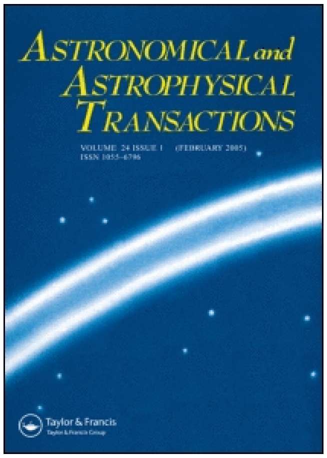

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GALAXY MASS SPECTRUM EXPLOSIVE EVOLUTION CAUSED BY COALESCENCE

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The possibility of 'explosive', (i.e. for a finite time) formation of the power mass spectra in the expanding Universe is shown.

KEY WORDS Galaxies, coalescence, merging, explosive evolution, mass spectra.

The coalescence of galaxies which is rare at the present time, might have occurred much more frequently in earlier epochs. Thus, they could determine mass spectra and morphology evolution, activity appearance and so on (see references in the works by Komberg, 1989; Kats, Kontorovich, 1989, 1990; Carlberg, 1990; Quinn, 1990). Various observational data witness in favour of sudden variations in the properties of galaxies, for instance quasar 'vanishing' at red shifts $z \gtrsim 2 \div 3$ (see Rees, 1990) or Batcher-Oemler effect—the blue excess (spiral prevalence?) in far clusters at $z \gtrsim 0.3 \div 0.4$ (see review by Quinn, 1990). As it seems, to the same group of phenomena may be added the radiosource evolution which is determined by the radiosource number–flux dependence (Zeldovich, Novikov, 1975).

We will show that in the framework of realistic assumptions the Smoluchowsky type kinetic equation (KE) which describes merging may lead to similar 'instant' processes in the expanding universe.

The evolution character essentially depends on the coalescence coefficient $U = \overline{\sigma v}$ mass and time dependence (which is factorised in the limit cases) $U(M_1, M_2; t) = \tilde{U}(M_1, M_2)\chi(t)$. This last is determined by galaxy mean square relative velocity change via the universe expanding. We will restrict ourselves by the simplest (and obviously the most interesting) case when the mean density equals to the critical one, $\Omega = 1$. In this case (Zeldovich, Sunyaev, 1980) the mean square velocity decreases with z increasing as the scale factor: $v^2(t) \sim (1+z)^{-1} \sim a(t) \sim t^{2/3}$. Here t is the time commencing from the cosmological singularity. As to the U dependence on masses we assume for simplicity that the cross-section is governed only by the gravitation focusing parameter $\gamma \equiv 2GM/Rv^2(t) \equiv v_g^2/v^2(t)$. Assuming that coalescence is impossible for $v > v_g$ taking the average over velocities and neglecting coefficients of the order of unity we thus obtain for 'large' masses $(\gamma \gg 1)\tilde{U} \simeq R^2 v_g \gamma^{1/2}(t_H)$, $\chi(t) = v(t_H)/v(t)$, and for 'small' masses $(\gamma \ll 1)\tilde{U} \simeq R^2 v_g \gamma^{3/2}(t_H)$, $\chi(t) = v^3(t_H)/v^3(t)$, i.e. $\tilde{U} \simeq C(M_1 + M_2)^2$ where $C \simeq G^2/v^3(t_H)$, $M = M_1 + M_2$, $R = R_1 + R_2$ is the mass (radius) sum of coalescencing galaxies, and t_H denotes the present moment.

Following the known procedure (Silk and White, 1978) we reduce the problem to the mass spectrum $\tilde{f}$ normalized at the comoving volume evolution in a non-expanding Universe for the KE of conventional form with time non-dependent velocity of merging $\tilde{U}$ by introducing variables:

$$\tilde{t}=\int_{t_0}^{t}\mathrm{d}t\chi(t)a^3(t_{\mathrm{H}})/a^3(t),\, \tilde{f}(M,\tilde{t})=f(M,t(\tilde{t}))\frac{a^3(t)}{a^3(t_{\mathrm{H}})} \tag{1}$$

$$\frac{\partial\tilde{f}}{\partial\tilde{t}}=\int_0^M \mathrm{d}M_1\,\tilde{U}(M_1,M-M_1)\tilde{f}(M_1,\tilde{t})\tilde{f}(M-M_1,\tilde{t})$$

$$-2\int_0^\infty \mathrm{d}M_1\,\tilde{U}(M_1,M)\tilde{f}(M_1,\tilde{t})\tilde{f}(M,t) \tag{2}$$

