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DRAGGING FORCE ON GALAXIES DUE TO STREAMING DARK MATTER

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It has been reported that galaxies in large regions (~10^2Mpc), including some clusters of galaxies, may be streaming coherently with velocities up to 600km/sec or more with respect to the rest frame determined by the microwave background radiation.[1] On the other hand, it is suggested that the dominant mass component of the universe is dark matter. Because we can only speculate the motion of dark matter from the galaxy motions, much attention should be paid to the correlation of velocities between the observed galaxies and cold dark matter. So we investigate whether such coherent large-scale streaming velocities are due to dark matter or only to baryonic objects which may be formed by piling up of gases due to some explosive events.

In fact, the observations of the large-scale structure of the universe [2] have changed the view of the formation of galaxies from the conservative one which mainly treates the increase of initial fluctuations in the expanding universe to some extreme ones as explosion scenarios or cosmic strings etc.[3,4] In these cases, galaxies or other astronomical objects, named sometimes as population III, are formed by accumulation of baryonic gases due to some explosions. In such situations, the relative velocities between the objects and dark matter are expected.

In the following, we calculate the decrease of velocity difference between dark matter and the baryonic object in a simplified model, considering only the gravitational interaction between a condensed object and dust-like cold dark matter within the expandiNg universe. The equation for the relative velocity v between the dark matter and object is

$$dv/dt=-2v/(3t)-2\pi nmG^2M \ ln\Lambda/v^2 \quad , \quad (1)$$

where the first term represents the decay due to the expansion of the universe and the second term represents the dragging force due to the dynamical friction by the dust-like paticles of dark matter. Λ is a numerical factor given by

$$\Lambda=[1+(b_{max}v^2/GM)^2]/[1+(b_{min}v^2/GM)^2] \quad ,$$

where b_{min} and b_{max} are taken as an order of the object size and mean distance between such objects.

The numerical calculations for equation (1) is given in Fig. 1 for $M=10^{12}M_{\odot}$. Then, if the observed peculiar velocity of $v_{ob}\simeq600$km/sec[1] are due to the relic of some explosions at $(1+z_{ex})$, the initial velocity must be larger than $v_{ob}(1+z_{ex})$. As the galaxy formation era is speculated as $(1+z_{ex})\geq6$, such events must be very explosive.

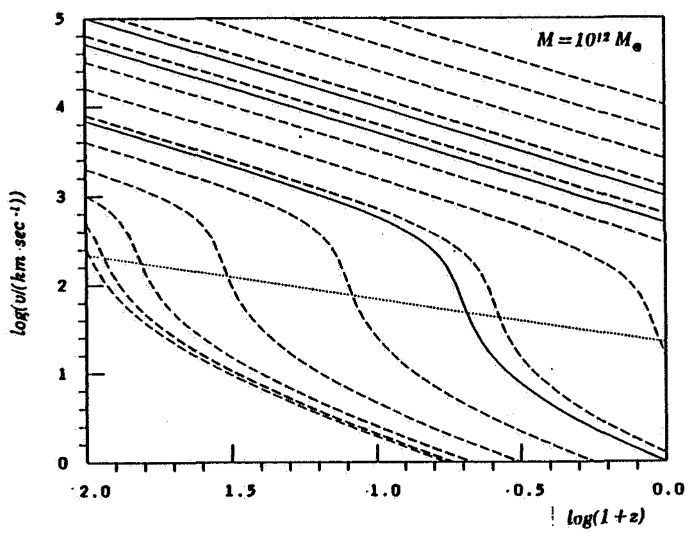

Fig. 1 The decrease of velocity difference for $M=10^{12}M_{\odot}$

The cases of boundary conditions for 1,500 and 10^3km/sec at 1+z=1 are given with solid lines. The cases of boundary conditions for 250×2^nkm/sec at $1+z=10^2$ where n=0,1,2,$\cdots$12 are also shown by dashed lines. The values of b_{min}=20kpc and b_{max}=4Mpc/(1+z) are adopted. The criterion $GM/v^2\geqq vt$ is depicted by a dotted line.

