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The Dynamics of the Substructures and the Bulk Flow of the Local Group

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Abstract. The S-tree method is used to reveal the substructures of the Local Group, namely the membership of each individual galaxy in the Milky Way and M31 subgroups; the method is determining the degree of mutual influence of the galaxies. Once the main physical subgroups of the Local Group are defined, we use a general method of reconstruction of their bulk flow using the radial velocity distribution of the member galaxies. The results particularly indicate the essential mutual bulk flow of the Milky Way and M31 subgroups which does not simply coincide with the radial approaching velocity (blueshift) of M31. Finally, having obtained the 3D velocity vectors of the both subgroups, we determine the 3D bulk flow of the Local Group itself, which in the Cosmic Microwave Background rest frame is equal to $V_{LG \to CMB} = 668$ km s^{-1} towards $l = 265$ and $b = 42$.

1. Introduction

The study of the properties of the substructures of the Local Group (LG) and, particularly of the 3D peculiar motions, are crucial for the understanding of its past and future evolution.

In the present study we consider the possibility to estimate the peculiar velocity of the LG using not the extragalactic information, but its internal dynamical properties combined with data on CMB dipole. Namely, we analyse the substructure of the LG, and perform a procedure of 3D reconstruction of the velocity of the whole system and its main subgroups, using the method developed by Gurzadyan&Rauzy (1997). The *first* step is performed by the S-tree technique (see Gurzadyan&Kocharyan (1994)) enabling, in particular, the analysis of systems such as groups or clusters of galaxies. For the *second* step, we use the data on the distribution of the line-of-sight velocities of the galaxies which are members of the LG and its subsystems, as revealed at the first step. Thus, we obtain the peculiar motions of the Milky Way and M31 subsystems with respect to each other. By the *third* step, from the bulk motions of the mentioned both subsystems we obtain the velocity vector of the Local Group in CMB frame.

2. The S-tree technique

The S-tree technique is developed for the investigation of properties of many-dimensional nonlinear systems and essentially uses the concepts of the theory of dynamical systems (Gurzadyan et *al* 1994; Gurzadyan&Kocharyan 1994). Its idea is based on the property of structural stability well known in theory of dynamical systems enabling to study the robust properties of the systems with limited amount of information. The advantage of the method in the context of galaxy clusters is in the self-consistent use of both kinematical and positional information on the galaxies, as well as of the data on their magnitudes.

This approach is introducing the concept of the *degree of boundness* between the members of the given N-body system, i.e. the definition of a nonnegative function $\mathcal{P}$ called the boundness function which describes the degree of interaction of a given subset Y of the initial set $\mathcal{A}$ with another subset $X \backslash Y$ according to some criterion. Particularly one can define a function

$$\mathcal{P} : \mathcal{S}(\mathcal{A}) \to R_+ : (X, Y) \mapsto \mathcal{P}_X(Y), \tag{1}$$

where $\mathcal{S}(\mathcal{A})$ is the set of all subsets of the initial set, when one of the sets contains the other one. The procedure of such splitting of $\mathcal{A}$ can be measured by a non-negative real number ρ using the boundness function, so that the problem is reduced to the finding out of a function $\Sigma(\rho)$ denoting the set of all possible ρ-subsystems $\{\mathcal{A}_1, \ldots, \mathcal{A}_d\}$ of $(\mathcal{A}, \mathcal{P})$.

Attributing for the given ρ the boundness matrix D to another graph matrix Γ, so that the problem of the search of a ρ-bound cluster is reduced to that of the connected parts of the graph $\Gamma(\rho)$ - a *S-tree* diagram.

For the matrix D_{ab} a representation via the two-dimensional curvature K of the phase space of the system can be used

$$D_{ab} = \max_{i,j} \{-K^{\mu}_{\nu}, 0\}, \tag{2}$$

where $\mu = (a, i), \nu = (b, j)$, $a, b = 1, ..., N$, $i, j = 1, ..., 3$. The two-dimensional curvature is represented by the Riemann tensor R via the expression: $K_{\mu\nu} = R_{\mu\nu\lambda\rho} u^{\lambda} u^{\rho}$. As a result, the degree of boundness between the members and subgroups of the given N-body system can be obtained, thus revealing the physically interacting system (cluster) and its hierarchical substructure.

