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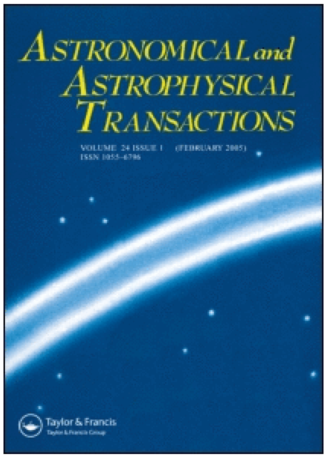

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Small bang on the background of the big one (the epoch of massive galaxies and quasars formation in the merging model)

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SMALL BANG ON THE BACKGROUND OF THE BIG ONE (THE EPOCH OF MASSIVE GALAXIES AND QUASARS FORMATION IN THE MERGING MODEL)

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An explanation of the "sudden" disappearance of quasars at large redshifts is given based on the "explosive" solutions of the Smoluchowsky type kinetic equation.

KEY WORDS **Evolution of quasars, Smoluchowsky equation, coagulation**

1 INTRODUCTION

Arguments pro and contra arising of massive galaxies and active objects (such as quasars, radio galaxies, etc.) by the "explosive" way in the frame of merging model are examined. In the context, "explosion" means that distributions of galaxies on mass and of quasars on luminosity are established in finite time to the largest masses and luminosities (in the expanding Universe). The results are based on the solution properties of the Smoluchowsky type kinetic equation describing coagulation of galaxies for the probability of coagulation growing faster than the first power of mass, valid for standard interaction between galaxies. We also use the activity model based on the galaxy angular momentum compensation in the coagulation process.

The well-known abrupt decrease in the comoving number density of bright quasars and radio galaxies for redshifts $z > z_{\rm cr}$ is naturally explained.

Starting from the initial Jeans masses in the post-recombination epoch ($M_0 \sim 10^5$–$10^6 M_\odot$, we come to reasonable parameters of quasars in their formation epoch.

The phenomenological scheme is also suitable for discussing the evolution of active objects during the later period of time.

If the Eddington luminosity plays the role of a restricting factor, the mass of the black hole in the center of a galaxy and its evolution become important parameters of the theory.

The difficulties of the early star formation in Jeans galaxies may be avoided by regarding merging of pre-star protogalaxies (Lyman-alpha clouds?). Among others, we discuss the following difficulties: the contribution of the orbital momentum; nonconservation of mass and angular momentum in the processes of merging; constrains in using the so-called "anysotropic" momentum distributions of galaxies in the initial state and so on.

2 THE GENERALIZED SMOLUCHOWSKY EQUATION

We consider a scenario in which largemass galaxies are formed due to coalescence (merging process) (Kats, Kontorovich, 1992; Kontorovich, 1994). Their mass function (MF) $f(M,t)$ may be found in this case from the kinetic Smoluchowsky equation (SE):

$$\frac{\partial f(M,t)}{\partial t} = \int dM_1\, dM_2[U_{12}\delta_M f_1 f_2 - \text{cycle} - \text{bicycle}] \tag{1}$$

Here $f_1 \equiv f(M_1,t)$ and so on, $\delta_M \equiv \delta(M - M_1 - M_2)$ is Dirac's δ-function. The dependence of $U_{12} \equiv U(M_1, M_2)$ of the mass of merging galaxies M_1 and M_2 is not known well, but a plausible expression for it leads to:

$$U \propto \begin{cases} (M_1 + M_2)(M_1^\beta + M_2^\beta), & \text{(large masses)} \\ (M_1 + M + M_2)^2, & \text{(small masses)} \end{cases} \tag{2}$$

where the power exponent β is defined by the dependence of the radius of a galaxy on its mass ($R \propto M^\beta$). For the case when the density of a galaxy does not depend on its mass, obviously, $\beta = 1/3$. However, as follows from observations, there are statistical dependences (Faber–Jackson and Tully–Fisher relations) according to which the index β rather equals 1/2 for galaxies (fractals ?).

In the same scenario we discuss the activity of galactic nuclei (AGN) appearing due to merging. Quasars, radio galaxies, and other active galaxies may arise as a result of compensation of angular momentum S via galaxy merging. This leads to the accretion of a part of the matter δm to the black hole in the galactic nucleus, the luminosity (power) L of an AGN in this scenario being proportional to the arising "cold" (disk) mass excess $\delta m(M,S)$: $L = B\delta m$.

