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DYNAMICAL STATE OF PAIRS OF GALAXIES

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Les estimations de masses de galaxies doubles sont obtenues sur la base des observations récentes de 148 paires de galaxies pour lesquelles les vitesses radiales des deux composantes ont été mesurées.

On montre que le rapport masse orbitale moyenne sur luminosité dépend essentiellement du type morphologique des galaxies doubles et du type d'intéraction entre les deux composantes de la paire. Les valeurs minimales de ce rapport sont obtenues pour les galaxies doubles dont les caractéristiques d'intéraction sont linéaires, à savoir : ponts, queues, ainsi que pour les paires avec des composantes compactes et des galaxies de Markarian.

La relation empirique entre le rapport masse-luminosité et la séparation spatiale des composantes de paires ne montre pas de façon évidente l'existence de halos stellaires cachés autour des galaxies doubles.

I. The terminology problem. In the recent studies (Turner, 1976, Fesenko, 1976, Karachentsev, 1974) there has been shown the essential importance of definition of a pair of galaxies and of statistical homogeneity of a sample of pairs for analysis of their dynamical state. The interpretation of large values of orbital masses of some double galaxies in terms of "stability/instability" of double systems or "presence/absence" of hidden masses is dependent to a considerable degree on the estimate of expected number of accidental

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pairs in the sample under consideration.

Two galaxies situated in space so close to each other that the contribution of the neighbouring galaxies to potential energy of the pair is negligibly small are naturally called a physical pair. Pratically, only observable values can be used in selection of double galaxies : apparent magnitudes, angular diameters, and projections of mutual distances of galaxies. It is preferable that in making up a sample of pairs radial velocities of galaxies should not be taken into account in order to avoid an observational bias. Apparently every criterion of a double galaxy must, if possible, satisfy the following conditions :

a) to include in the sample a few accidental optical pairs, say, no more than (IO - 2O)%,

b) to preserve in the sample a considerable part, say, 5O% of physical pairs. The two conditions define a statistical efficiency of the criterion,

c) the criterion must be synonymous, i. e. excluding a situation when one galaxy could be a member of different pairs,

d) the criterion must be symmetrical relative to the measured values of both components of a pair, but not that of galaxy's membership of the pair,

e) application of the criterion must be convenient requiring, in particular, finite examination of the neighbouring galaxies.

A number of criteria for a pair of galaxies have been suggested by different authors (Lundmark, 1927, Holmberg, 1937, Karachentsev, 1972, Turner, 1976). Comparison of these criteria in efficiency and other features mentioned is a special task which is not considered here.

In this report we confine ourselves to a discussion of the data on the dynamics and morphological features of double galaxies from catalogue "CPG" (Karachentsev, 1972) which contains 603 northern sky pairs whose apparent magnitudes of components are brighter than $15^{m}_{.}7$.

II. The basic data on the sample. In table I there presented the general data on the catalogue of 603 pairs of galaxies : the number of the objects overlapping with catalogues by Holmberg (1937), CGCG (Zwicky et al., 1961-1968), MCG (Vorontsov-Velyaminov et al., 1962-1968) and with atlases of interacting galaxies by Vorontsov-Velyaminov (1959) and Arp (1966). As can be seen from these data, more than half of the pairs (55%) have features of interaction between the components. Using catalogue MCG we have the same relative number of interacting systems (190/332 = 56%), which confirms the reality of the indicated features of interaction. As it is known the appearances of interaction between galaxies are quite diverse and difficult to be classified. Nevertheless the cases of interaction can be reduced to three basic types : a) the presence of linear structures in the form of tails and bridges in the pair's components, "LIN", b) the distortion of the shape of one or both components, "DIS", c) the presence of the amorphous or shredded atmosphere which envelopes the components, "ATM". According to the data of Table I each of these types of interaction occurs in the sample of pairs at about the same frequency.

In the last lines of Table I there indicated the number of pairs with different combinations of morphological types of components, and also the number of double galaxies satisfying criteria of isolateness with different levels of hardness.