The computer code based on the S-tree method has been used for the study, for example, of the substructure of Abell clusters from ENACS program (Gurzadyan & Mazure, 1998), etc.

3. Bulk flow reconstruction

The reconstruction of the 3D velocity distribution function from the observed line-of-sight velocity distribution is an interesting inverse problem solved by Ambartsumian (1936) for stellar systems. The only assumption made was the independence of the distribution function on the spatial directions, or equivalently, that the 3D velocity distribution $\phi(v_1, v_2, v_3)\, dv_1\, dv_2\, dv_3$ of such systems was invariant under spatial translations, i.e. the probability density reads

$$dP_{\rm th} = \phi(v_1, v_2, v_3)\, dv_1\, dv_2\, dv_3\ \rho(r, l, b)\, r^2 \cos b\, dr\, dl\, db \tag{3}$$

where $\phi(v_1, v_2, v_3)$ is the 3D velocity distribution function (in galactic cartesian coordinates) and $\rho(r, l, b)$ is the 3D spatial distribution function (in galactic coordinates). Under this assumption, Ambartsumian had proven the theoretical possibility of reconstructing of $\phi(v_1, v_2, v_3)$ from the observed radial velocity distribution function $f(v_r, l, b)$

$$dP_{\rm obs} = f(v_r, l, b)\ \cos b\, dl\, db\, dv_r \tag{4}$$

where $v_r = \mathbf{v}.\hat{\mathbf{r}}$ is the projection of the velocity $\mathbf{v} = (v_1, v_2, v_3)$ on the line-of-sight direction $\hat{\mathbf{r}} = (\hat{r}_1, \hat{r}_2, \hat{r}_3) = (\cos l \cos b, \sin l \cos b, \sin b)$.

However, computer experiments show that the direct application of the Ambartsumian's formula is hardly possible for this purpose, because of the small number of galaxies in the system. Nevertheless, some quantities of interest such as the first order moment of this distribution, i.e. the mean 3D velocity of the system, can be obtained. Additional hypotheses on the distribution function $\phi(v_1, v_2, v_3)$ are then necessary. Hereafter, we assume that $\phi(v_1, v_2, v_3)$ can be written as follows

$$\phi(v_1, v_2, v_3)\ dv_1\, dv_2\, dv_3 = \prod_{i=1}^{3} \phi_i(v_i)\, dv_i \tag{5}$$

where the distribution functions ϕ_i are centered on $\overline{v}_i$ and of variances σ_i ($\phi_i(v_i) = \phi_i(v_i; \overline{v}_i, \sigma_i)$). We choose the Gaussian representation ($\phi_1 = \phi_2 = \phi_3 = g$ with g Gaussian) and assume the isotropic velocity dipersions ($\sigma_1 = \sigma_2 = \sigma_3 = \sigma_v$). The velocity field of the system is, thus, split into a mean 3D velocity $\mathbf{v}_B = (v_x, v_y, v_z) = (\overline{v}_1, \overline{v}_2, \overline{v}_3)$ (i.e. a bulk flow) plus a 3D random component, isotropic Maxwellian, centered on $\mathbf{0}$ and of velocity dispersion σ_v.

The fact that gravitating N-body systems do posess strong statistical properties peculiar to Kolmogorov systems (Gurzadyan&Savvidy, 1986; see also Gurzadyan&Pfenniger, 1994), is the justification for the separable form of distribution functions in Eqs.(3) and (5).

4. The Local Group Subsystems.

The S-tree analysis has revealed the following substructure of the LG (Gurzadyan et *al.* (1993)):

- *Milky Way subsystem* - 12 galaxies: Milky Way, SMC, Sculptor S, IC1613, Fornax D, LMC, Carina, Leo I, Leo II, UM, Draco, N6822;
- *M31 subsystem* - 7 galaxies: N 147, N185, N205, M31, M32, LGS-3, M33;
- *The field galaxies of the Local Group* - 13 galaxies: IC10, N55, IC342, Leo A, N3109, Sex A, DDO155, Sagittarius, DDO210, IC5152, Hog, Pegasus, W-L-M.

