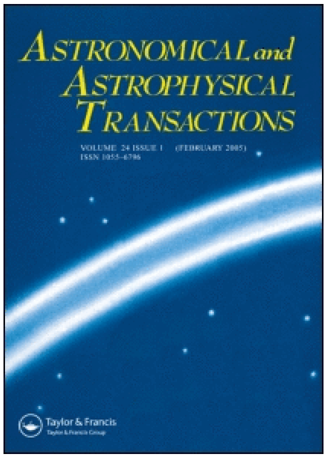

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THE CONNECTION BETWEEN THE INTERACTION OF GALAXIES AND THEIR ACTIVITY

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The observations of the last decade indicate quite clearly the connection between the galactic nuclei activity (quasars, powerful radio sources) as well star formation in superluminal infrared galaxies with the interaction and even merging of galaxies.

The merging model leads to "explosive" evolution which naturally explains the abrupt disappearance of quasars and radio galaxies at large redshifts $z > z_{\rm cr}$. For this it is quite enough to have the merging of objects which appeared in the epoch of recombination with the (Jeans) mass of the order of 10^5 to 10^6 $M_\odot$.

KEY WORDS Galaxies, quasars, radio galaxies, activity, interactions, merging, explosive evolution, luminosity function

1 INTRODUCTION. IDEAS AND MOTTOES

The idea of connection between the activity of galaxies and their interaction was expressed in fact just after the discovery of the very first radio galaxies (Baade and Minkovsky, 1954) concerning Cyg A, but later it was neglected for a long time. Nevertheless the observations accumulated later and results of theoretical evaluations and model supercomputer calculations made it necessary to return to the old idea at a new level. A successful search for active objects among the interacting personages of the catalogues Arp (1966), Arp and Madore (1987) and Vorontsov-Velyaminov (1977) is now aptly added with the finds of interacting galaxies among active objects such as superantennae, for a most powerful IR (Mirabel *et al.*, 1991) source (Figure 1).

The previous decade had passed under the mottoes:

Stoking the furnace
Toomre & Toomre, 1972

Feeding the monster
Gunn, 1979

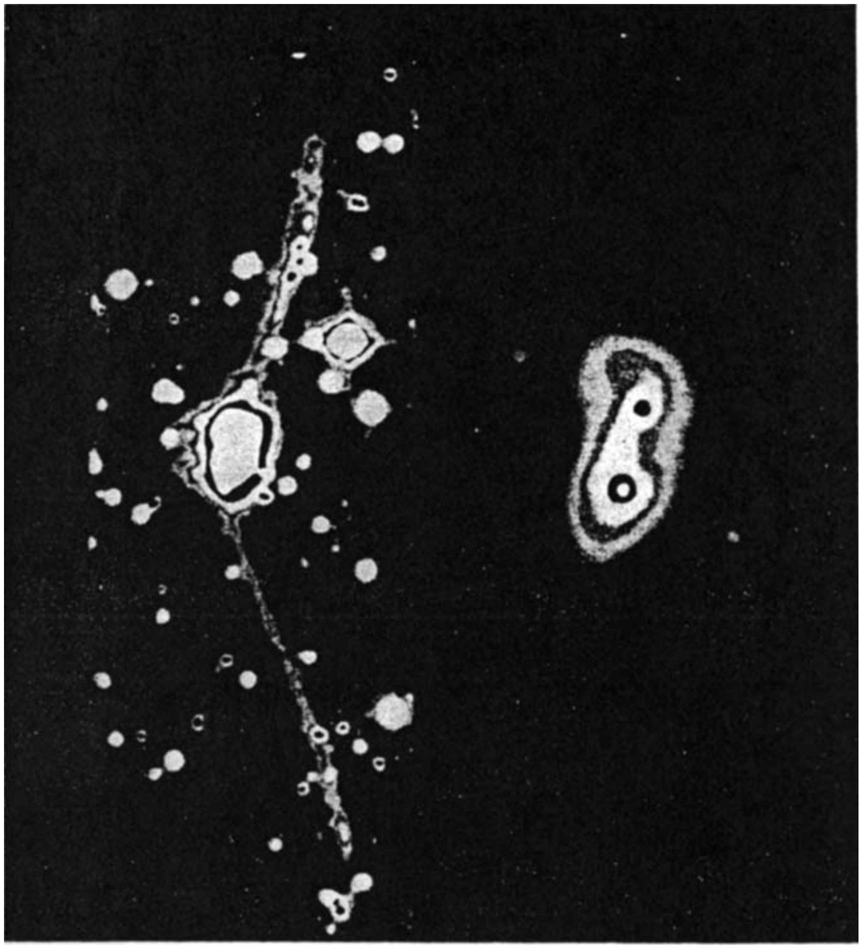

Figure 1 The superantennae (Mirabel *et al.*, 1991). Interacting galaxies with a tidal configuration close to the well-known "Antennae". The central part which contains two nuclei is shown on the right. These galaxies were found at a place of a strong IR source from the IRAS list. Such a method for search of interacting systems proved very fruitful.

In the case of powerful sources only such a grandiose phenomenon as interaction and merging of galaxies can give the necessary supply of fuel–feeding to the monster–furnace, i.e., the mass flow towards the central compact objects. A confirmation of this has been found in many close active objects (see pioneering photographs by Stocton (1982), Figure 2 and CCD picture from Hutching's review (1983), Figure 3). In favour of the interaction and merging hypothesis also witness the statistical data referring to more distant objects as the preference of quasars to the groups (z <0.4–0.6) and rich galaxy (z >0.4–0.6) clusters (Yee and Green, 1987) and such cosmological tests as data on luminosity functions (see Bingelli *et al.*, 1988) and source countings (Figure 4). And finally, natural explanation of active object

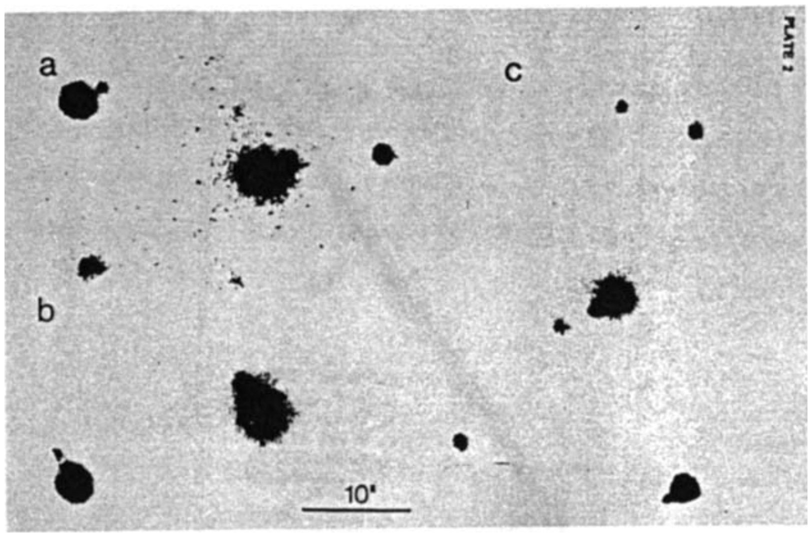

Figure 2 Three photoplates with QSO's interacting with their close companions (Stocton, 1982). In the corner of each of the plates the image with the highest resolution is placed. Redshift closeness was the argument for attributing them as physical pairs. Later the number of examples both in continuum and in lines was essentially increased (see ref. in Stocton's 1990 review); there are also references to critical analysis of the first results, particularly proof of objects closeness (which requires better spectroscopy).