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The preliminary calculation shows that among strongly isolated pairs (criterion "++") the number of optical pairs is one order smaller than in the pairs satisfying only the basic, soft ("--") criterion of the catalogue.

Table I

The numbers of double galaxies from catalogue CPG grouped in accordance with different features.

Sample type	Number
All pairs	603
Common with Holmberg	108
Common with CGCG	176
Common with MCG	336
Common with Arp	84
Common with AIG (VV)	81
Interacting pairs	332
"LIN" - interacting	104
"DIS" - interacting	133
"ATM" - interacting	95
Interacting according to MCG	190
"EE" - pairs	79
"ES, SE" - pairs	165
"SS" - pairs	359
Strongly isolated ("+ +")	204
Medium isolated ("+ -, - +")	243
Weakly isolated ("- -")	156

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III. Dynamical state of pairs of galaxies. The problem of motion of galaxies in pairs was studied by many authors. In the classical works by Page (1952, 1961) a method was developed for determination of the mean mass of double galaxies under assumption of circular motions of components. Also the regressions of radial velocity difference of components on the projection of their mutual distance, $E\left\{\Delta V_r \mid x\right\}$, were calculated by Page for the cases of circular and parabolic motions. Later on the problem of determining the type of motion in pairs by $E\left\{\Delta V_r \mid x\right\}$ -regression method was considered by Zonn (1968), Karachentsev (1970), Noerdlinger (1975) and Turner (1976). Another method based on the dependence of the double galaxy mass distribution on the supposed type of motion in pairs was employed by Page (1952), Karachentsev and Shcherbanovsky (1970), Jenner (1974), and Karachentsev (1975). These studies differ by both the observational material used and the completeness of the analysis of different types of motion in double galaxies. The absence of the common opinion with the authors of the papers mentioned on the dominant type of motion in pairs is apparently caused by the lack and inhomogeneity of the statistical data.

The subject of our further discussion will be the sample of 148 double galaxies from catalogue CPG in which a difference of radial velocities of the components has been measured. In comparison with the data presented earlier (Karachentsev, 1975), here are used the results of the late radial velocity measurements by Karachentsev et al. (1976), Turner (1976), Tully (private communication) and Karachentsev (1976).*

* - Besides, to make the homogeneity of the sample better we have excluded from the list (Karachentsev, 1975) 31 southern and faint pairs which are not contained in CPG.

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For any pair of galaxies, which has the difference of radial velocities, V_r, the projection of the linear distance between the components, x , and the integral luminosity, L , the unbiased estimate of the orbital mass-to-luminosity ratio, $f = \mathcal{M}/L$, is

$$f = (32/3\pi)\,(1 - 2e^2/3)^{-1}\,\gamma^{-1}(\Delta v_r^2 - \delta^2_{\Delta v})\,.\,x.\,L^{-1},$$

where γ is the gravitational constant, e is the orbital eccentricity, and $\sigma_{\Delta v}$ is the root mean square error of the radial velocity difference measurement. For the sake of certainty let us confine ourselves to the case of circular motions ($e = 0$) at which the value of f is minimum.

With no regard for five obviously optical pairs (see the discussion below) the mean value of circular mass-to-luminosity ratio for 143 pairs is (18 $\pm$ 5) $f_\odot$ at Hubble's constant H = 75 km/s Mpc.

Table II

The mean unbiased value of the circular mass-to-luminosity ratio and the standard error of the mean for different samples of double galaxies.

Sample	n	$\langle f \rangle \pm \sigma_{\langle f \rangle}$
All pairs	143	18 $\pm$ 5
"EE"	19	17 $\pm$ 6
"ES, SE"	31	39 $\pm$ 13
"SS"	93	11 $\pm$ 5
"LIN"	35	7 $\pm$ 3
"DIS"	43	32 $\pm$ 12
"ATM"	28	12 $\pm$ 4
Compact	33	14 $\pm$ 5
Markarian	28	10 $\pm$ 7
"+ +"	56	11 $\pm$ 6
"+ -, - +"	58	24 $\pm$ 8
"- -"	29	21 $\pm$ 9

In table II there presented the mean values, $\langle f \rangle$, with indication of standard errors of the mean, $\sigma_{\langle f \rangle}$, and the sample numbers, n, for the pairs grouped according to the morphological type of the components, the type of interaction, and the degree of pair isolateness. Separately are given the pairs whose members are compact Zwicky's galaxies and blue Markarian objects.