Thus the membership of galaxies in two main subgroups - dominated by the Milky Way and of M31, has been revealed, in general, confirming the conventional views. Physical connections between some individual galaxies have been also indicated, not reported before (e.g. of NGC 6822 and IC 1613). Some galaxies appeared to have no actual influence on the dynamics of LG and vice versa, and therefore, were considered not to be its members. Existence of galaxies obscured by the Galactic disk, like newly discovered Dwingeloo 1,2 also cannot be

ruled out, though it seems unlikely that, at least the latter ones can essentially influence the substructure of the LG (Lynden-Bell, 1996). Thus in accord to our analysis, MW and M31 subsystems contain respectively 12 and 7 galaxies.

For each subsystem, as it is assumed in Eq. (3), the velocity distribution function $\phi(v_1, v_2, v_3)$ is translation invariant, so that $\phi(v_1, v_2, v_3)$ can be split into a bulk flow $\mathbf{v}_B = (v_x, v_y, v_z)$ plus a 3D random component, isotropic Maxwellian, centered on $\mathbf{0}$ and of velocity dispersion σ_v. According to the standard bulk flow statistics derived by means of the likelihood function, i.e. $\mathcal{L} = \mathcal{L}(v_x, v_y, v_z, \sigma_v)$ reads thus :

$$\mathcal{L} = -\ln \sigma_v - \frac{1}{N} \sum_{k=1}^{N} \frac{\left(v_r^k - v_x \hat{r}_1^k - v_y \hat{r}_2^k - v_z \hat{r}_3^k\right)^2}{2\sigma_v^2} \tag{6}$$

where $\hat{r}_1^k = \cos l^k \cos b^k$, $\hat{r}_2^k = \sin l^k \cos b^k$ and $\hat{r}_3^k = \sin b^k$; k denotes the k-th galaxy. Maximizing $\mathcal{L}$ with respect to v_x, v_y and v_z leads to the 3×3 matrix equation

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \mathbf{M}^{-1} \begin{bmatrix} \langle v_r \hat{r}_1 \rangle \\ \langle v_r \hat{r}_2 \rangle \\ \langle v_r \hat{r}_3 \rangle \end{bmatrix} \tag{7}$$

where

$$\mathbf{M} = \begin{bmatrix} \langle \hat{r}_1 \hat{r}_1 \rangle & \langle \hat{r}_1 \hat{r}_2 \rangle & \langle \hat{r}_1 \hat{r}_3 \rangle \\ \langle \hat{r}_1 \hat{r}_2 \rangle & \langle \hat{r}_2 \hat{r}_2 \rangle & \langle \hat{r}_2 \hat{r}_3 \rangle \\ \langle \hat{r}_1 \hat{r}_3 \rangle & \langle \hat{r}_2 \hat{r}_3 \rangle & \langle \hat{r}_3 \hat{r}_3 \rangle \end{bmatrix} \tag{8}$$

where $\langle . \rangle$ denotes the average on the sample.

The results of computations are as follows:

• *Milky Way subsystem*: $(v_x = 104 \pm 64, v_y = -116 \pm 42, v_z = 45 \pm 33)$ or $\mathbf{v}_B = 162$ km s^{-1} in the direction $(l = 312, b = 16)$ or $(\alpha = 13\,38.75,\ \delta = -45\,43.8)$ with a velocity dispersion of $\sigma_v = 69 \pm 15$ km s^{-1};

• *M31 subsystem*: $(v_x = -117 \pm 541, v_y = 85 \pm 267, v_z = 309 \pm 254)$ or $\mathbf{v}_B = 341$ km s^{-1} in the direction $(l = 144, b = 65)$ or $(\alpha = 11\,54.35,\ \delta = 50\ 07.09)$ with a velocity dispersion $\sigma_v = 69 \pm 15$ km s^{-1}.

