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PAIRS OF ONE MARKARIAN AND ONE COMPACT GALAXY

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The existence of close physical pairs consisting of a Markarian and a compact Zwicky galaxy has been statistically shown. A list of 18 such pairs is given. The mean separation of their components (67 *kpc*) is much smaller than the sizes of groups of galaxies. Four of the examined pairs may be gravitationally bound systems.

1. *Introduction.* Heidmann and Kalloghlian [1] have shown the existence of close physical pairs made up of two Markarian galaxies and Casini and Heidmann [2] have shown the existence of close physical pairs made up of one Markarian galaxy and one normal galaxy. We complete here the study of the pairing of Markarian galaxies by an investigation of pairs made up of one Markarian and one compact Zwicky galaxy.

2. *Distribution of Separations.* The Markarian galaxies are taken from the seven lists prepared by Markarian [3—5] and Markarian and Lipovetsky [6—9], with coordinates from Peterson [10] for the first five lists.

The compact galaxies are taken from Zwicky's *Catalogue of Selected Compact Galaxies and of Post-Eruptive Galaxies* [11], using the 2370 regular entries which on the average contain 1.3 object each. They include 2600 compacts and galaxies with compact parts, more than 90 % of which are compacts.

We will consider two galaxies to be a pair when a Markarian and a Zwicky compact galaxy are separated by less then 15 *arc min.*

From Zwicky's list, only compact galaxies or galaxies with a significant compact component, as seen on the *Palomar Sky Survey* prints, were used. Sixty-two Markarian galaxies coincide with the

Zwicky compact galaxy. These were not counted as pairs except for fifteen objects which were part of a multiple Zwicky system and which were only counted as a *Markarian-Compact* pair if components of the system were separated well enough. In this way we will not count as a pair a single system with a compact part and a part with a Markarian ultraviolet excess. Details are given in the notes of Table 2 for pairs with separations $r < 5'$ and in the following notes for pairs with $r > 5'$.

Table 1

Markarian number	Notes
51	$r = 9.2$, counted twice as II Zw 61 is a double compact, with separation 5".
60	$r = 9.9$, not counted because Zw 12 57.2 + 28 14 are most probably related to NGC 4874.
171	$r = 14.5$, counted twice as VII Zw 405 is a double compact, with separation 13".
210	$r = 14.2$, is pair with Markarian 209 = I Zw 36.
233	$r = 8.3$ to VII Zw 492, counted only once.
247	$r = 14.9$ to I Zw 54 which may be a star.
326	is pair with Markarian 325 = IV Zw 149 with $r = 6.7$.
360	$r = 8.7$, counted twice as III Zw 35 is a double compact, with separation 12"; Markarian 360 = III Zw 33 is pair with Markarian 361 = Zw 01 42.0+16 50 with $r = 12.5$.
393	not counted because VII Zw 262 is in a very distant cluster.
422	not counted because Zw 11 08.5+28 57 is three compacts linked to NGC 3561.
507	$r = 0.9$, counted twice as VII Zw 742 is a double post-eruptive with (important) compact cores, with separation 10".
695	$r = 8.9$, counted twice as III Zw 75 is a double compact, with separation 6".

Forty-three pairs of galaxies were found with separations of up to 15 *arc min*. The distribution of the differential number of *Markarian-Compact* pairs $\Delta n/\Delta r$ versus angular separation r is given in Fig. 1. For a random distribution one should have

$$\Delta n/\Delta r = 2\pi MNr, \qquad (1)$$

where M is the number of Markarian galaxies (700) and N the area density of compact galaxies.

It is seen that the distribution shows a significant excess above a random distribution for r up to 5 *arc min*. Equation (1) fitted to the distribution for $r > 5$ *arc min* gives

$$N = (0.19 \pm 0.04 \text{ m. e.})\, deg^{-2}.$$

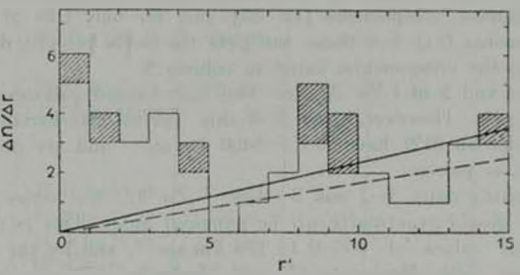

Fig. 1. Number of pairs $\Delta n/\Delta r$ versus angular separation r of the components in *arc min*. per $\Delta r = 1$ *arc min* intervals. The straight solid line corresponding to a random distribution is fitted to the distribution for $r = 5$ to 15 *arc min*. Shaded squares should be omitted if close double compacts are not considered as 2 but only as 1 companion. In this case the solid line should be replaced by the dashed line.