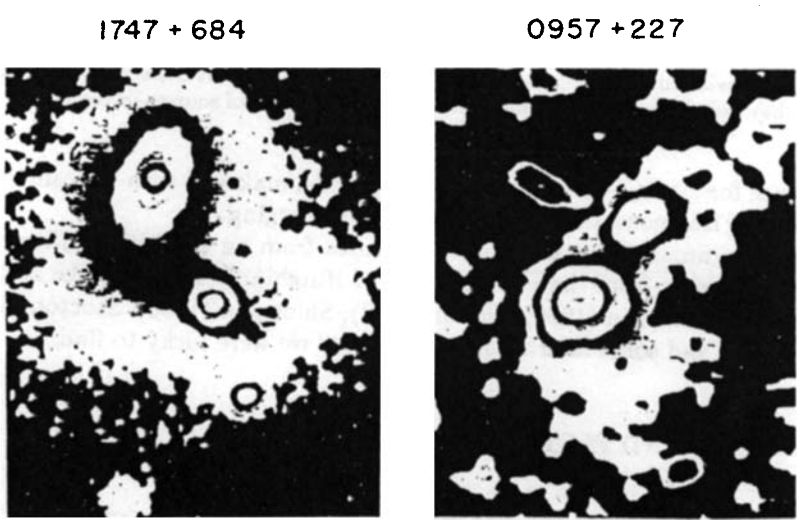

Figure 3 CCD pictures of the QSO host galaxy interacting with a neighbouring galaxy (Hutchings, 1983).

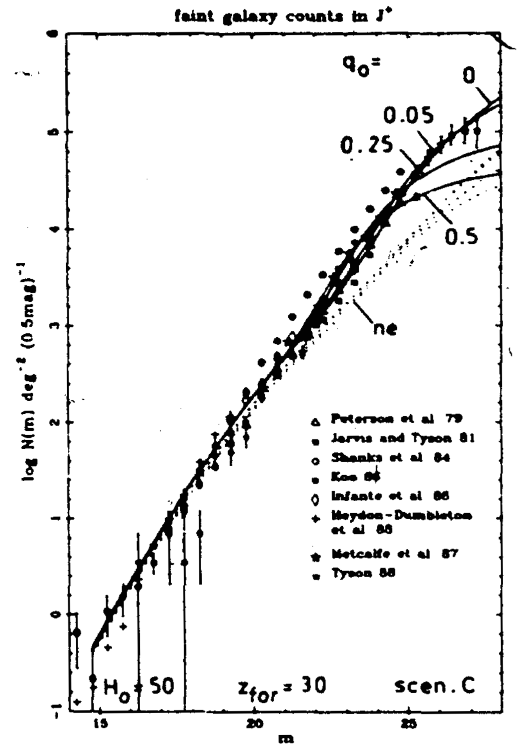

Figure 4 The deceleration parameter q influence on faint galaxy counts (Guiderdoni and Rocca-Volmerange, 1990. See ref. in their work). One can see the excess of weak far sources for the value of $q = 0.5$, which is preferable from the theoretical point of view. In model counting the individual galaxy evolution has been taken into account though without changes in their number. Let us note that the merger model naturally increases the number of sources in the past.

disappearance for $z > z_{cr} \sim 2$–3 in the merging model makes us turn to cosmological scenarios not of fragmentation but clustering and merging.

Our short summary gives only some "pictures from an exhibition" illustrating the main idea arising from the vivid reviews of Hutchings (1983), Fricke and Kollatschny (1989), Heckman (1990), Quinn (1990), Shlosman (1990), Stocton (1990), Komberg (1992) and some later interesting papers we were lucky to find.

2 ARGUMENTS AND FACTS

Most often an interaction is identified according to the disturbed morphology which was noted already by Holtzmark (see Ref. in Tremain's review, 1982), though in cases we are interested in there is some danger of including also the morphology disturbed by activity, say by jets – see the depiction of an early galaxy in Figure 5

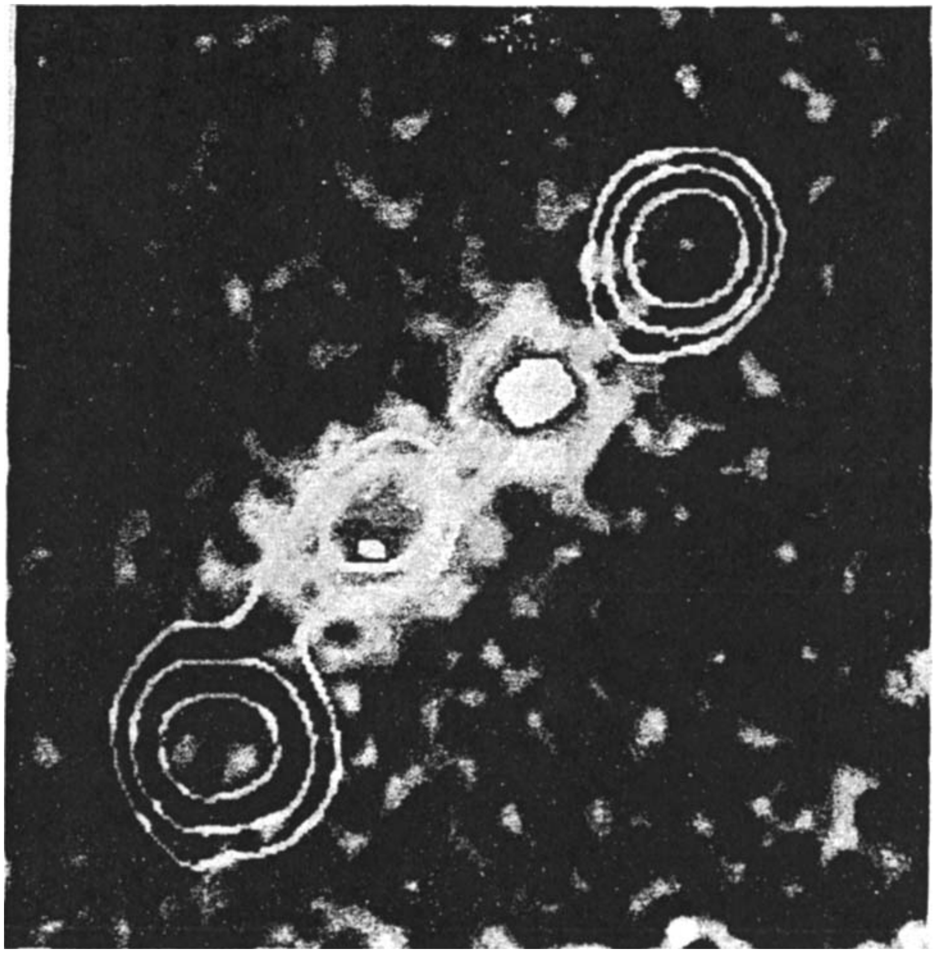

Figure 5 An early galaxy with coinciding optical and radio axes (Miley *et al.*, 1992). This property of early galaxies can be treated both as the indication of interaction and, vice versa, as the back reaction of powerful cosmic jets (typical for radio galaxies) on their optical structure.

from Miley *et al.* (1992), where it is not clear what is primary – interaction or activity. In favour of the interaction may witness the presence of a close companion or in general denser surroundings (the latter is used for more distant objects).