It is known that for $U=2CM_1M_2$ there exists an exact solution (Voloshchuk, 1984) which has an explosive character. Namely, for localized in a small mass region M_* initial distribution

$$f_0(M)=\frac{N_0M^\nu}{\Gamma(1+\nu)M_*^{1+\nu}}\exp\left(-\frac{M}{M_*}\right)$$

the solution asymptotic for masses $M\gg M_*$ takes the form:

$$f(M,t)\simeq t^{-(1/2)(5+2\nu/(3+\nu))}M^{-5/2}$$

$$\times\exp\left\{-\frac{1}{2+\nu}\frac{M}{M_*}\left[2+\nu+\frac{t}{t_{\mathrm{cr}}}-(3+\nu)\left(\frac{t}{t_{\mathrm{cr}}}\right)^{1/(3+\nu)}\right]\right\}. \tag{3}$$

As is clear from (3) at $t\rightarrow t_{\mathrm{cr}}=(4C(\nu+2)\mathfrak{M}M_*)^{-1}$ i.e. at the finite time interval the power spectrum achieves the infinite mass $M=\infty$ because the exponent tends to zero. The parameter $\mathfrak{M}$ which defines t_{cr} is the first moment, i.e. the mass density localized in galaxies. At $t\rightarrow t_{\mathrm{cr}}$ the second moment of f tends to infinity. For the case of $U=C(M_1+M_2)^2$ the exact solution is unknown, but it is proved that the critical time also exists and $t_{\mathrm{cr}}<(8C(\nu+2)\mathfrak{M}M_*)^{-1}$. We will explore this result for the KE in variables (1) considering that

$$\tilde{t}_{\mathrm{cr}}\simeq(8CM_*\mathfrak{M})^{-1},\qquad C\simeq G^2/v^3(t_{\mathrm{H}}). \tag{4}$$

The value for convenience can be rewritten in the form

$$\tilde{t}_{\mathrm{cr}}/t_{\mathrm{H}}=t_{\mathrm{H}}/t_*, \tag{5}$$

where $t_*=4G\mathfrak{M}M_*/3\pi\rho_{\mathrm{H}}v^3(t_{\mathrm{H}})$ and $\mathrm{t_H}=(6\pi G\rho_{\mathrm{H}})^{-1/2}$ is the age of the universe. Coming back to conventional variables we obtain for $\Omega=1$

$$t_{\mathrm{cr}}=t_0\left(1-2\frac{t_0}{t_{\mathrm{H}}}\cdot\frac{t_0}{t_*}\right)^{-1/2}, \tag{6}$$

where t_0 is the initial time. It is the case of interest when $t_{\mathrm{cr}}\gg t_0$, i.e. $t_0/t_{\mathrm{H}}\simeq(t_*/2t_{\mathrm{H}})^{1/2}$. For the inequality $t_{\mathrm{cr}}<\mathrm{t_H}$ fulfilment it is necessary that $1-2t_0^2/t_{\mathrm{H}}t_*>(t_0/t_{\mathrm{H}})^2$, where the right-hand side value is small.

Let us note that for the condition $t_{\mathrm{cr}}<\mathrm{t_H}$ validity of which is necessary for the explosive evolution be finished until the present moment we have (as is usually done for gas-kinetic estimation of coalescence cross-section) to increase the U value. It can be formally done by $\mathfrak{M}$ increasing in the equation solution.