Since not only masses but also angular momenta are essential in these processes, one should use the generalized SE (Kats, Kontorovich, 1991a):

$$\frac{\partial f(M,S,t)}{\partial t} = \int d1\, d2[W_{M|M_1M_2} f_1 f_2 - \text{cycle} - \text{bicycle}], \tag{3}$$

$$d1 = dM_1\, dS_1, \quad f_1 = f(M_1, S_1; t),$$

$$W_{M|M_1M_2} = U(M_1, M_2)\delta(M - M_1 - M_2)\delta(S - S_1 - S_2).$$

The model allows us to find the luminosity function of active objects $\varphi(L,t)$, connected with $f(M,S,t)$ by the integral relation quadratic in f. It supposes the luminosity – mass excess Δm relation: $L = B \times \Delta m$ (mass Δm is able to fall to the center).

The model of activity based upon the idea that a galaxy is the bearer of mass and angular momentum is also essential. Further we use some assumptions (Kats, Kontorovich, 1991a, 1991b) in which the complex Eq. (3) is simplified and effectively reduced to the form (1). Some limitations used in such approach may be removed in numerical simulations (anisotropy of the initial distribution, a more detailed consideration of the orbital momentum, etc). A number of aspects require a more detailed physical analysis (U dependence on angular momenta, limitations to the validity of description of the process by SE).

3 CONDITIONS OF THE “EXPLOSIVE” EVOLUTION

Using of (1) we encounter an analog of the phase transition (“explosion”) or collapse, namely, at a finite time $t = t_{\mathrm{cr}}$ a power tail is formed from a localized initial distribution, stretching to the infinite mass region. This effect was discovered due to exact solutions which exist for the kernels U =const ($u = 0$), $U = M_1 + M_2$ ($u = 1$), and $U = M_1 M_2$ ($u = 2$). The value u in the brackets denotes a homogeneity power of the kernels $U \propto M^u$ (more accurately, $U(\lambda M_1, \lambda M_2) = \lambda^u U(M_1, M_2)$). The explosion exists for $u > 1$, i.e. in the latter example. The $u = 1$ case is the border one ($t_{\mathrm{cr}} = \infty$). The explosive character was discovered more than 50 years ago by Stockmayer (1943) who investigated the phase transition to the gel-phase from the statistical point of view and linked it with the SE. Later (B. A. Trubnikov (1971), R. L. Drake, I. B. McLeod and some other authors, see Voloshchuk, 1984; Ernst, 1986 as review) this result was obtained as an exact solution of the Cauchy problem for SE.

It is very essential that the expansion of the Universe does not prevent the explosion although there appear some limitations (see Kats, Kontorovich, 1991a; Kats *et al.*, 1992). As mentioned above, the cosmological time dependence in the kernel of the Smoluchowsky equation may be removed by the substitution of some $\tilde{t}$ for the time t. The expansion of the Universe slows down mergers and can stop the merging process at a finite value $\tilde{t}_\infty$ (see the dependence $t(\tilde{t})$ in Kats, Kontorovich, 1991a; Kats *et al.*, 1992, for example):

$$\tilde{t}_\infty = (3t_H/4)(t_H/t_0)^{4/3},$$

for U arising in the large mass region. Here $\Omega = 1$ and the mean velocity of galaxies is proportional to $t^{1/3}$, as in the linear theory of the gravitational instability. There is enough time for the “explosive” formation of the power-type $f(M)$ if $\tilde{t}_{\mathrm{cr}} < \tilde{t}_\infty$. In the case $t_{\mathrm{cr}} = t(\tilde{t}_{\mathrm{cr}}) \gg t_0$ we have $\tilde{t}_{\mathrm{cr}} \approx \tilde{t}_\infty$. It gives some limitations for the initial masses M_0 and the initial time t_0. Hear, according to Kats *et al.* (1992):

$$\tilde{t}_{\mathrm{cr}} \propto 1/(c\mathcal{M}M_0^{u-1}),$$

where c is the coefficient of the proportionality in U $(c \equiv c(t_H))$, $\mathcal{M}$ is the mean density of the mass concentrated in galaxies:

$$\mathcal{M} = \int_0^\infty dM\, M\, f(M).$$

So, the explosion (an analog of collapse) may occur in the case of interacting galaxies (according to (2), $u > 1$), and we proposed to explain in such a way the sudden arising of radio galaxies and quasars at redshifts $z \simeq z_{\rm cr}$ as a result of this phenomenon and made an attempt to obtain the corresponding luminosity function (LF) for AGN and to compare it with observations (Kontorovich *et al.*, 1992).