The abundance of Seyfert galaxies in disturbed and interacting systems indicated by Adams (1977) served, according to the reviews sited, as a source of optimism in search for interaction as the cause of activity. And though, as a result of further works, the interaction model became "the dominant paradigma" (Heckman, 1990) in explaining the nucleus activity in radio galaxies and quasars, let alone powerful IR galaxies (see Figure 6), for the Seyferts proper the situation was but little cleared up, and it is quite possible that for these objects of relatively low luminosity as well as for

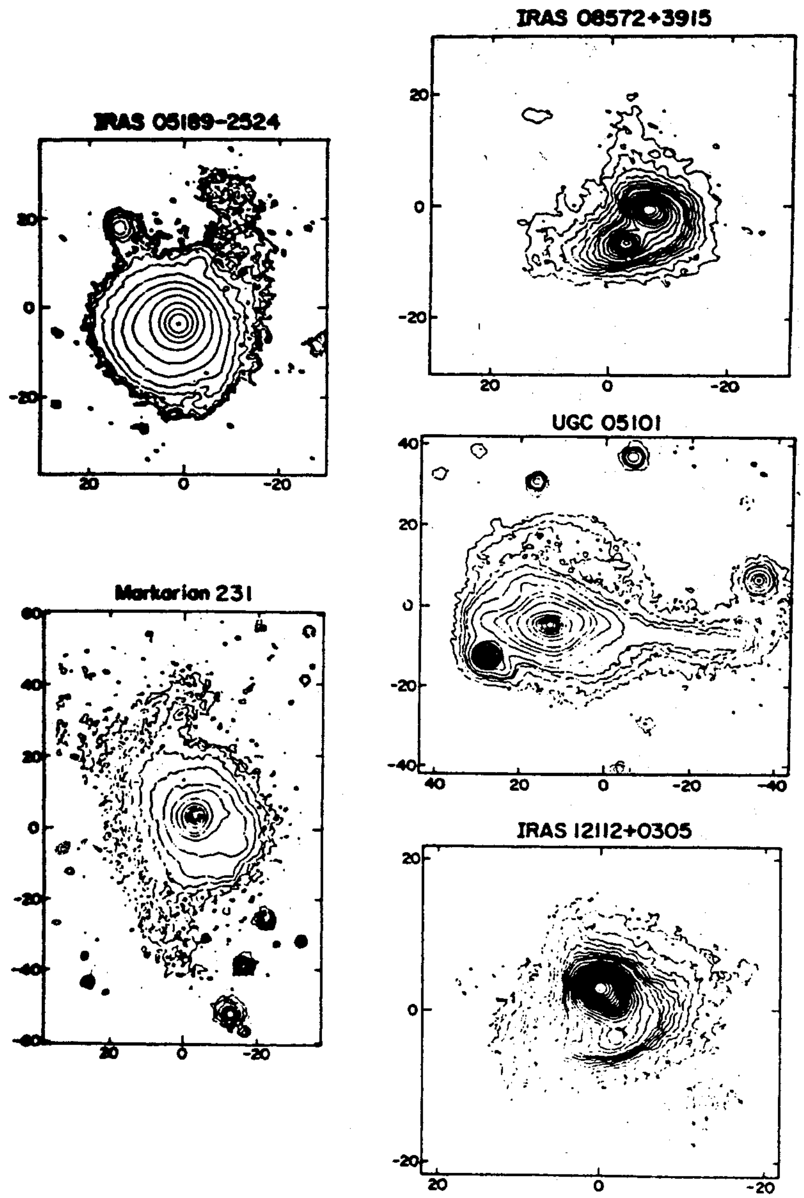

Figure 6 The disturbed structure of superluminal IRAS sources (Sanders *et al.*, 1988). The high resolution of optical images of very powerful IR sources in all cases show strongly disturbed peculiar pictures: double and multiple nuclei, tails and other evidences for tidal interaction.