This value is (14 ± 3 m. e.) times smaller than the value found by Casini and Heidmann [2] for the area density of galaxies in Zwicky's *Catalogue of Galaxies and of Clusters of Galaxies*. In principle this Catalogue covers the same sky area as the one of compact and post-eruptive galaxies, and contains 30 000 galaxies against 2 600 for the last one. So that the N value found here (somewhat deficient) may be considered as satisfactory, especially in view of the warning given by Zwicky for statistical use of the Catalogue of Compact and Post-Eruptive Galaxies. Accordingly the line of Fig. 1 may be interpreted as representing the counts due to the random distribution with the consequence that the excess of pairs does not significantly extend farther than $r = 5$ *arc min*.

Among the 20 pairs obtained for $r < 5'$, 2.5 should be due to random optical pairs, while 17.5 should be physical *Markarian-Compact* pairs of galaxies.

Among the pairs up to $r = 15'$ there are separations r which are counted twice because the compact companion is itself a double compact object. These double compacts are usually very tight, with separations smaller than a few tens of *arcsec*. If one counts them only once, thus considering the double compacts as single physical objects,

one should remove from the histogram of Fig. 1 the shaded squares. One then gets $N = 0.15$ deg^{-2} and the excess of pairs for $r < 5'$ is still evident and is equal to 14.5.

3. *The Close Pairs.* The 20 pairs with $r < 5'$ are listed in the first four columns of Table 2. The radial velocities are known for most of the Markarian components [12—17] and for only five of the compact components [11]. For these one gets the radial velocity differences ΔV between the components, listed in column 5.

Parts 1 and 2 of I Zw 37 are two intertwined galaxies and form a physical pair. However, part 3 of this system (Markarian 211) and part 1 (Markarian 212) have $\Delta V = 5400$ $km\ sec^{-1}$ and are probably an optical random pair.

Eliminating pairs 3—1 and 3—2 of I Zw 37, *the other 18 pairs of Table 1 should practically all be physical pairs.* This is reinforced by the small values of ΔV, 0 to 170 $km\ sec^{-1}$, and by the fact that the two pairs with Markarian 271 and Markarian 477 have their components connected.

From the radial velocities of the Markarian components, using a Hubble constant 75 $km\ sec^{-1} Mpc^{-1}$, one may convert the angular separations, r, into linear (projected on the sky) separations, R in *kpc*. These are listed in column 6 and displayed in the histogram of Fig. 2. excluding the two optical pairs referred to above.

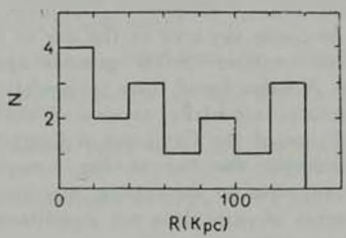

Fig. 2. Number of pairs N versus linear (projected) separation R of the components in *kpc*, per $\Delta R = 20$ *kpc* intervals.

The separations are smaller than 140 *kpc* with a mean value 67 *kpc*. Therefore the physical *Markarian-Compact* systems, like the *Markarian-Markarian* pairs [1] and the *Markarian-Normal galaxy* pairs [2], are *systems 20 times smaller than the sizes of groups* of galaxies, as given for example by de Vaucouleurs [18]. They are physica l

Table 2

MARKARIAN-COMPACT PAIRS WITH SEPARATIONS SMALLER THAN 5'ARC MIN

Markarian number	Zwicky galaxy	Zwicky number	r arc min	ΔV km sec^{-1}	R kpc	Note
97	08 46.9+65 45	VII 253	4.9	—	137	
111	09 23.6+68 39	VII 280	1.2	—	17	N
			1.2	—	17	
133	09 57.6+72 25	VII 303	3.5	38	29	
211—212	12 25.8+44 43	I 37	0.2	—	9.5	N
			3.7	—	—	
			3.9	5400	—	
214	12 27.3+65 49	VII 460	2.6	—	94	
220—221	12 41.5+55 10	I 41	0.6	0	110	N
262	13 29.0+75 50	VII 518	1.6	—	56	N
271	13 39.8+55 56	I 69	0.5	connected	15	
287	14 35.6+73 45	VII 556	0.2	—	—	N
			0.3	—	—	
361	01 41.8+16 50	III 35	4.5	—	140	N
			4.5	—	140	
369	02 34.8+20 58	—	3.8	—	57	
477	14 39.1+53 44	I 92	0.8	connected	35	N
486	15 35.3+54 43	I 121	1.3	0	59	N
486	15 35.4+54 41	—	2.1	—	95	
500	16 47.0+48 47	I 166	2.2	170	66	N

