per □" may have saturated images on Palomar Sky Survey red prints. In other words, among the galaxies showing saturated images on red prints we have many noncompacts. However, for faint galaxies of 17 and 18 magnitude another effect enters which changes the situation.

Sufficient Conditions of Compactness of Faint Galaxies

The images of faint galaxies of small angular diameter are strongly influenced by the effect of the broadening of images. It is the same effect which makes the diameters of faint stars (of magnitudes 18-20) different from zero. The broadening is of instrumental, atmospheric and photographic nature.

Owing to this broadening the effective surface brightness which determines the density of photographic images is lower than the true surface brightness of the given galaxy. The effect of broadening on the surface brightness of galaxies of large angular diameter ($d > 15''$) is negligible. But for galaxies of small angular diameter it is of importance since the relative increase of angular diameter owing to the broadening is large.

If, for example, the diameter of the image of a galaxy exceeds 1.32 times its true angular diameter, the surface brightness corresponding to the image on the photograph will be $(1.32)^2 = 1.74$ times lower than the true surface brightness. This means that if the image of such a galaxy is saturated and thus has a surface brightness higher than $20^m.6$ per □" its true surface brightness will be higher than $20.6 - 2.5 \log 1.74 = 20.0$. Thus all galaxies for which the relative increase of radius exceeds 1.32 and have saturated images on the photographs (or prints) are compact.

In the Appendix to this paper it is shown that there is an interval of integral magnitudes of galaxies $m_1 < m < m_2$ in which the galaxies with saturated images have relative increase of radius greater than 1.32. Consequently, all galaxies whose apparent magnitudes are within that interval and which have saturated images on the red prints are compact.

Under certain assumptions we find (see the Appendix) that for red prints of Palomar Sky Survey we have approximately $m_1 = 17.5$ and $m_2 = 18.5$.

By some coincidence the integral magnitudes of the majority of members in many compact groups of the Shakhbazyan lists [4-6] fall within the interval $17.5 < m < 18.5$. Therefore the saturation of their images is a sufficient condition of their compactness. Since this condition is certainly fulfilled for a considerable number of members of those groups it is quite reasonable to consider those groups as systems of compact galaxies.

Of course, for galaxies brighter than m_1 the saturated image on the plate (or on the print) is not a sufficient evidence of compactness and special photographic study is necessary.

It is essential also that by the application of K-correction the surface brightness of galaxies increases. For the galaxies of apparent magnitudes between 17^m-18^m this correction in the red is mostly between $0^m.10$ and $0^m.25$. This makes more certain the compactness of faint galaxies having saturated images on red maps.

Unusually small angular sizes, very red colors, and mostly diffuse images of components on blue photographs with their almost starlike images on red photographs (the copies of Palomar Sky Survey and, in some cases, also the plates obtained with 40-inch Schmidt telescope of the Byurakan Astrophysical Observatory have been used) support the idea that these groups represent a new type of systems of galaxies - <u>Compact Groups of Compact Galaxies</u>.

TABLE 1. Photographic Observations of Some Compact Groups of Compact Galaxies

Shakhbazyan No.	Data (1974)	Tele-scope	Plate No.	Emulsion (Kodak)	Filter	Ob-server*	Exposure time
31	August, 12	4-m	1118	098—02	RG—610*	H, M	30 min
34	" 12	"	1120	IIaF, IK2	"	"	45 "
35	" 10	"	1105	098—02	"	M, S,	30 "
41	" 12	"	1119	098—02	"	H, M	45 "
43	" 11	"	1112	098—02	"	"	25 "
79	July, 23	200-inch	6874	098—04	RG—2	A, M	45 "
81	" 23	"	6879	124—01	—	"	20 "
82	" 24	"	6884	124—01	—	"	20 "
83	August, 12	4-m	1117	098—02	RG—610	H, M	30 "
84	July, 23	200-inch	6880	124—01	—	A, M	15 "
129	" 24	"	6881	098—04	RG—2	"	45 "
Anon†	" 24	"	6882	098—04	"	"	45 "

*RG-610—RG-2 (the GR-610 is a new designation - "cut" at 6100A).
†After a revision of the lists of compact groups of compact galaxies this group has not been included in the published lists [4-6].
Observers: A - H.C. Arp, H - A.A. Hoag, M - L.V. Mirzoyan, S - S.E. Strom.

