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КРАТКИЕ СООБЩЕНИЯ

ON THE 3D VELOCITY RECONSTRUCTION OF CLUSTERS OF GALAXIES*

1. The reconstruction of the 3D velocities of the clusters of galaxies and their large-scale motion remains one of the central problems of observational cosmology (see [2,7] and references therein). The reason is clear: these properties should contain crucial information on the mechanisms of formation of the filaments and even on more early phases of evolution of the Universe, as well as on the present values of the cosmological parameters.

Below we are formulating the problem of the 3D velocity reconstruction of the cluster of galaxies based essentially on the measured redshift i.e. 1D velocity distribution of the galaxies within the cluster. The procedure we propose includes the following steps: a) the determination of the physical cluster; b) the obtaining of the galaxy redshift distribution of that cluster; c) the reconstruction of the mean 3D velocity distribution of the cluster from the redshift distribution of galaxies.

The first step can be performed by S-Tree [4,5,8] or similar technique enabling one the separation of the physically interacting galaxies from the 2D-image of the cluster area. We illustrate the proposed reconstruction procedure by numerical simulation, thus revealing the possibilities and the limitations posed by the observational parameters of the clusters of galaxies.

2. In 1935 Ambartsumian [1] has solved the stellar dynamical problem of reconstruction of 2D and 3D velocity distributions based on the observed line-of-sight velocity distribution of stars. The main assumption made was the independence of the distribution functions on the spatial regions (directions). Ambartsumian's formula relating the 3D velocity distribution function $\phi(v_x, v_y, v_z)$ with the observed line-of-sight velocity distribution $f(v_r, l, b)$ has the form:

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$$\phi(v_x, v_y, v_z) = -\frac{1}{8\pi^2}\int dW \frac{1}{W}\frac{d}{dW}$$
$$\int \frac{\cos b\, dl\, db}{\eta(l,b)} f(v_x \cos l \cos b + v_y \sin l \cos b + v_z \sin b + W, l, b) \tag{1}$$

where $W = v_r - x\cos\alpha - y\sin\alpha$ in some frame. Computer experiments show that the direct application of this formula is hardly possible for that purpose: the given distribution for the numerically simulated clusters does not coincide with the reconstructed one by means of that formula. The reason is clear: the derivation of a smooth function based on discrete information on relatively small number of points (10^2-10^3) in a nonlinear problem. This fact is a consequence of the principal difference between the N-body problem in stellar dynamics and dynamics of clusters of galaxies.

However, we notice that the Ambartsumian's formula has an interesting feature - the radial velocity parameter W is entering into it in a similar way as the coordinates. Therefore an additional physically reasonable information on the features of the function $\phi(v_x, v_y, v_z)$ can make the problem correctly formulated and much stable with respect to the initial noise. In the following, we explore such an approach.

3. Our assumption is the representation of the 3D velocity distribution in the following form:

$$\phi(v_x, v_y, v_z)\, d\,v_x\, d\,v_y\, d\,v_z = \prod_{l=1}^{3} g_l(v_l; v_0^l, \sigma_v^l)\, d\,v_l \tag{2}$$

with $g_l(x; x_0, \sigma_x)$ being a smooth probability density function centered on x_0 and of dispersion σ_x. The peculiar velocity field within the cluster is thus split into a mean 3-dimensional velocity $v_c = (v_0^1, v_0^2, v_0^3)$ plus random components of velocity dispersion σ_v^l. Herein, we consider the isotropic case, choosing $g_l \equiv g$ gaussian , i.e. the random component has a 3D Maxwellian distribution of dispersion σ_v.

Note that the peculiar radial velocity $v_r = \hat{r} \cdot v$ of the galaxies is not completely furnished by the observed redshift $z = H_0 r + \hat{r} \cdot v$, with H_0 the Hubble's constant. Instead of usually made assumption that all galaxies lie at the same distance we prefer a more realistic one, permitting the cluster to have a spatial line-of-sight extension σ_c, with galaxies isotropically distributed around the center of the cluster.

Then, we rewrite the theoretical density probability in terms of the observable variables z, l and b. The successive integrations over the distance r and over 2 components of the 3-dimensional velocity field give the following observed probability density:

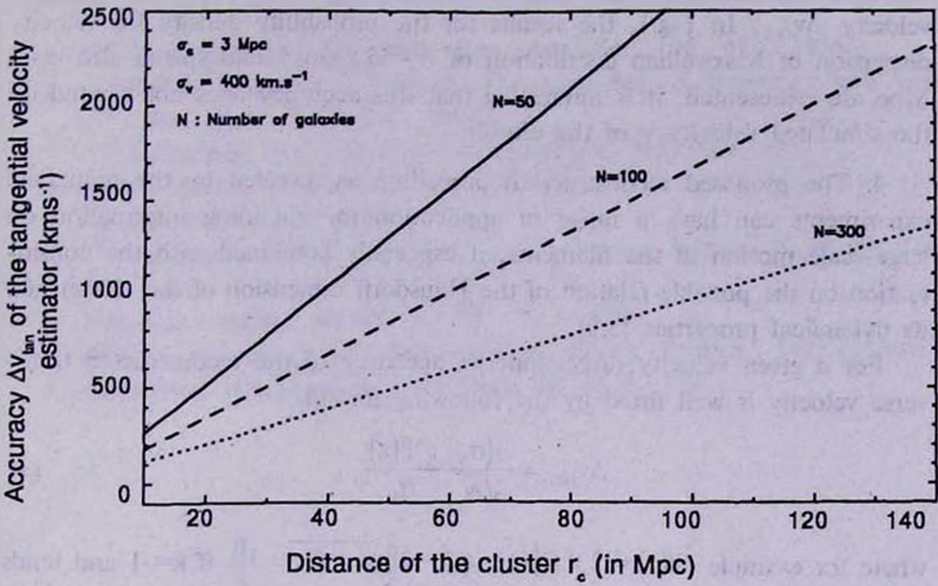

Fig.1

$$dP_{obs} = g\left(z - H_0 r_c; v_1 \cos l \cos b - v_2 \sin l \cos b - v_3 \sin b, \sqrt{\sigma_v^2 + \sigma_c^2}\right) \times$$
$$\times\, \eta(l,b) \cos b\, dl\, db\, dz.$$

The estimates of the parameters v_1, v_2 and v_3 are obtained by the maximized likelihood function with respect to v_1, v_2, v_3, $H_0 r_c$, s_v and s_c.
For $A = \cos l \cos b - \langle \cos l \cos b \rangle$, $B = \sin l \cos b - \langle \sin l \cos b \rangle$, $C = \sin b - \langle \sin b \rangle$, $D = z - \langle z \rangle$ where $\langle . \rangle$ denotes the average on the sample, we obtain the following system of linear equations:

$$\begin{bmatrix} \langle A^2 \rangle & \langle A.B \rangle & \langle A.C \rangle \\ \langle B.A \rangle & \langle B^2 \rangle & \langle B.C \rangle \\ \langle C.A \rangle & \langle C.B \rangle & \langle C^2 \rangle \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \end{bmatrix} = \begin{bmatrix} \langle A.D \rangle \\ \langle B.D \rangle \\ \langle C.D \rangle \end{bmatrix} \qquad (3)$$

One can see that spatial line-of-sight expansion σ_c is added quadratically to the peculiar velocity dispersion σ_v, enhancing thus the redshift scatter σ_z (in kms^{-1}) of the cluster. Moreover, because the distance r_c of the cluster normally is also an unknown parameter, it is impossible to disentangle the estimates of $H_0 r_c$ and of the mean radial velocity $v_{rad}\left(v_{rad} = \langle \hat{r} \rangle \cdot v\right)$. However it turns out that without the knowledge of r_c, one can evaluate the mean tangential velocity v_{tan} of the cluster

$$v_{tan} \cdot \langle \hat{r} \rangle = 0\,.$$

We have estimated the accuracy of reconstruction of the mean tangential velocity Δv_{tan}. In Fig.1, the results for the probability density for velocity dispersion of Maxwellian distribution of σ_v=550 kms^{-1} and spatial size σ_c=3 Mpc are represented. It is interesting that this accuracy does not depend on the simulated velocity v_c of the cluster.

4. The proposed reconstruction procedure as revealed by the numerical experiments can have a range of application for obtaining information on large-scale motion of the filaments, if especially combined with the consideration on the possible relation of the Hausdorff dimension of the cluster and its dynamical properties [3,6].

For a given velocity dispersion the accuarcy of the reconstructed transverse velocity is well fitted by the following formula:

$$\Delta v_{tan} = \frac{A(\sigma_v)}{\sqrt{N}} \frac{c\Psi(z)}{H_0}, \tag{4}$$

where for example $\Psi(z) = 2/\Omega\left(\Omega z + (\Omega - 2)\left[\sqrt{1+\Omega z} - 1\right]\right)$ if k=-1 and tends to z for small redshifts, $A(\sigma_v) = \sqrt{\sigma_c^2 + \sigma_v^2}$, thus relating the reconstructed Δv_{tan} with the Hubble constant and other cosmological parameters.

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О ВОССТАНОВЛЕНИИ 3D СКОРОСТИ СКОПЛЕНИЙ ГАЛАКТИК

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Сформулирована проблема восстановления 3D - скорости скоплений галактик с помощью распределения красных смещений этих же галактик. Хотя численные эксперименты указывают на невозможность прямого использования формулы Амбарцумяна (выведенной для звездных систем) из-за небольшого числа объектов в скоплениях, дополнительное физичекое допущение о форме искомого распределения скоростей может дать возможность получения поперечной скорости скопления. Оценена точность предлагаемой восстановительной процедуры.

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