The first term of equation (1) is greater than the second term when v is greater than v_c where v_c is given as

$$v_c=(3\pi nmG^2M\ t\ln\Lambda)^{1/3}$$

$$=9\cdot 10\ h_{50}{}^{1/3}(M/10^{12}M_{\odot})^{1/3}(ln(\Lambda/10^2))^{1/3}(1+z)^{1/2}\ \mathrm{km/sec} \quad ,$$

taking $nm=1/(6\pi Gt^2)$. When v is much greater than v_c, the effect of dragging due to dark matter could be neglected. The velocity v_c at present ($v_c\simeq10^2$km/sec) seems to be rather small compared to the observed dispersion velocity of galaxies ($\simeq$200km/sec), including the galaxies in pairs and groups. So, it seems rather difficult to imagine that each galaxy has followed the cold dark matter velocity field. There is the possibility that the field galaxies have followed the motion of dark matter as far as their dispersion velocities are smaller than v_c. [5)]

If the velocity difference has much decreased due to such dragging force, dark matter may fall into the object. Hence it is interesting to investigate whether M/L ratio depends on the degree of the velocity dispersion. It seems natural to infer that M/L ratios are different between field galaxies and galaxies in cluster.

For clusters of galaxies where mass is order of $M\simeq10^{15}M_{\odot}$, v_c is expected as large as $\simeq10^3$ km/sec. M/L ratio is also very large for clusters of galaxies. Then it is probable that the motion of cluster of galaxies has followed that of dark matter. The numerical calculations for $M=10^{15}M_{\odot}$ are given in Fig. 2. The cases for the dwarf galaxies of $M=10^9M_{\odot}$ are also shown in Fig. 3. If velocities of dwarf galaxies are smaller than $v_c\simeq10(M/10^9M_{\odot})^{1/3}$km/sec, they represent the velocity field of dark matter. It should be reminded here that, if the dispersion of cold dark matter is larger than v_c, there is no any such dragging effects, so the decrease of velocity difference could not be expected for the case of hot dark matter.