Below we describe the results of the photographic observations of some compact groups obtained with large scale, which give evidence in favor of this idea, with a short discussion of the problem.

Observations

Direct photographs of 12 compact groups of compact galaxies from the lists [4-6] have been obtained at the primary focuses of the 200-inch telescope of the Palomar Observatory (F/3.67) and 4-m telescope of the Kitt Peak National Observatory (F/2.75) in July-August, 1974.

The observational data are presented in Table 1.

The scales on the original plates are equal, correspondingly, to 11"/mm (200-inch telescope) and to 18".5/mm (4-m telescope).

As it is seen from the data of Table 1 most observations of compact groups of galaxies have been obtained in red color for the better study of the structure of objects in these groups.

All red plates Kodak 098-04 used during observations with the 200-inch telescope have been baked 2 h at 70°C. The Kodak "J" plates 124-01 are unbaked. Used without filter in the 200-inch these 124-01 plates register from about 3900 to 5400Å wavelength. All plates were developed 8 min in the developer MWP-2. The Kitt Peak plates were processed in D-19 for 5 min.

Appearance of Compact Groups

The direct photographic observations of 12 compact groups of compact galaxies obtained by us show large variety in their appearances. All galaxies in the observed groups seem to run a gamut of forms from stellar-appearing objects through compact to nearby normal-looking galaxies with sharp nuclei and faint outer regions.

Here we present a general description of appearances of all observed groups of galaxies according to the original plates reproduced at the end of this paper.

Shakhbazyan 31. The group is in the field of numerous but much fainter galaxies. Many of them seem to be members of a much larger cluster of galaxies. It is not excluded that Shakhbazyan 31 is the distinct "nucleus" of this cluster consisting of its central, brightest members. The images of galaxies in this group are very compact. Object 3 consists of two compact galaxies. Object 5 is a spiral galaxy. Around objects 1, 2 (both components), and probably object 6 there are faint diffuse halos.

Shakhbazyan 34. The group is compact and isolated. The four brightest objects 1, 2, 4, and 5 are very compact and it is possible that one or two of them are stars. Galaxies 3 and 9 are diffuse objects. Objects 6 and 7 are compact and faint.

Shakhbazyan 35. The group is isolated. Galaxy 1 is surrounded by a diffuse halo and can hardly be considered as compact. Objects 2, 3, 4, and 5 are certainly compact galaxies. Object 6 is starlike. Between objects 2 and 4 there is a faint object, probably a member of this group.

Shakhbazyan 41. The group is more compact than Shakhbazyan 1. According to Borngen and Kalloglyan [9] this group consists of eight exceedingly red galaxies. Around this group there are many faint diffuse objects. Objects 3, 5, and 7 are very compact and have starlike images. Object 1 is an elliptical galaxy with a faint halo. Objects 2, 4, and probably 6 are spiral galaxies. The group is probably not a very distant one.

Shakhbazyan 43. The group is well isolated. All objects in this group except 5 and 8 are compact. Objects 1, 2, 3, 6, and 8 have faint halos. Object 5 has a diffuse appearance. In the field of this group, especially around object 1, there are some faint objects, probably galaxies.

Shakhbazyan 79. This system is one of the richest among the studied groups. It is not sufficiently isolated. Some of the nearby galaxies are probably also members of this group. All objects in the group except 5 are compact. Object 5 and possibly object 10 are spiral galaxies.