Consideration of this data allows to draw the following conclusions :

i) the mean orbital mass-to-luminosity ratio for 143 pairs is essentially smaller (by a factor 5) than the estimate by Page (1961) and only 2-3 times the normal value found from the rotation of galaxies,

ii) in "SS" - pairs the value of $\langle f \rangle$ is about a factor 2 smaller than in "EE" - and "ES" - pairs,

iii) pairs of galaxies with different types of interaction between the components have markedly different values of $\langle f \rangle$,

iv) mass-to-luminosity ratio has a tendency to decrease from weakly isolated pairs to strongly isolated, which may evidence for a presence of optical pairs in the sample.

Let us consider each of these points separatly.

i. In the recent paper by Turner (1976), where the author has paid the most thoroughful attention to the question of the purity and homogeneity of the sample of double galaxies, the mean circular mass-to-luminosity ratio $\langle f \rangle = 90 f_{\odot}$ at H = 75 km/s Mpc turned out to be quite close to Page's estimate. The difference between Turner's and our estimates is apparently caused rather by the softness of the criterion of double galaxies he used than by the smaller (about 2 times) population of Turner's sample.

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Indeed, out of 156 Turner's pairs more than half of them (80 pairs) are contained in CPG, however, only one pair out 8 optical pairs according to Turner (those in which $|\Delta V_r| > 425$ km/s) appears in our catalogue. The distribution of the linear distance projection for 143 pairs is steeper when $x > \langle x \rangle$ (see Fig. I) than the distribution $N(x) \sim x^{1/2}$ obtained by Turner. Therefore we suggest that the difference of $\langle f \rangle$ -estimates, $18 f_\odot \longleftrightarrow 90 f_\odot$, are due to a smaller number of optical pairs in our sample.