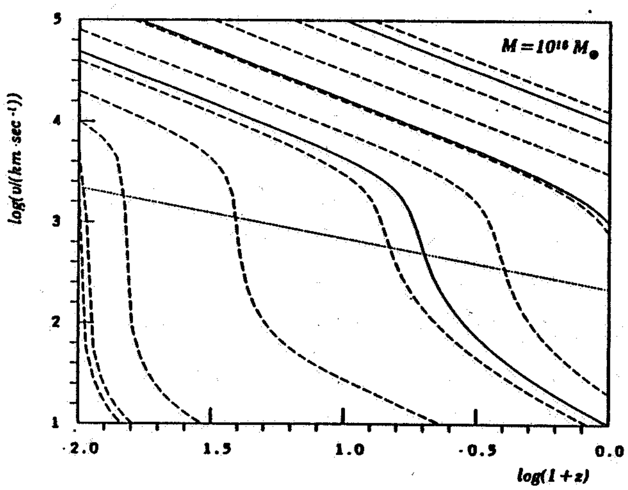

Fig. 2

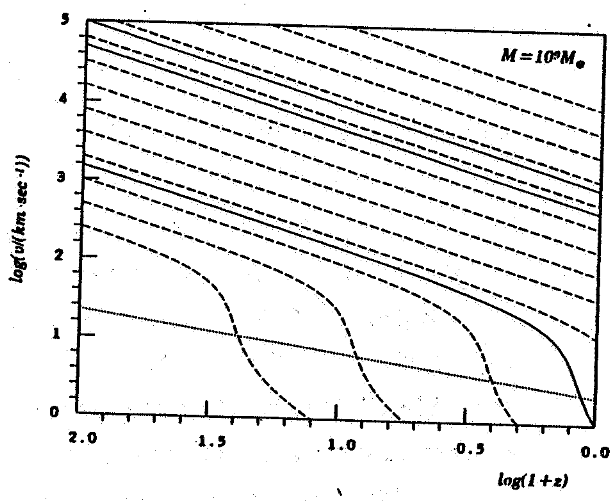

Fig. 3

In Eq. (1), it should be noted that $ln\,\Lambda$ term behaves as $(b_{max}v^2/GM)^2$ when v approaches to zero ($b_{max}v^2/GM \ll 1$), then the first term becomes dominant again and the velocity decreases as $v \propto (1+z)$. But the approximation of Rutherford scattering for the dragging term is inappropriate in the case that the accretion radius ($b \simeq GM/v^2$) is greater than the length that dark matter moves ($b \simeq GM/v^2 \geqq vt$).

Our scenario is as follows that the large-scale peculiar velocities ($\geq 10^2$ Mpc) are due to the motion of dark matter and clusters of galaxies follow such large-scale peculiar velocities. Such large scale peculiar velocities of dark matter may be due to density fluctuations of initial adiabatic perturbations which could be constrained by the observed isotropic background radiation. The velocity field of dark matter of such adiabatic perturbations is estimated from the continuity equation as

$$v \simeq \lambda\delta/t = 10^3(\lambda/10^2\mathrm{Mpc})(\delta/10^{-1})/(t/4{\cdot}10^{17}\mathrm{sec})\,\mathrm{km/sec}\,,$$

where λ and δ are the characteristic wave length and density amplitude of the pertubations.

If we take Zeldovich spectrum for the initial adiabatic perturbations, the constraint for the density amplitude of scale $\lambda \leqq \lambda_c$ ($\lambda_c \simeq 10^2$ Mpc) is given [6]

$$\delta \leqq 3\times(1.4\times10^{-5})\times(1+z_{eq})\quad,$$

and for $\lambda \geqq \lambda_c$

$$\delta \leqq 3\times(1.4\times10^{-5})\times(1+z_{eq})\times(\lambda/\lambda_c)^{-2} \quad ,$$

where $1+z_{eq}$ and λ_c are the era of the equal density of radiation and matter and the present size of the horizen at $1+z_{eq}$. We take the observed upper limits of the background temperature fluctuations as $\Delta T/T \leqq 1.4\times10^{-5}$ at 7.15 minutes. The upper limits for the velocity field of dark matter are depicted in Fig. 4. It could be said that the peculiar velocity field of dark matter in the large region ($\lambda \gg \lambda_c$) must be smaller than the value at λ_c.

The nonlinear density enhancements for the formation of galaxies and clusters of galaxies may not depend on the initial adiabatic perturbations. We would like to consider cosmic strings as the trigger for the formation of the objects, so the structure and velocity field around the cluster of galaxies would be determined by cosmic strings.

It seems that, although each galaxy will not follow the motion of dark matter, clusters of galaxies may represent the velocity field of dark matter. The origin of the velocity field of dark matter would be due to the initial adiabatic perturbations and, in fact, the observed peculiar velocities of clusters are within the allowed region constrained from the istropy of the microwave background radiation.

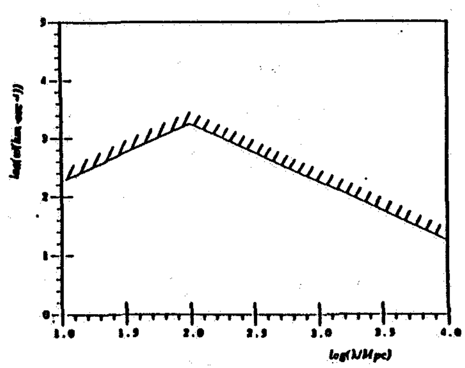

Fig. 4

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