Shakhbazyan 81. The group is situated in a rich field and some of the nearby objects probably belong to the group. Object 2 has starlike image. Object 7 and possibly objects 5 and 6 are spiral galaxies. Objects 1, 3, 4, 5, and 6 have faint diffuse halos.

Shakhbazyan 82. A very compact and isolated group with a small number of components. Objects 1, 2, 4, and 5 are compact. Object 3 is starlike. Objects 1, 2, and 5 have faint diffuse halos.

Shakhbazyan 83. In the field surrounding the group there are some faint and diffuse objects. All bright objects are compact and have spherical forms except object 6 which is elliptical. Objects 1, 4, and 5 have faint diffuse halos. Object 8 is double, both components having diffuse images.

Shakhbazyan 84. A compact and well-isolated group. The comparatively large angular sizes together with brightnesses of the component galaxies imply that this group is not very distant. Objects 1, 2, 3, and 6 have diffuse halos. Objects 4 and 5 do not differ from stars. South of the object 6 there is a faint galaxy with a brightness close to that of the object 5. There is also a very diffuse object near the object 3, to the northwest from it.

Shakhbazyan 129. A well-isolated compact group. All objects in this group have starlike images and form rings. Only the objects 2, 3, and probably 4 can be suspected to be galaxies by their images. A spectroscopic examination of this group is very desirable.

Anon ($\alpha = 14^h48^m.3$, $\delta = +68°13'$, 1950). A very rich and extended group, not completely isolated. Many objects in the group have starlike images. There are some very faint objects in the field. Probably some of them, if not all, are members of the group. Almost all the objects are very compact. Objects 1, 4, 7, and 9 have faint diffuse halos. Object 3 is double.

Population and Colors in Compact Groups

The population of the compact groups is rather inhomogenous. Most of the members of these groups have symmetrical and almost starlike images. Among the members of many groups there are some spiral and elliptical galaxies. But the irregular galaxies are practically absent in the groups studied.

Correspondingly, the colors of the components in compact groups are different as well. The majority of them are very red. In fact, this property of the galaxies in compact groups has been used [4-6] for detection of these groups.

Colors of galaxies in compact groups have been measured by Börngen and Kalloglyan [9] using the photographic observations of four compact groups (Shakhbazyan 17, 18, 41, and 42) obtained with the 2-m telescope of the Tautenburg Observatory. Most of the measured galaxies in these groups have B − V colors larger than +1.0. This supports the idea that the majority of galaxies in compact groups are exceedingly red objects [4-6].

However, not all of them are very red. Moreover, probably some of them are not red. For example, the UBV-observations of the object 2 (V = 17.51) in the group Shakhbazyan 129 obtained by D. L. Crawford and one of the authors (L.V.M.) with 2.1-m telescope and the Kinman-Mahaffey Photometer [10] of the Kitt Peak National Observatory showed that it has the colors similar to an F-type star:

$$B - V = 0.43, \quad U - B = -0.05.$$

Distances, Sizes, and Luminosities in Compact Groups

Redshifts of the brightest members of two already studied groups, Shakhbazyan 1 [1] and Shakhbazyan 123 [11], are practically the same: z = 0.116. This corresponds to a distance of ~700 Mpc if we take the value 50 km/sec · Mpc for the Hubble constant.* The similar result (z ≈ 0.1) on the group Shakhbazyan 4 obtained by Lynds and Khatchikyan [12] has not yet been published.

For this distance the diameters of the corresponding groups are equal to ~300 Kpc (Shakhbazyan 1) and ~400 Kpc (Shakhbazyan 123). The diameters of the member galaxies in both groups are equal to ~10 Kpc.

The luminosities of all the studied galaxies are rather large. The brighter galaxies in the cluster Shakhbazyan 1 have luminosities brighter than -22^m. In the group Shakhbazyan 123 the corresponding luminosities are smaller but still higher than -20^m. In both cases these luminosities are the lower limit, since these estimates correspond to the comparatively bright central regions of the galaxies.