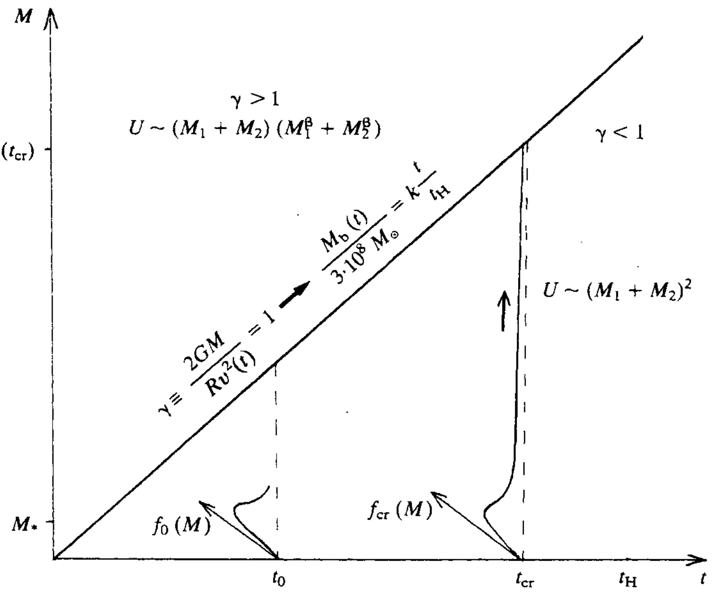

Figure 1

The boundary $M_b(t)$ for the areas of 'small' and 'large' masses corresponds to $\gamma = 1$ ($v^2(t) = v_g^2$) and in the (M, t) plane for the $\Omega = 1$ case it is a straight line (see Figure 1):

$$M_b(t)/3 \cdot 10^8 M_\odot = kt/t_H, \qquad k = \frac{1}{4}\sqrt{\frac{3}{2\pi}}\, v^3(t_H)/\sqrt{G^3\rho} \cdot 3 \cdot 10^8 M_\odot \simeq 1$$

where $\rho \simeq 10^{-22}\,\mathrm{g\,cm^{-3}}$ is the galaxy density, and

$$M_b(t_0) \simeq 3 \cdot 10^8 M_\odot t_0/t_H \sim 10^2 M_\odot \left(\frac{M_*}{M_\odot}\frac{\mathfrak{M}}{\rho_H}\right)^{1/2}$$

The $M_* \ll M_b(t_0)$ condition takes the form of the inequality

$$(M_*/M_\odot)^{1/2} \ll 10^2(\mathfrak{M}/\rho_H)^{1/2}$$

which may take place for instance when $M_* \sim 10^5 M_\odot$ with $\mathfrak{M}/\rho_H \sim 10^3(t_0/t_H \sim 3 \cdot 10^{-3})$ or when $M_* \sim 10^6 M_\odot$ with $\mathfrak{M}/\rho_H \sim 10^4(t_0/t_H \sim 3 \cdot 10^{-2})$.

According to (3) the explosive formation of mass spectra in the range of masses $M \gg M_*$ takes place for the time $\Delta t/t_{cr} \sim (M_*/M)^{1/2}$ (the bigger M the shorter the time).

The power distribution function ensures flux constancy along the spectrum from M_* to M_b which slowly (in the t_{cr} scale) decreases with increasing t. So at $t \lesssim t_{cr}$ the power spectrum reaches the large mass region ($\gamma > 1$). In the area the homogeneity index $u = 4/3$ is also greater than 1 ($U = C_{4/3}(M_1 + M_2)(M_1^{1/3} + M_2^{1/3})$). There are reasons to believe that in this case explosive evolution of the spectrum is also possible. It follows both from the self-similar solutions and the moment equations leading to the estimation of $t_{cr} \lesssim [(u-1)C_u\mathfrak{M}^{(u-1)}M_*]^{-1}$ (Voloshchuk, 1984), where $\mathfrak{M}^{(l)}$ is the lth moment of f. The $t_{cr} \to \infty$ at $u \to 1$.

This property caused the absence of explosive evolution in the works of Kats, Kontorovich (1989, 1990) where $U = \text{const}$ was used, and Khersonskii, Voschinnikov (1990) where the authors used the exact solution for $U \sim (M_1 + M_2)$.

The transition through M_b leads to spectrum breaks (compare with Vinokurov *et al.*, 1985) and its slope and the evolution velocity are sensitive to details (especially asymptotics) of behavior. In the simplest cases we thus obtain the spectrum which corresponds to the constant flux of a number of galaxies, which occur in the system at $M = M_b$, i.e. $f \sim M^{-u}$. For $u = 1 + 1/3$ the exponent is close to the observed Shechter's exponent of mass spectrum. It may be noted that we have used in $R \sim M^{\beta}$ mass-radii dependence $\beta = 1/3$ value, neglecting possible deviations from $\beta = 1/3$ as well as differences of the luminosity function exponent from that of mass function. These assumptions as is seen are not essential.

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