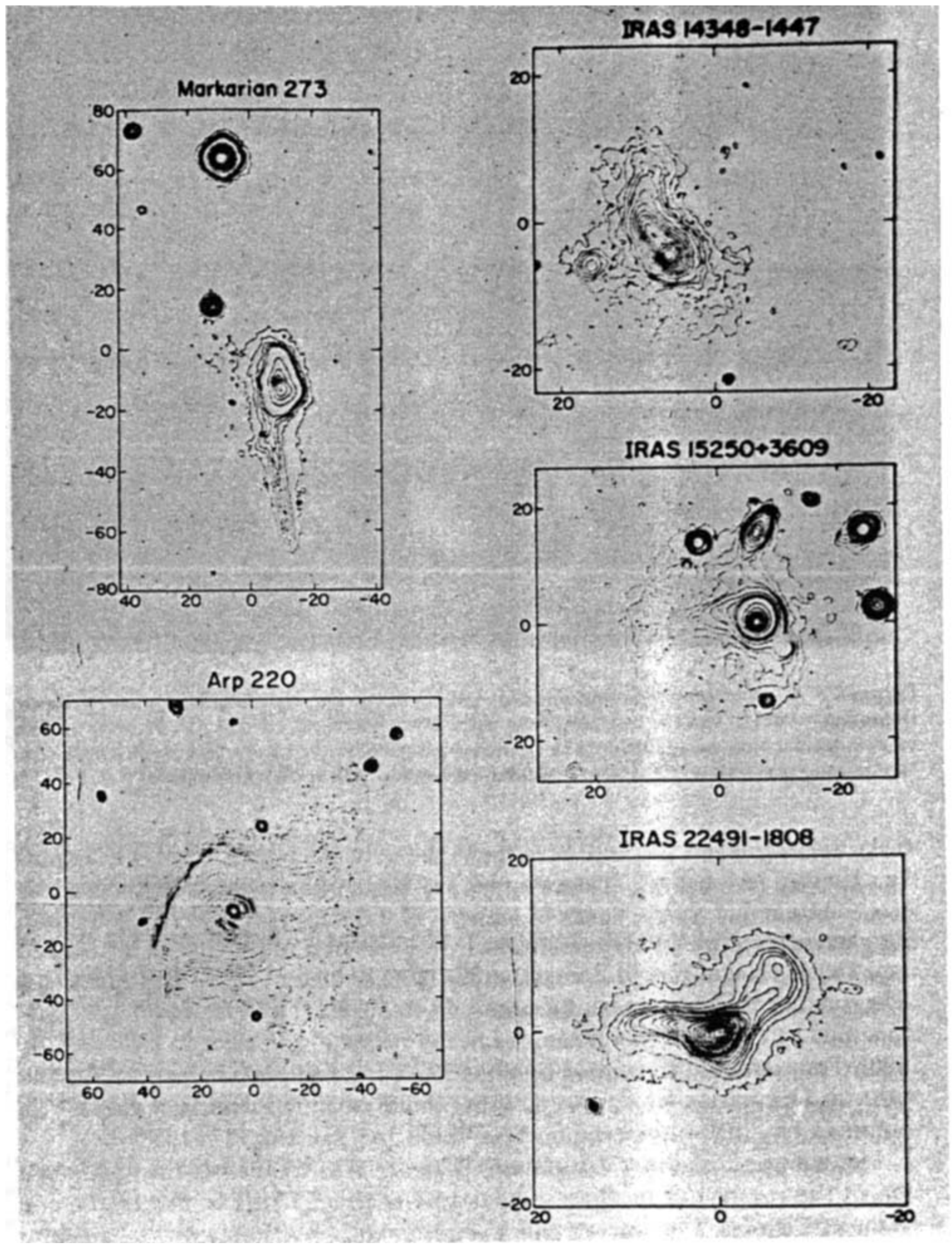

Figure 6 Continued.

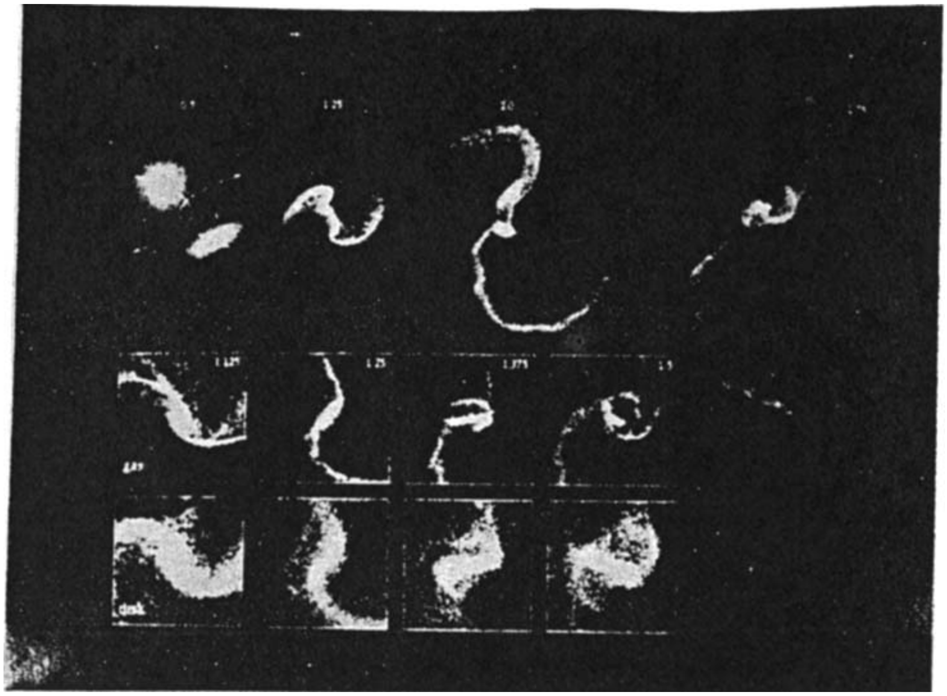

Figure 7 A close parabolic collision and merging of two gas–rich disk/halo galaxies (Barnes and Hernquist, 1991). One of the numerous calculation examples carried out by theses authors on very powerful computers. Each of the galaxies is represented as a set of a great number of points interacting gravitationally (stars – without dissipation, gas – with dissipation).

weak radio galaxies one can do without the outward interference† when explaining the activity (see below). Thus we may say that, what concerns relatively close objects, interaction as the cause of activity of quasars, powerful RG, superluminous IR galaxies is quite reliably established. In particular, if Stocton in his work of 1982 came to the conclusion of interaction for QSO in 20% of cases, Hatchings in 1983 – 30%, sooner this percentage increased up to 35–50%, and for radio loud QSO this amounted to 70–77% (see references in the reviews of Heckman, 1990 and Stocton, 1990). For powerful IR sources from the IRAS catalogue low energy output efficiency with star formation leaves just no other choice but the merging of galaxies. This is confirmed by direct observations (see Table 1 in Sanders *et al.*, 1988).

Model supercomputer calculations begun in the late 70s allowed to get convinced that in the course of merging a great part of matter falls to the centre – see, for example, Figure 7 in Barnes and Hernquist and the results given in other works by these authors. As much effective is the explanation of the shells around the elliptical galaxies (see Figure 8), which in model experiments arise as a result of spiral absorption (Quinn, 1990).

†However see Rafanelli, Violato, 1993.

Table 1.

Morphology	*Moderate* (10–11)	*lg Luminosity* $L/L_\odot$ *High* (11–12)	*Ultra* >12
#-Number of obj.	#80	#80	#10
Strongly interacting	10%	40%	100%
Close pair	15%	30%	-
Isolated	75%	30%	-

IRAS galaxy morphology vs increasing IR luminosity (Sanders *et al.*, 1988).

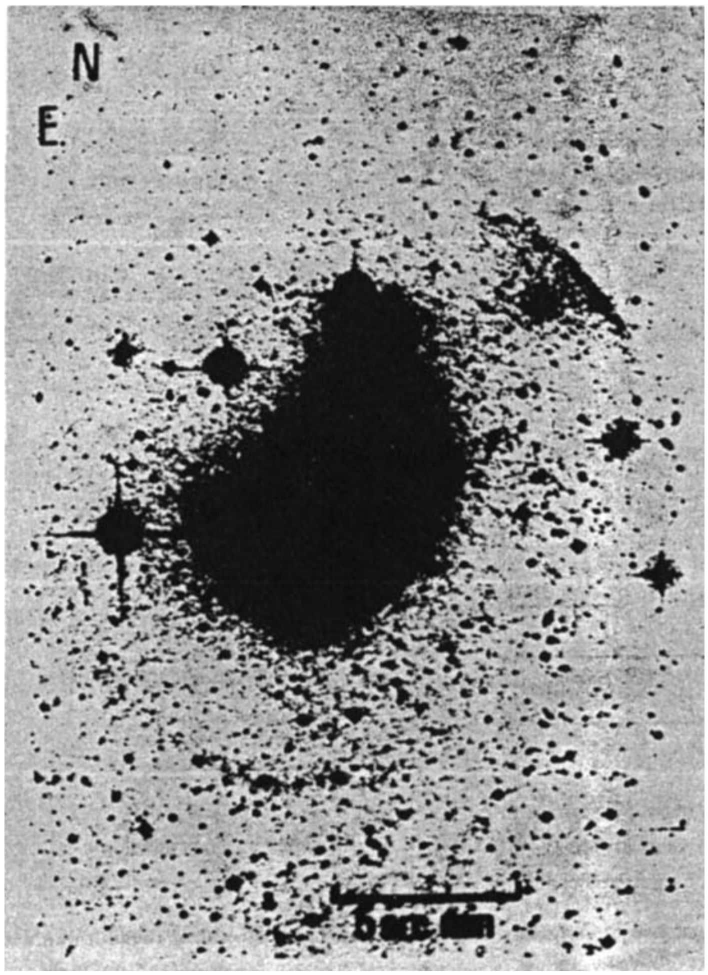

Figure 8 A shell galaxy – a possible remnant from a merger event (review by Quinn, 1990). The figure is a photograph of the galaxy NGC 1344 Malin and Carter, 1983. Model calculations of merging of an elliptical galaxy with a small spiral lead to similar pictures.