Thus, the brightest galaxies in compact groups have comparatively small sizes and high luminosities.

Dispersion of the Radial Velocities in Compact Groups

One of the most unusual properties of the groups Shakhbazyan 1 and 123 is very small dispersion of the radial velocities of the measured component galaxies. In both these systems the observed dispersion is even smaller than the estimated errors of the measurements [1, 11]. It is possible, but seems very improbable, to suppose that in both cases the small dispersion of the radial velocities is a result of chance. But for the further study of this unusual phenomenon new, more accurate measurements are necessary.

The spectroscopic observations of the brightest numbers of the group Shakhbazyan 4 obtained by Lynds and Khatchikyan [12] have shown that the small dispersion of the radial velocities is not a common property of all compact groups of compact galaxies. In this group the dispersion of radial velocities is comparatively larger [12].

Some General Conclusions

The direct photographic observations of some of the groups found in the

*The distance 400 Mpc for the cluster Shakhbazyan 1 obtained in [1] is due to larger value taken for the Hubble constant (75 km/sec · Mpc) and an arithmetical error in the calculation of the radial velocity.

Byurakan Astrophysical Observatory by R. K. Shakhbazyan, M. C. Petrosyan, as well as by W. F. Baier and H. Tiersch, partly in the Central Institute of Astrophysics, Academy of Sciences of the GDR [4-6], together with the spectroscopic observations of three of them (Shakhbazyan 1, 4, and 123) lead to the following conclusions:

1. Most groups included in lists [4-6] have unusually small sizes and consist of compact and luminous galaxies.

2. Among the objects of those lists investigated so far there are very few cases of random groups of projected stars and galaxies (for example, Shakhbazyan 78 [11]).

3. In some groups the images of the components are starlike even on the photographs obtained with the 200-inch telescope (for example, Shakhbazyan 129). The nature of such groups can be determined only through spectroscopic observations.

4. All existing data support the idea that the groups included in lists [4-6] in their majority represent a new type of systems: compact groups of compact galaxies.

The authors are grateful to Dr. R. K. Shakhbazyan for giving the data on compact groups of compact galaxies in advance of publication, Dr. S. E. Strom for the assistance in obtaining of the direct photograph of the group Shakhbazyan 35, and to Dr. D. L. Crawford for the help during UBV-observations of object 2 in the group Shakhbazyan 129.

One of the authors (L.V.M.) thanks Prof. L. Goldberg and Dr. H. W. Babcock for their hospitality during his work at the Kitt Peak National Observatory and the Palomar Observatory and the staffs of these observatories for their assistance.

APPENDIX. SOME SUFFICIENT CONDITIONS OF COMPACTNESS OF GALAXIES

In the main text of this paper it was stated that all galaxies that have saturated images and for which the relative increase of the surface owing to the broadening exceeds some value k = 1.74 are compact.

Now if a galaxy has a true surface s and the apparent size of surface on the photograph s' the ratio s'/s must be a function of s:

$$s' = f(s)\, s.$$

Two properties of $f(s)$ are evident:

1) $f(s)$ monotonically decreases from ∞ at s = 0 to 1 at s = ∞;
2) the product $sf(s)$ monotonically increases with s.

Owing to these properties there is a single value of s for which $f(s) = k = 1.74$. We denote it by s_1:

$$f(s_1) = k.$$

Furthermore, if i_0 is the minimum surface brightness of compact galaxies (20^m per $\square''$), then it is easy to show that the following two conditions are sufficient for the compactness of a galaxy:

1) It is saturated on the photograph. This means that the surface brightness corresponding to the image of galaxy i' satisfies the condition

$$i' = \frac{i}{f(s)} > i'_0 = \frac{i_0}{k} = \frac{i_0}{f(s_1)}, \tag{1}$$

where i'_0 is the surface brightness which corresponds to the image which is just saturated and is equivalent to $20\overset{m}{.}6$ per $\square''$.