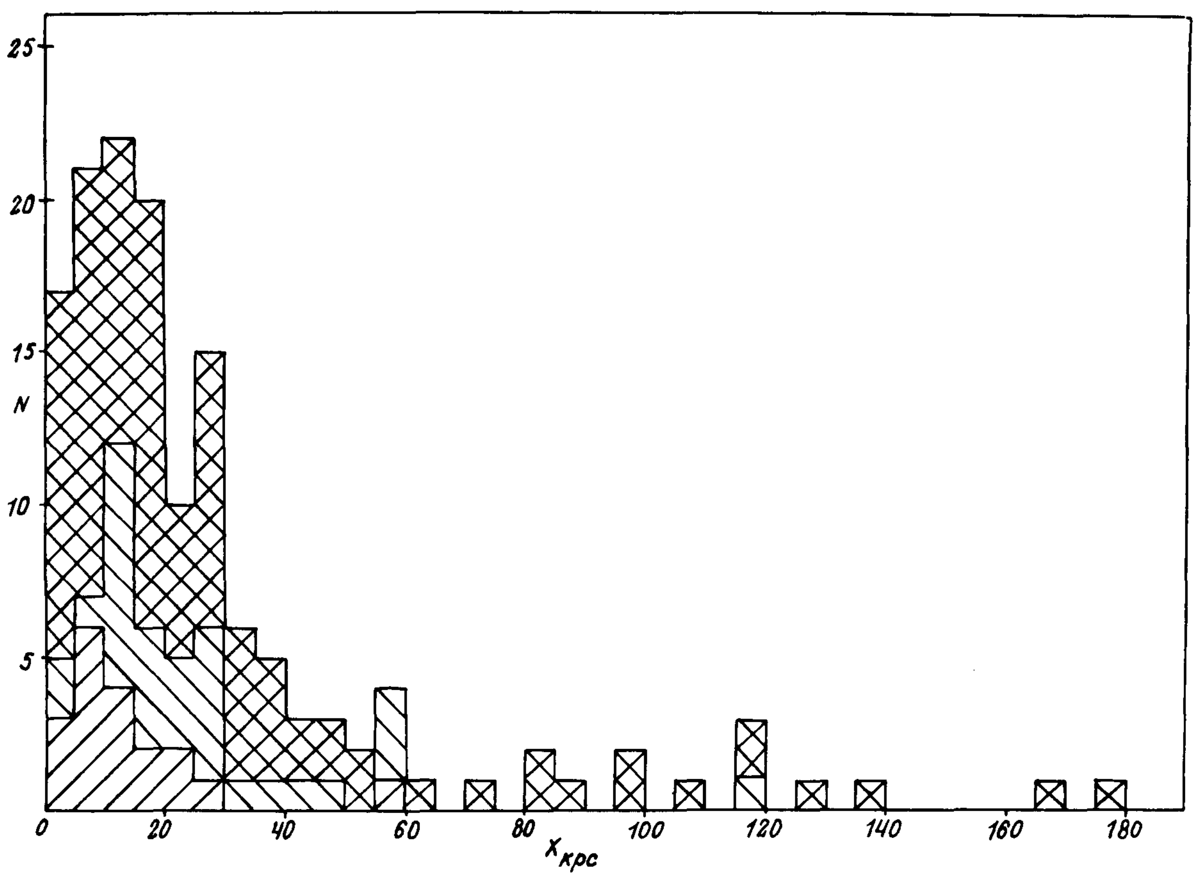

Fig. I. The distribution of the linear distance projection for 143 double galaxies. The pairs with different morphological type of galaxies are marked by various symbols :

◩ - EE, ⧅ - ES, SE, ⊠ - SS.

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ii. According to Turner (1976) the mean ratio f_E/f_S is 2.0 ± 0.5, which corresponds approximately to the data in Table II. Note, however, that $\langle f \rangle$ is essentially dependent on the presence in the sample of one or several pairs having large values of f. If one excludes the pairs with $f > 100 f_\odot$ as optical, we have then $\langle f_{SS} \rangle = (4 \pm 3)\, f_\odot$, $\langle f_{ES} \rangle = (14 \pm 5)\, f_\odot$, and $\langle f_{EE} \rangle = (17 \pm 6) f_\odot$.

As can be seen from Fig. I, the pairs with one or both E-components have on the average smaller mutual distances than SS- pairs. This fact resembles the known segregation of E- and S- galaxies in clusters. The difference in luminosities of E- and S- components is not large : $\langle m_E - m_S \rangle = 0\overset{m}{.}12 \pm 0\overset{m}{.}08$ over 131 pairs with the mixed morphological composition.

iii. The progress in explaining of interaction phenomena for double galaxies on the basis of tidal theory (Toomre, 1974) will apparently allow to link the morphological pecularities of interaction with the parameters of interacting galaxies and also with the phase of their orbital motion. As far as we know, no definite attempts have been made to compare the kinematic data, $\{\Delta V_r , \ x\}$, with the presence of certain tidal features of the pair's components. In order to draw attention to this point we present in Table 3 the following data : the type or interaction, the number of pairs from CPG with the given type of interaction, the relative number of elliptical galaxies in each sample, E (%), the mean linear distance between components in projection, x , maximum linear separation, x_{max} , and the circular mass-to-luminosity ratio, $\langle f \rangle$. The latter three values refer only to the pairs with the measured radial velocities of components. This data gives the initial notion about the effective radius of each type of interaction.

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As can be seen, the $\langle f \rangle$ - values are close in the majority of cases to the normal value calculated from rotation of galaxies.

Let us point out an interesting feature which is not evident in the theory of tidal phenomena. In the pairs, where the structure distortion occurs only in one component, they are observed mostly (61%) in the brighter component.

iv. As it was stated above, five pairs of galaxies (n°110, 160, 344, 357, 391 in CPG) were excluded from the consideration as optical. All of them do not show any distinct signs of physical interconnection and have $f \gtrsim 500\ f_\odot$. In each pair the fainter component has a larger radial velocity.

Table III.