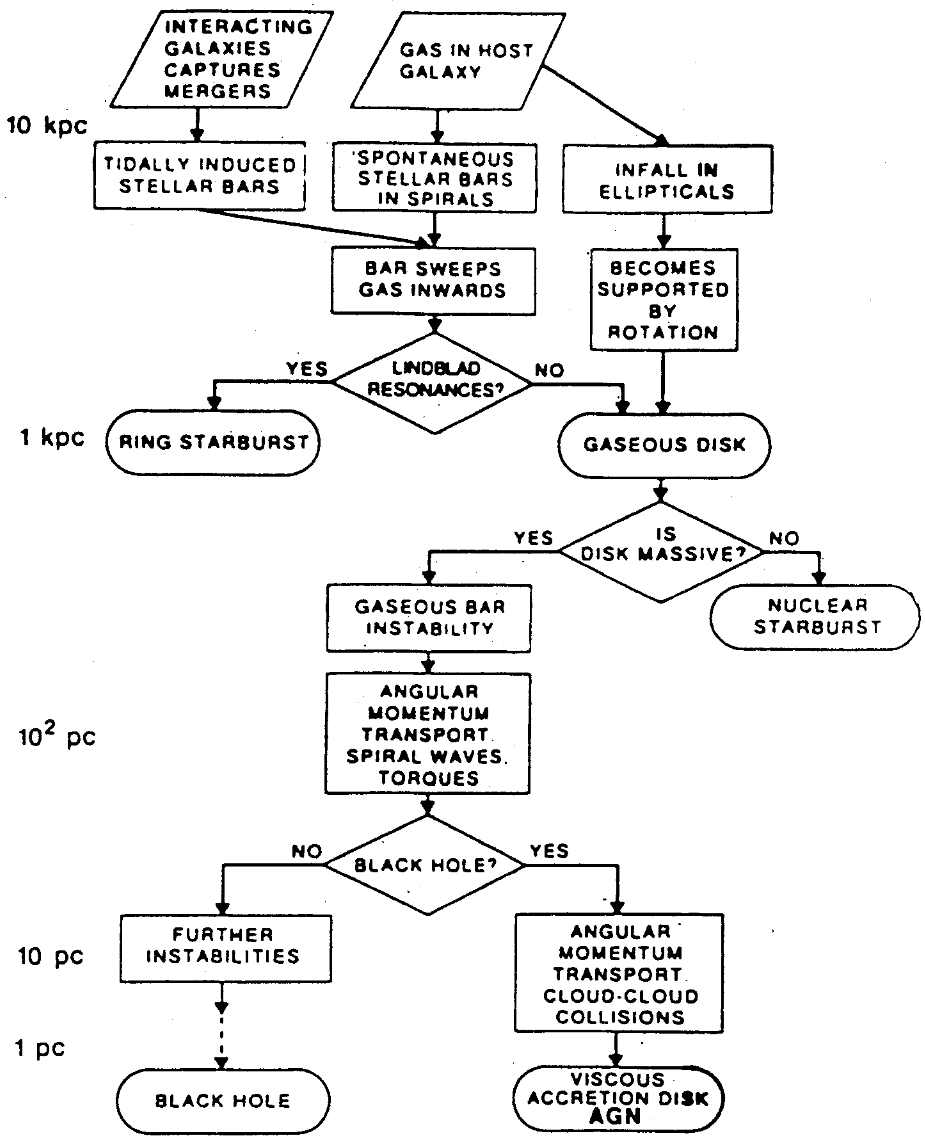

Figure 9 The scheme of angular momentum transfer to the central region of an active galaxy (Shlosman *et al.*, 1990).

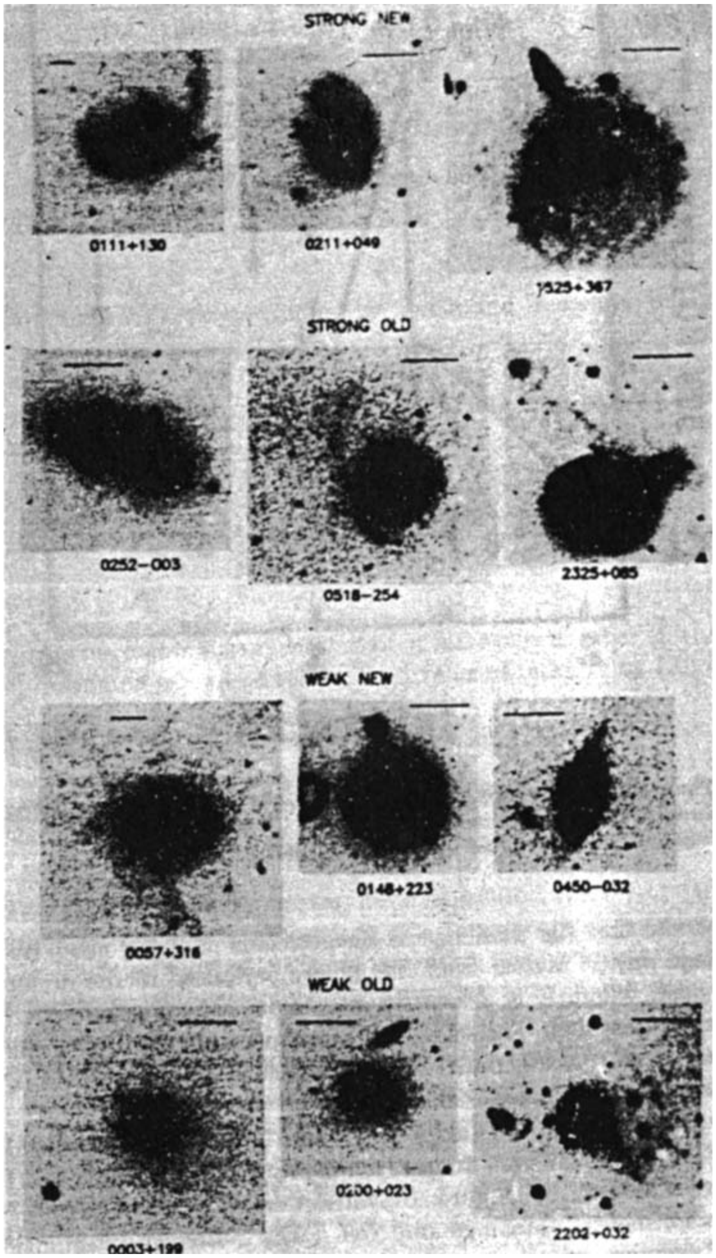

Figure 10 The Strong–Weak and Old–New classification of interacting galaxies by Hutchings and Neff (1991). The authors propose a qualitative estimate of the age and the intensity of interaction basing on morphology and other "rough" data. This gives them a possibility to draw their conclusions about the evolution of the active objects (see the next figure).