2) The integral brightness I satisfies the inequality

$$I < i_0 s_1 \tag{2}$$

or

$$i_0 s_1 > is \tag{3}$$

where i is the true surface brightness of galaxy.

Multiplying the conditions (1) and (3) we obtain

$$s_1 f(s_1) > sf(s)$$

from which follows

$$s < s_1$$

and

$$f(s) > f(s_1) = k.$$

This means that when both our conditions are fulfilled the broadening ratio is larger than k.

We have already seen that this together with the first condition (the saturated image) is sufficient to define compactness of the galaxy under consideration.

In order to express in stellar magnitudes the inequality (2), which corresponds to our second condition, we must determine the numerical value of s_1 in square seconds of arc.

According to definition s_1 is the root of the equation $f(s) = 1.74$. But we do not know the exact expression for $f(s)$. For an approximate evaluation of s_1 we can introduce the simplest assumption

$$s' = sf(s) = s + s_0, \tag{4}$$

where s_0 is the apparent surface of the image of the faintest star.

Therefore

$$f(s) = 1 + \frac{s_0}{s} \tag{5}$$

and the solution of the equation $f(s_1) = k = 1.74$ is

$$s_1 = \frac{s_0}{k - 1}.$$

As it was stated in the main text the smallest stellar image has the radius $r_0 = 1''5$. From this