The parameters of interacting double galaxies

Type of interaction		Number of pairs	E(%)	$\langle x \rangle$ kpc	x_{max} kpc	$\langle f \rangle \pm \sigma_{\langle f \rangle}$ $f_\odot$
	("bridge"	49	14	20	73	10 ± 5
"LIN"	("bridge+tail"	22	18	25	41	5 ± 4
	("tail"	33	32	20	109	2 ± 5
"DIS"	(one	87	18	29	96	58 ± 22
	(both	46	4	22	88	8 ± 10
	(amorphous	37	90	12	23	9 ± 5
"ATM"	(shredded	58	32	12	42	13 ± 5
Noninteracting		271	26	52	179	18 ± 9

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If, according to Fesenko (1975), one consideres any pair with $f > 100 f_{\odot}$ as optical, it is necessary then to exclude eight more pairs (n°127, 202, 210, 218, 349, 356, 396, 419) from 143. For the components of seven pairs there also take place the coincidence of Δm- and ΔV_r - signs, which increase the suspicion that they are fictitious. By arbitrary combination of galaxies with the measured radial velocities from CPG we have obtained a sample of surely accidental pairs in whose components the frequency of Δm- and ΔV_r - sign coincidence is 0.84 ± 0.04. This confirms the supposition on the accidental nature of pairs with $f > 100 f_{\odot}$ *). The exclusion of these 8 pairs levels the difference in $\langle f \rangle$ between strongly and weakly isolated pairs. So without 9% pairs treated as a result of accidental projection the mean circular mass-to-luminosity ratio, $\langle f \rangle = (8 \pm 3)\, f_{\odot}$, is in excellent agreement with the normal value calculated from the inner motion of stars in galaxies (Chiao and Reinchardt, 1973, Faber and Jackson, 1976).

On the other hand, 5 out of 8 pairs having $f > 100\, f_{\odot}$ show interaction signs. So the members of the nearest pair n°218, M81 and M82, have a weak bridge visible in the optical-and radio-range and consequently belong to united physical system. For any type of their orbital motion the minimum value of the orbital mass-to-luminosity ratio, $37\, f_{\odot}$, is too large for the late-type galaxies. Apparently new careful observation are needed to check up the presence of physical connection in the components of double galaxies with a large difference of radial velocity.

* - We do not discuss other variants of explaining this effect viz. a) the existence of non-Doppler redshifts dependent on the luminosity of galactic nucleus, b) mutual removing of the pair's components enveloped in an absorbing matter, etc.

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IV. On the absence of massive haloes around double galaxies.

Ostriker and Peebles (1973), and Einasto et al. (1974) supposed that around galaxies there existed massive hidden haloes wich extended to distances of 0. 1 - I. 0 Mpc. One of Einasto's argument in favour of the presence of haloes was the dependence of double galaxy orbital mass on the distance between ist components. The data on 143 double galaxies represents the most suitable material for checking this hypothesis.