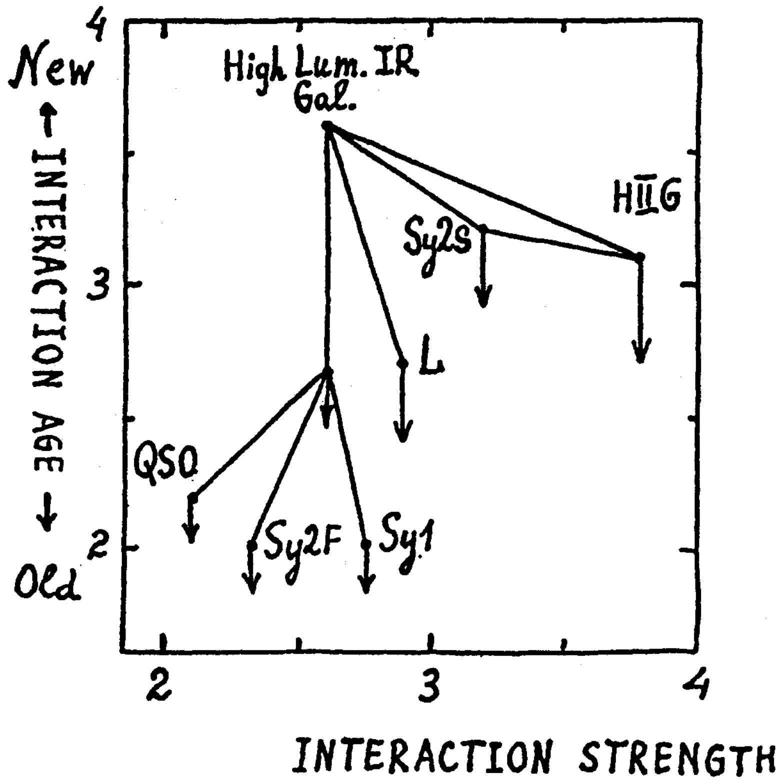

Figure 11 The evolution scheme of interacting IR galaxies to Sy, Liners, H II galaxies and QSO, idem. This scheme is based on the classification of the interaction duration and intensity carried out by Hutchings and Neff (1991) (see the previous figure).

It is no doubt that the challenge to theoreticians is in the necessity of tracing the multi-stage way of matter from the galaxy periphery to the minute as to its size central part, where it is drawn by attraction though interfered by rotation (the momentum presence). The scheme of subsequent instabilities (Figure 9) given in Schlossman *et al.* (1990) makes clear the essence of the problem (see also an analogous scheme in Herriquist, 1989).

To follow the evolution of galaxies as a result of interaction is also possible by studying the objects at different stages of this process. By introducing the scale of age and power of interaction (Figure 10) which is based on the data on morphology, photo- and colorimetry, Hatchings and Neff (1991) obtained an evolution scheme for bright IR galaxies, which, in particular, at later stages of evolution passes into Sy I and Sy II, liners, H II - galaxies, and though with little probability, into QSO (Figure 11).

A study of evolution was carried out by Gubanov (1991) on the ground of radio source spectra. In Table 2 taken from his work which uses the correlation between

Table 2.

RG with pecular morphology	z	Mean value of α_{100}	α_{5000}	*RG without signs of interaction*	z	Mean value of α_{100}	α_{5000}
#19	0.079	0.77	0.77	#21	0.141	0.77	0.91

The correlation between radiospectra and signs of interaction in powerful radiogalaxies (Gubanov, 1991).

radio emission and morphology, studied by Smith and Heckman, one can see that the steepening of radio spectra at high frequencies correlates with the active object age. Hence the author comes to the conclusion that radio galaxies are older then quasars (not in cosmological meaning, of course, but with respect to the start of the interaction).

3 DOUBTS AND HOPES
(The Epoch of Appearance of Massive Galaxies and Quasars)

Quite striking is the fact of disappearance of quasars (the number of which increases to the past) beginning from a certain critical value of redshift z_{cr} (Figure 12). The behaviour of radio sources is similar (Figure 13).

The more striking is the luminosity function of quasar evolution (Figure 14), whose power of steepness does not depend in fact on z, but the point of fall on the bright end displaces with the diminishing of z towards the weak side. The luminosity function seems to be prepared in the far past and as if "fades" approaching our epoch.

Such a paradoxical behavior proves, however, quite natural from the view point of the merging model, which is based on the Smoluchowski equation (see the review by Kats and the author, 1992). Moreover, it finds numerical confirmation in the critical behavior of the merging gravitating systems, being close to the phase transition.

It must be noted that the appearance of active objects (quasars) in the merging model studied results from the moment compensation of the colliding galaxies at merging, which allows a certain part of matter to fall to the centre. Thus the emerging of quasars must accompany the appearance of massive galaxies through merging. So further we shall follow only the mass (and referring the readers to the activity problems in the articles by Kats, Krivitski and the author, 1991, 1992). As early as in the 70s the possibility of a critical behavior of the Smoluchowski equation solution when the probability of merging U increases rather rapidly with the mass M ($U \sim M^u$, $u > 1$; see the reviews by Voloshchuk, 1984, Ernst, 1986, Kats and the author, 1992) was already established. It should be noted that the conclusion was based to a certain extent on the exact solution for

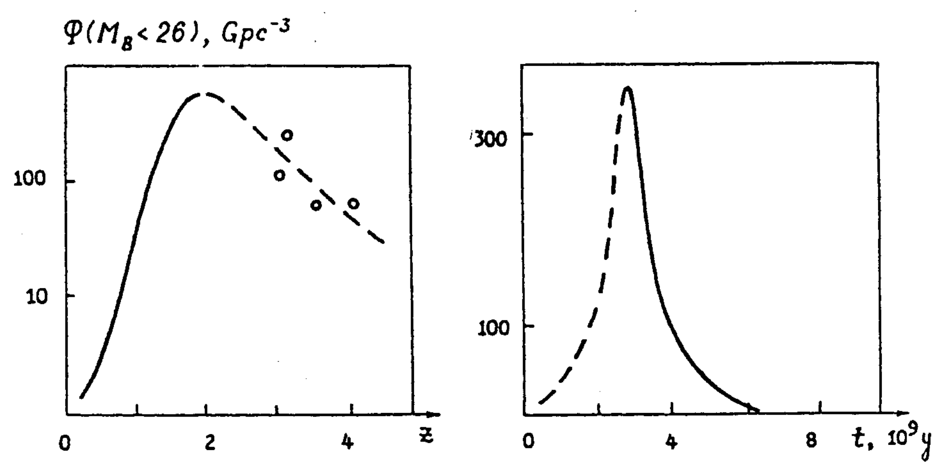

Figure 12 The break of space density of quasars (reviews by Rees, 1990 and Smith, 1989). The growth of quasar density towards the past (in comoving volume) begins decreasing fairly rapidly at some not very strictly defined $z_{cr} = 2–3$, which may indicate the primary birth of quasars in just the same epoch $z \sim z_{cr}$.