The behavior of LF is sensitive to details of the model. The simplest calculation scheme results in the luminosity function $\varphi \sim L^{-1}$ in the power-law region, close to the observed one, if the asymptotic expression of the mass function (MF) is $f(M,t) \equiv \int f(M,S,t)\, dS \propto M^\alpha$ with $\alpha = -(u+2)/2$, almost independently of the value of u, where u is defined by the dependence of coalescence coefficient $U \propto M^u$ on mass. A MF with $\alpha = -(u+2)/2$ corresponds to approximate conservation of the number of massive galaxies, if their interaction with small ones (masses $\sim M_0$) prevails (Kontorovich *et al.*, 1993).

This situation, however, seems unrealistic, as it will be seen from the numerical analysis. The lack of universality makes the problem more difficult, but, on the other hand, gives a possibility (in principle) to determine the parameters of the interaction of galaxies from manifestations of their activity.

4 NUMERICAL SIMULATIONS

The numerical solution of the Smoluchowsky equation (Krivitskii, 1995) shows that the results in the "explosive" region ($u > 1$) are essentially different for the local case and for the nonlocal one to which the model for the galaxy interaction belongs. In the numerical analysis, the use of a limit mass (i.e., physically the sink) is of principal significance. In conditions of locality, its role is practically unessential up to close vicinity to $t_{\rm cr}$. The index of the power-law asymptotics is close to $(u+3)/2$. The self-similarity of the solution can be clearly seen. The transition time $t_{\rm cr}$ can be determined reliably enough, for example, from the behavior of the inverse second moment.

In the nonlocal case, however, the role of the limit mass is very essential, self-similarity is absent, both the asymptotic dependence of the distribution on mass and of its moments $\mathcal{M}^{(p)}$ on time are not pure power laws (in certain cases, however, $f(M)$ is nonpower-law even for $u < 1$ in the local case). Note that the explosion process in this case is accelerated compared with the local case though the definition of $t_{\rm cr}$ is nonuniversal and depends on what quantity we are interested in. The interaction of galaxies in the case with $\beta = 1/3$ demonstrates a weak nonlocality: $t_{\rm cr}$ may be accurately determined from the second moment $\mathcal{M}^{(2)}(t)$. To our surprise, the distribution in this case showed also the self-similarity similar to the local form (Kontorovich *et al.*, 1994).

Contrary, the case $(M_1 + M_2)^2$ shows strong nonlocality. Since the interaction of galaxies belongs to the nonlocal case, the problem of the limit masses, on which the character of the interaction must change, assumes great importance and the spatial inhomogeneity of the distribution, as well as other neglected factors, become essential. For large enough masses $M_f \geq 10^{14} M_\odot$, the maximum value of the impact parameter is already limited by the mean free pass length or mean distance between the galaxies. So the mass dependence of the merger cross-section σ and U changes ($u \rightarrow 0$, for example) and the "explosion" may stop.

5 SOME PROSPECTS

Some ways to overcome the arising difficulties are prompted by the perfection of the activity model. The connection between indices of quasar LF and galaxy MF in the model appears to be rather realistic, even without the assumption of formation of the MF by mergers. (I.e., mergers are only responsible for the activity, whereas the galaxy mass spectrum is formed in different way, e.g., by the direct rise of the initial fluctuations). Then the idea of collapse (explosion) has to be rejected.

Another way is taking into account the role of the Eddington luminosity limit (Kontorovich and Krivitskii, 1995). Then the LF may reflect the mass distribution of black holes. The problem of the spectrum vanishes[†], whereas the phenomenon of the collapse, explaining the observations, remains.

So as it was noted by Kontorovich *et al.* (1994) the "explosion" phenomenon is akin to wave collapse phenomenon or to the explosive behavior solutions in the weak turbulent systems with decay spectrum. As a matter of fact, for galaxies this means, in a somewhat different language, a manifestation of the gravitational instability but on the nonlinear stage. But one can see that these phenomena are in a row of other ones, linked rather with attraction (the result of which is merging) than directly with gravitation.

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[†] More precisely, it is replaced by the more difficult problem of appearance and evolution of black holes. They are born and grow together with the galaxy, but may be thrown out, or, on the contrary, captured by it.

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