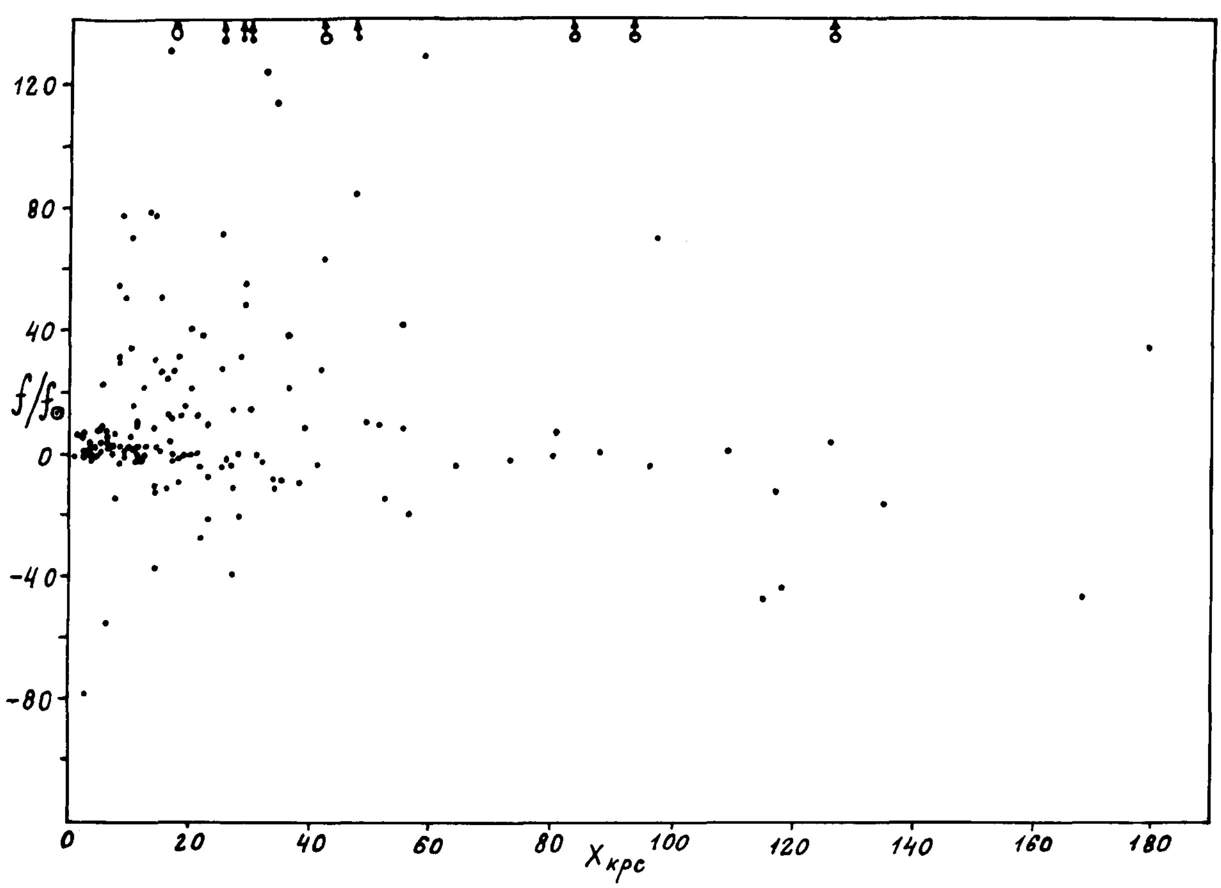

Fig. II. The distribution of the unbiased value of the circular mass-to-luminosity ratio, $f/f_{\odot}$, and of the linear distance projection for 148 pairs. Five optical pairs are denoted by open circles at the top of the Figure.

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In Fig. II there presented the distribution of the orbital mass-to-luminosity ratio, f , and of the projection of linear distance between the components, x_{kpc} , for 143 pairs. Note that the negative values of f correspond to the pairs in which the difference or radial velocities is smaller than the error of its measurement, $\Delta V_r^2 < \sigma^2_{\Delta v}$. As it can be seen, there is no systematic increase fo f (x). For 8 pairs with $x > 100$ kpc we have $\langle f \mid x > 100 \text{ kpc} \rangle = (-16 \pm 10) f_{\odot}$. Since the distance x is introduced as a multiplier in the mass estimate, overestimation of radial velocity errors for the components of wide pairs may affect in a systematical way on the dependence $\langle f \mid x \rangle$. However, assuming even $\sigma_{\Delta v} = 0$ we have $\langle f^{*} \mid x > 100 \text{ kpc} \rangle = (20 \pm 8) f_{\odot}$. Thus the data considered does not provide any evidence for existence of massive hidden haloes around double galaxies.

V. Concluding remark. We consider it necessary to emphasize that only one fourth of the CPG- pairs is covered by spectral observations. The reasons affecting the selection of this or that pair for radial velocity measurement varied. Therefore the sample we have considered may contain a number of biases which are difficult to be statistically analyzed. We hope that the answer to the question on the dynamical state of double galaxies will be obtained after the accomplishment of spectral survey of the whole catalogue of double galaxies.

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