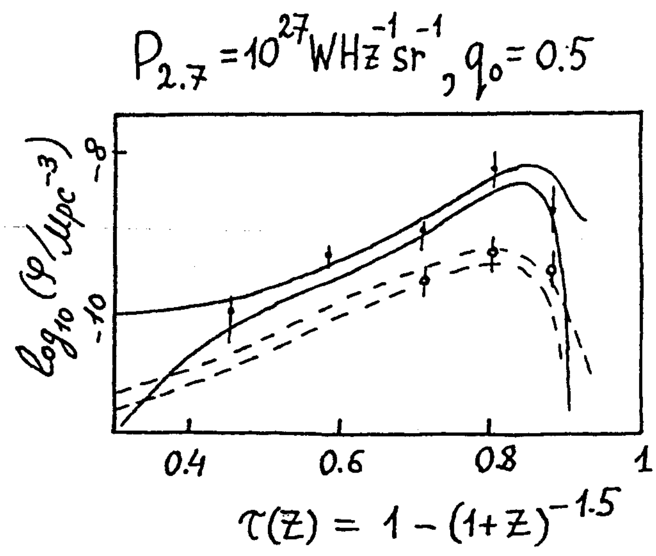

Figure 13 The abruption of space density radio sources (Peakock, 1989). This break analogous to that of quasars in optics was more definitely found in radio sources with flat spectrum (among which there are many quasars) and somewhat less definitely in radio sources with steep spectrum (where radio galaxies predominate).

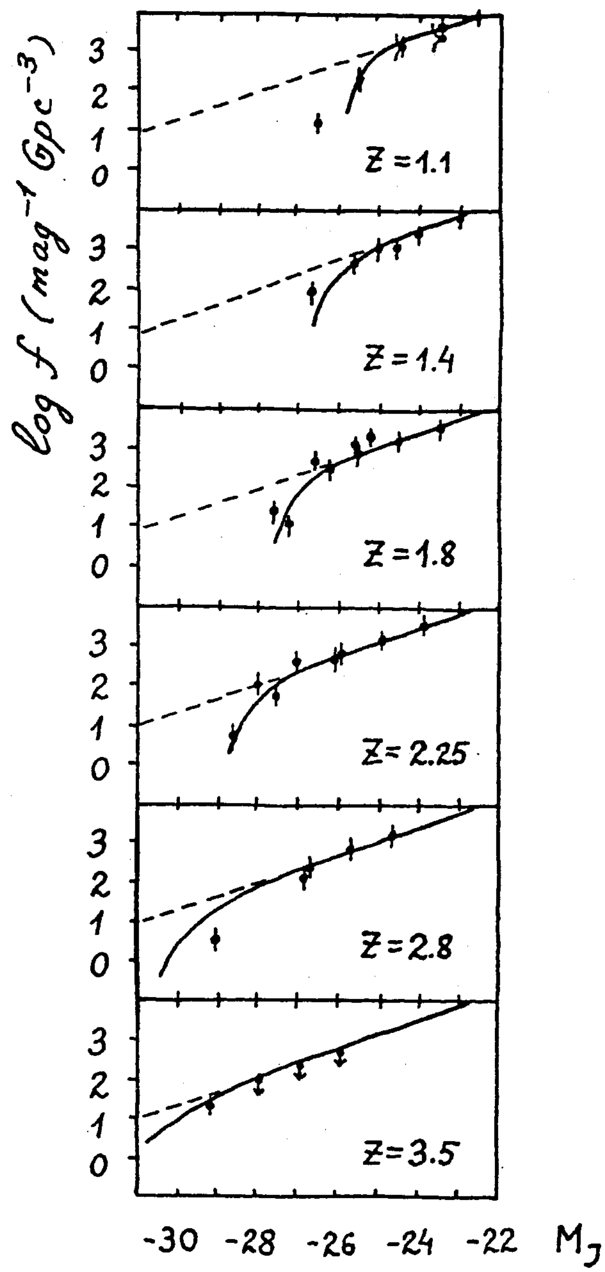

Figure 14 The evolution of the luminosity function of quasars (Koo and Kron, 1983). For all redshifts z the power-like part of LF changes as $1/L$. A similar slope also follows from the data of Boyle *et al.* (1988) and Cristiani *et al.* (1993). The evolution of the LF with z decreasing reminds of the burning up of the formerly settled distribution function on its bright end.

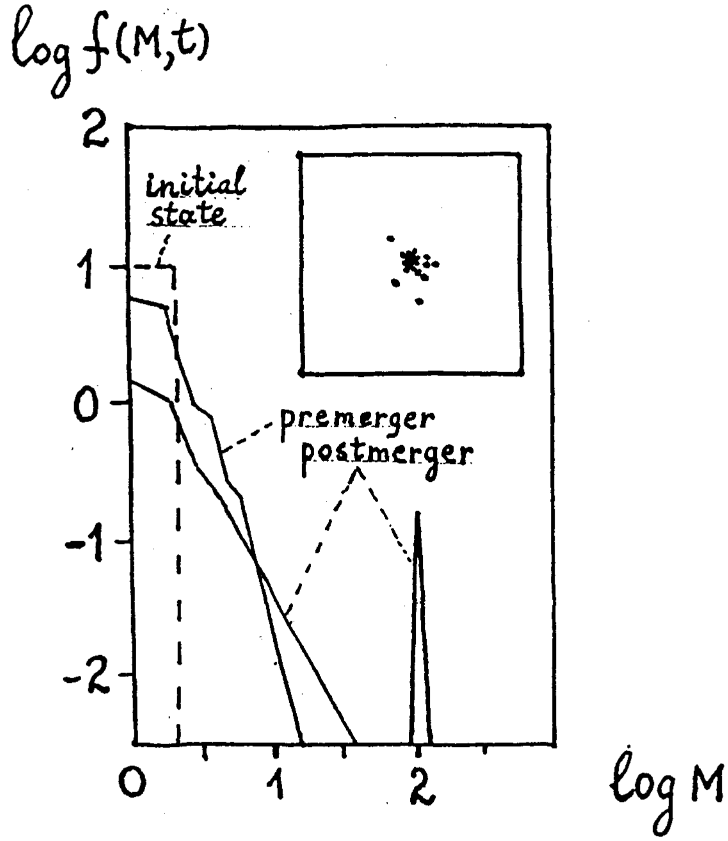

Figure 15 The "phase transition" in a group of galaxies resulting in the formation of a central CD–like galaxy (Cavaliere *et al.*, 1991). The transition takes place as a result of mergings. The numerical solution of the coagulation equation cited in the figure shows that for a finite time from small–mass galaxies making up the group a massive galaxy is formed, identified in theoretical description with a new phase. In the insert shown is the result of the earlier model solution of the dynamic equations in which such a massive galaxy appeared very quickly that finds its explanation in the examined "phase transition".