$$s_0 = 7.1 \square''$$

and

$$s_1 = 9.6 \square''.$$

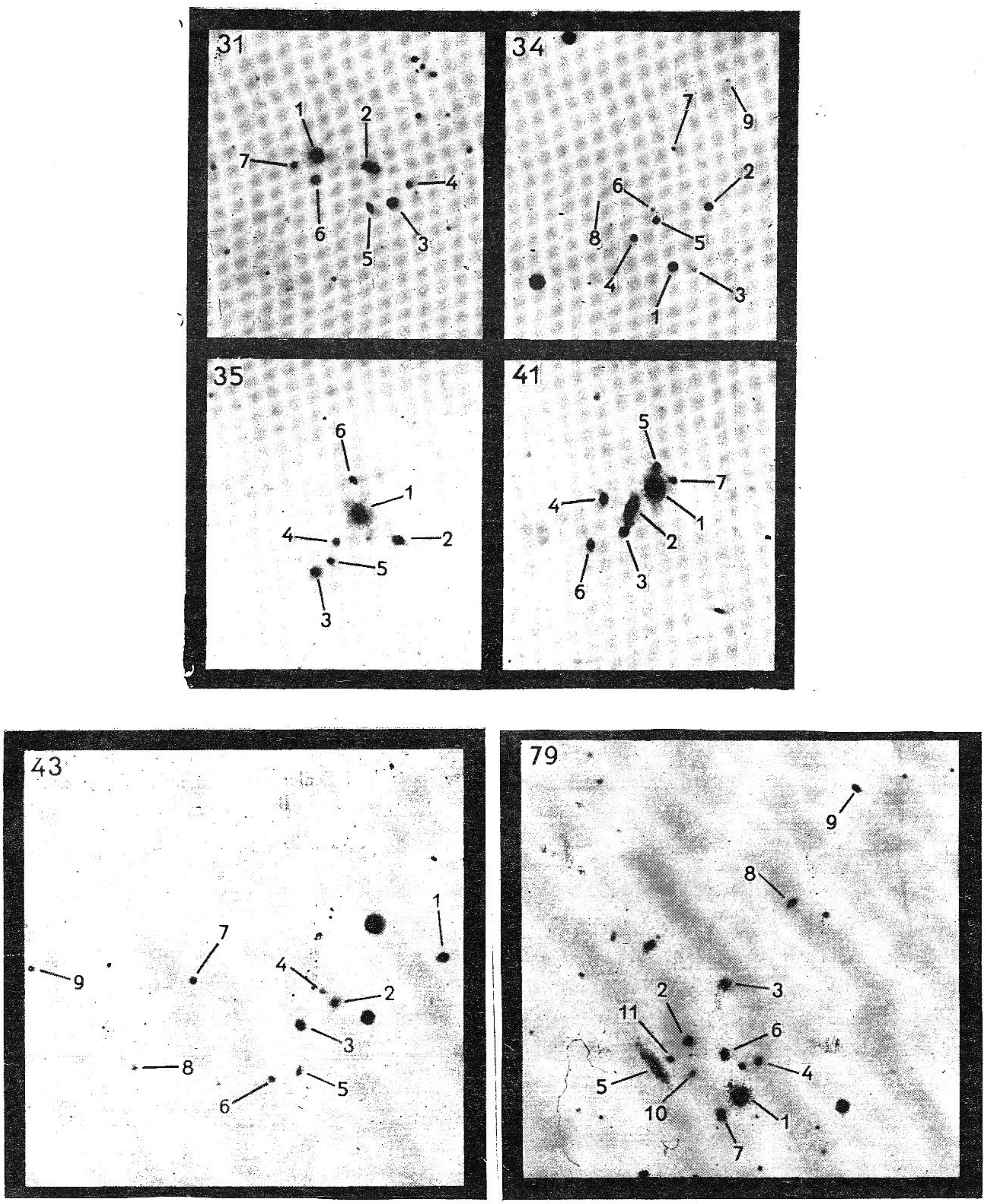

Fig. 1. Compact groups of compact galaxies. North: above; East: left. Scale ∿ 2".2/mm. Numbers: according to the lists [5, 6].