Notes to Table 2

111—not counting the W component of VII Zw 280, whose core is not important enough, but counting twice the close pair of compacts 1'S.

211—212—Markarian 212—E component of nos 1—2 of I Zw 37; Markarian 211—no 3 of I Zw 37; r=0.2 is for Markarian 212 to W component of nos 1—2 of I Zw 37, r=3.7 for Markarian 211 to the same and r=3.9 for Markarian 211 to Markarian 212.

220—221—is a pair of Markarians.

262—is pair with Markarian 261—VII Zw 518.

287—distances from brightest compact (=Markarian 287) to the two fainter close compacts.

361—counted twice as III Zw 35 is a double compact, with separation 12".

477—for no 1 (=Markarian 477) to no 2 of I Zw 92.

486—r=1.3 for no 1 (=Markarian 486) to no 2 of I Zw 121.

500—is a pair with Markarian 499—I Zw 166.

entities and not simply the chance association of two galaxies belonging to the same group.

The *Palomar Sky Survey* prints have been searched in the vicinity of the close pairs for eventual peculiarities. In addition to those already noted by Zwicky in his *Catalogue*, we found a pair of blue compact objects, 1.0 SE of Markarian 486 ($m_p \sim 19$ and 20, separation 12″).

4. *Conclusion.* We have statistically shown the existence of close physical pairs of a Markarian and a compact galaxy and produced a list of 18 of them for further morphological and spectrographic investigations. This number appears to be somewhat larger than the one which may be expected from the number of *Markarian-Normal* pairs [2] when the number of normal galaxies is reduced to the number of compact ones. For the case of *Markarian-Markarian* pairs [1] their number is four times larger than expected from the number of *Markarian-Normal* pairs.

The mean separation of the components of the pairs of Fig. 2 is 67 *kpc*, much smaller than the sizes of groups of galaxies. In four cases the compact components themselves form a still closer pair.

In four cases where they are known, the radial velocity differences between the components are in the range 0–170 *km sec*$^{-1}$, a statistical indication for these systems to be gravitationally bound.

Using various arguments, Casini *et al* [19] presented as a working hypothesis a scheme for the pair production of galaxies; in this scheme an unknown parent body ejects two objects which each evolves through the stages *compact – Markarian – normal galaxy*. The pairs found here could then correspond to one of the early phases of this process in which only one of the compacts has evolved into a Markarian galaxy.

Ambartsumian (private communication) suggests another possibility: two Markarian galaxies originate from an initial event, such as a fragmentation. Then one of them looses its Markarian activity and, in case it had already a compact morphology, it gives rise to a *Markarian-Compact* pair. According to Markarian, his galaxies occupy an intermediate stage between quasars and usual galaxies [20].

It is also possible that in the Casini *et al* scheme, one of the compact bodies fails in some cases to develop into a normal galaxy and produces a compact galaxy, giving rise again to a *Markarian-Compact* pair.

Because of Zwicky's broad definition of compact galaxies [11] these include a large variety of objects and it will be interesting to

find out whether those in the physical *Markarian-Compact* pairs have some other characteristics in common. More statistical, morphological and spectroscopic studies of pairs of galaxies of all types are needed to shed light on such processes of recent galaxy formation.

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ПАРЫ, СОСТОЯЩИЕ ИЗ ОДНОЙ ГАЛАКТИКИ МАРКАРЯНА И ОДНОЙ КОМПАКТНОЙ ГАЛАКТИКИ

Ж. АЙДМАНН, А. Т. КАЛЛОГЛЯН

Статистически показано существование тесных физических пар, состоящих из одной галактики Маркаряна и одной компактной галактики Цвикки. Приводится список 18 подобных пар. Среднее расстояние между компонентами (67 *кпс*) во много раз меньше размеров групп галактик. Четыре из рассмотренных пар могут быть гранитационно устойчивыми системами.

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