$U = cM_1M_2$ † (indices numerate the colliding objects). At a finite time, for the initial localized mass distribution a power–law tail develops stretching to infinity, i.e. something reminding a phase transition occurs. Cavaliere *et al.* (1991, 1992) used this idea to explain a rapid formation of gigantic cD galaxies in groups. At the same time, the gigantic galaxy was related with the nearly emerged phase (see Figure 15). Quite independently the idea of critical explosive behaviour in the merging gravitating systems was used by Kats, Krivitski and the author as applied to the formation of massive galaxies and quasars. It is important that for interacting

†For the first results see Stockmayer, 1943 and also Trubnikov, 1971 (refs. in the above last review, 1992).

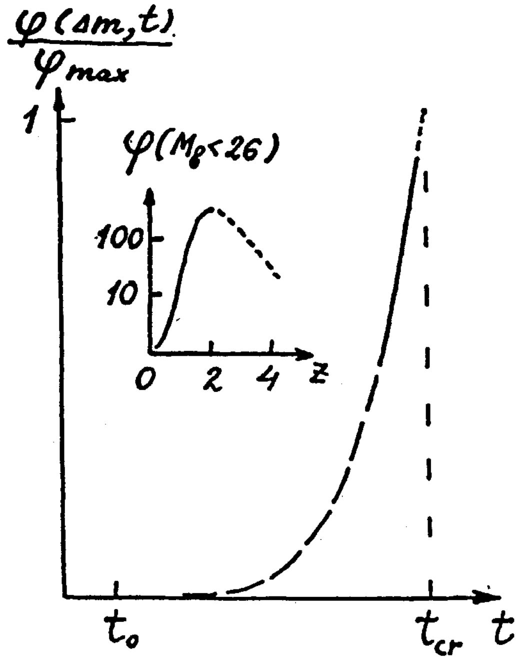

Figure 16 The "explosive" appearance of active objects (quasars) as a result of merging (Kontorovich *et al.*, 1991). This is the result of phase transition-like behaviour of the solution of coalescent equation which in the discussed model of activity leads to "explosive" origin of quasars. In principle it explains the above illustrated abrupt in the distribution of quasars on redshifts (reproduced also in the insert).
Nonexplosive appearance of quasars due to interactions and mergings was discussed in the frames of different schemes of activity by de Roberties (1985), Roos (1985), Carlberg (1990) and other authors. In some of these, the self-similar Press and Shechter's scheme is used. The evolution of quasars not entirely connected with interaction is discussed by Small and Blandford with Blandford's, 1986 motto "Feast or Famine" (in the frame of a black hole nonstationary theory, 1992).

galaxies the index u exceeds unity: $u = 2$ if the masses are small and $u = 1 + \beta$ for large masses, where $\beta > 0$ is defined via $R \sim M^{\beta}$.

Consider now the cosmological scenario. If we take into account the expansion of the Universe and the density dilution (and with the latter the probability of merging decreasing), to realize an adequate number of coagulations, it is needed to maintain very hard conditions for the initial masses, their concentrations and the time of interaction. But they can be maintained, for example, if we let them start in the epoch of recombination ($z_r \sim 1500$) from objects with the mass of order 10^5 to 10^6 $M_{\odot}$, which corresponds for this epoch to the Jeans mass and realizes for isothermal disturbances. Such objects were considered first by Ya. B. Zeldovich with coauthors as unstable forms of "superstars". Peebles and Dicke have shown that they may be stable by fragmenting into stars and survive till nowadays in the form of globular clusters (for this the corresponding pro and contra say).

Type of interaction	Morphology	Star formation and IR luminosity	Spectral type: 0-I wide allowed	Spectral type: II average	Spectral type: III narrow-forbidden	Radio properties: Type	Radio properties: L_2 erg/s	Radio properties: P_2 W/Hz
Multiple merging in rich groups in central parts	Basically SG in rich groups	↑ Growth of star formation rate; Growth of IR luminosity	OSS II (SS) $[10^{-8}]$ Mpc^{-3}	NG (radio)	NLRG	PR II (gEG)	$\geq 10^{44}$	$>10^{25}$
	SG + EG in scattered clusters		QSS (((SE) $[5\times10^{-8}]$ Mpc^{-3}	BLRG $[3\times10^{8}]$	$[3\times10^{7}]$	FR I (cD)	$>10^{43}$	$<10^{25}$
	Basically EG in rich compact clusters		QSS II (EE) $[10^{-8}]$ Mpc^{-3}	NG (no radio)	cD, gE	radioactive nuclei	$<10^{43}$	$<10^{21-24}$
Low-number mergings in poor groups	S + S		QSG (SS), SG	SG II	SG III	↑ Growth of $L_{radio}^{nucleus}$	10^{37-40}	
			Weak RS corresponding to thickening of log N – log S					
	S + E		QSG (SE) $[10^{-7}]$ Mpc^{-3}	LINERS (?) $[3\times10^{6}]$	EG_{pec} $[3\times10^{-5}]$		10^{34-38}	
Galaxy fields or in voids (without interaction)	SG		QSG I (S) $[10^{-6}]$ Mpc^{-3}	Micro SG dw SG	Extended star formation		Weak radio sources	
	EG		QSG I (E) $[10^{-5}]$ Mpc^{-3}	$[3\times10^{5}]$	$[3\times10^{4}]$			
Length of active phase (yr)			$<3\times10^{7}$	3×10^{8}	3×10^{9} → Evolution			
Z of the population			>4 QSO I <4 QSO II	from 2 to 0				

Figure 17 Possible evolutionary scheme of AGN considering merging of galaxies (Komberg, 1992). Evidently, the scheme should not be used literally, in particular, many mergers ought to take place in the process of galaxy evolution.

It is natural in our case to regard them as priming dwarf galaxies whose minority merges to form massive galaxies and active objects such as quasars. In general this point of view confirms the idea of clustering but not only the fragmentation of massive primordial objects, arisen from adiabatic disturbances (though the coagulations of fragments may lead to the same results, but in a more complicated way, see for example, Quinn, 1990).

To conclude, it would be appropriate to quote Zeldovich: "Though adiabatic fluctuations seem physically more natural, there is no need to overlook the possibility of isothermal fluctuations, and, probably, in the finest theory both types of fluctuations would be essential".

4 ACKNOWLEDGEMENTS

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