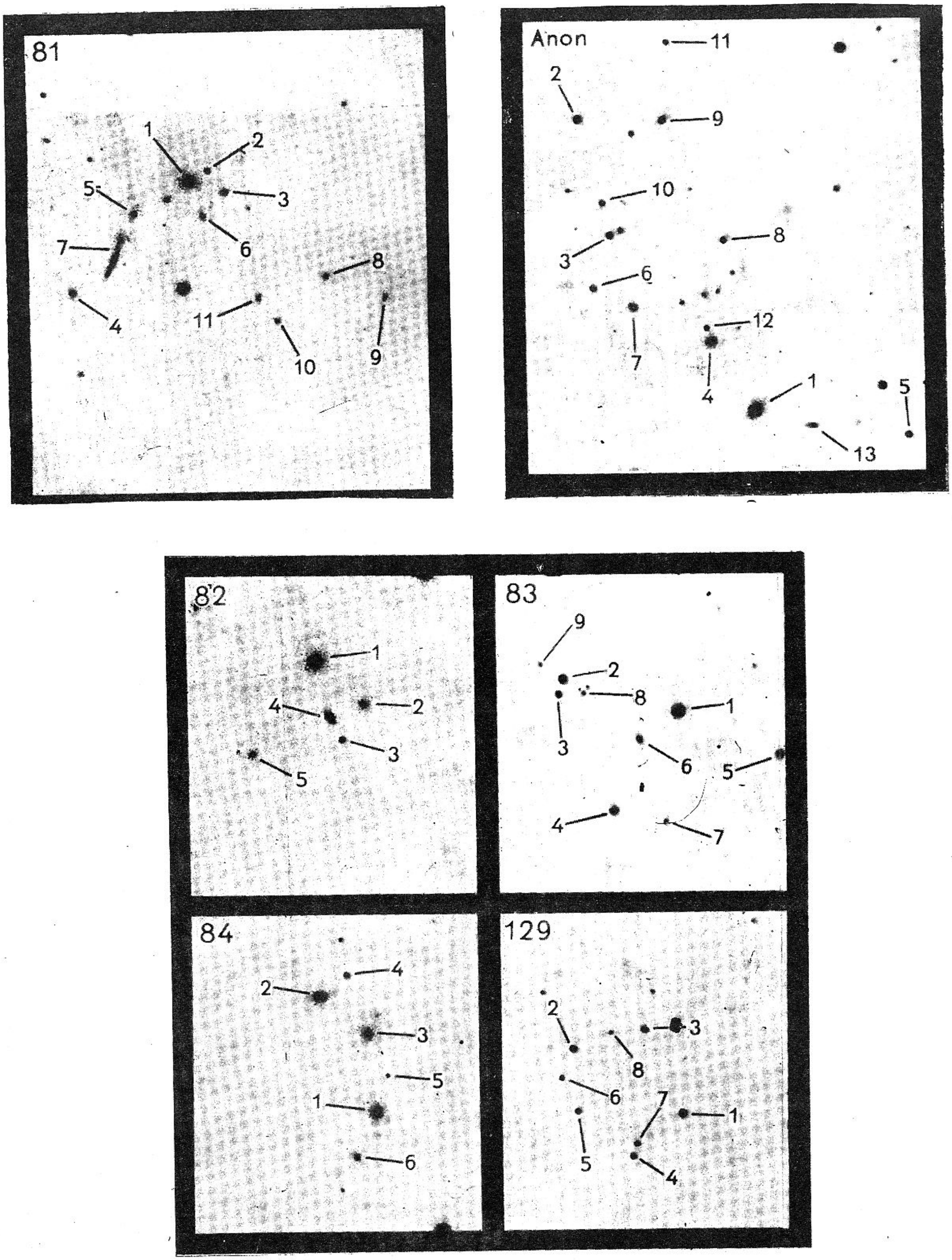

Fig. 1 (continued)

Introducing this in (2) we can easily transform it into the inequality for the integral red magnitude of the galaxy

$$m > m_1 = 17.5 .$$

Thus all galaxies for which $m > m_1 = 17.5$ and which have saturated images are compact.

Of course we recognize that both the expression (5) adopted for $f(s)$ and the numerical values obtained above are to be revised. This can modify the value $m_1 = 17.5$. On the other hand, there is no doubt that the limit m_1 must change from one print to another. Therefore it will be more cautious only to state that the galaxies which are fainter in the red than 17.5 and have saturated images are either compact or very near to compactness.

We must add to this that not only galaxies but even the stars with $m > 18.5$ cannot be saturated on prints. Therefore the saturated galaxies we are discussing are to be found in the interval of integral magnitudes

$$17.5 < m < 18.5 .$$

At the same time it is clear that even the images of compact galaxies fainter than $18^m.5$ are not saturated on the prints. This makes it difficult to recognize them.

LITERATURE CITED

1. L. B. Robinson, E. J. Wampler, Astrophys. J., 179, L135 (1973).
2. R. K. Shakhbazyan, Astr. Circ. USSR, No. 177, II (1957).
3. H. C. Arp, G. R. Burbidge, and T. W. Johnes, P.A.S.P., 85, 423 (1973).
4. R. K. Shakhbazyan, Astrofiz., 9, 495 (1973).
5. R. K. Shakhbazyan and M. B. Petrosyan, Astrofiz., 10, 13 (1974).
6. F. W. Baier, M. B. Petrosyan, H. Tiersch, and R. K. Shakhbazyan, Astrofiz., 10, 327 (1974).
7. F. Zwicky and M. Zwicky, Catalog of Selected Compact Galaxies and Post-Eruptive Galaxies, Zurich (1971).
8. G. de Vaucouleurs and A. de Vaucouleurs, Reference Catalog of Bright Galaxies, University of Texas Press, Austin (1964).
9. F. Börngen and A. T. Kalloglyan, Astrofiz., 10, 21 (1974).
10. T. D. Kinman and C. T. Mahaffey, P.A.S.P., 86, 336 (1974).
11. L. V. Mirzoyan, J. S. Miller, and D. E. Osterbrock, Astrophys. J., 196, 687 (1975).
12. C. R. Lynds and É. E. Khatchikyan (E. Ye. Khatchikian), Private Communication.