These velocities are expressed in km s^{-1} and with respect to rest frame of the Milky Way. For each system, the values of the velocity dipersion σ_v and of the accuracy of the bulk flow estimate are calculated by using numerical simulations (see Rauzy&Gurzadyan 1998 for details).

In the coordinates frame such that X-axis is aligned with M31 line-of-sight (i.e. toward $l = 121.2$ and $b = -21.6$) and Y-axis lies in the galactic plane, the 3D bulk flow of M31 subgroup reads $\mathbf{v}_B = (10 \pm 34, 72 \pm 623, 335 \pm 291)$. In this coordinates, bulk flow of the MW subsystem reads $\mathbf{v}_B = (-155 \pm 57, -26 \pm 53, -15 \pm 26)$.

To check this, we have repeated our analysis on the 32 Local Group galaxies situated nearer than 2 Mpc, but ignoring the MW and M31 dynamical substructures. The values of the velocity dispersion estimator for the MW and M31 subsamples appear to be significantely greater than the above mentioned ones, thus indicating the existence of genuine kinematic substructures in the Local Group, and so, strengthening the present analysis.

5. Discussion

The motions of the two subsystems of the Local Group have been estimated, containing respectively 7 and 12 galaxies, as identified via the S-tree technique.

We have obtained that the relative velocity of M31 subsystem with respect to the MW subsystem when projected on the line joining MW to M31 is -165 ± 66 km s^{-1}, confirming the conventional views (e.g. Peebles, 1994). On the other hand, the 3D inner motions inside the Local Group, if significant, are found to be surprisingly large: M31 subsystem has a relative 3D velocity of amplitude 399 km s^{-1} with respect to the MW subsystem.

The CMB temperature dipole, if interpreted as the signature of our motion with respect to the rest frame of this radiation (CMB frame), gives for the Milky Way a peculiar velocity $V_{MW\to CMB}$ of 552 km s^{-1} pointing toward the galactic coordinates $l = 266$ and $b = 29$, e.g. Kogut et al. (1993). This MW motion in the CMB frame is traditionnally split into two components

$$V_{MW\to CMB} = V_{MW\to LG} + V_{LG\to CMB} \tag{9}$$

where $V_{MW\to LG}$ is the velocity of the Milky Way relative to Local Group rest frame, which originates from the internal non-linear dynamics governing the Local Group and $V_{LG\to CMB}$ is the peculiar motion of the Local Group as a whole in the CMB frame, created by large scale mass fluctuations present in the Universe. The latter can be infered in some sense from various dipoles obtained by now, such as the optical galaxies, X-ray galaxies, IRAS galaxies, clusters of galaxies, etc. (see Branchini and Plionis, 1996).

Note that the peculiar motion of the Milky Way in the Local Group rest frame $V_{MW\to LG}$ can be obtained from the analysis of the dynamics of the Local Group and its substructures. Substracting it to the observed $V_{MW\to CMB}$ thus gives a local estimate of $V_{LG\to CMB}$, which can be compared with its values extracted from dipoles analysis, as mentioned above.

Herein, we assigne to the Local Group the mean motion of its main substructures, i.e. both MW and M31 subsystems being equally weighted. It gives $V_{MW\to LG} = (7 \pm 303, 15 \pm 155, -177 \pm 144)$ or 178 km s^{-1} toward $l = 65$ and $b = -85$. Finally, our local estimate of the LG peculiar velocity in the CMB frame yields $V_{LG\to CMB} = (-41 \pm 303, -497 \pm 155, 445 \pm 144)$ or 668 km s^{-1} in amplitude pointing toward $l = 265$ and $b = 42$. This result within 1 σ level is in agreement with the estimation by Yahil et al. (1977), based on the Solar system motion relative to the LG centroid : $V_{LG\to CMB} = 622$ km s^{-1} toward $l = 277$ and $b = 30$ or $(66, -535, 311)$ in galactic cartesian coordinates.

The existence of some discrepancy between these two values, if significant, can be interpreted as follows. The LG centroid had been defined by specific choice of the main and satellite populations and with further search of the best-fit solution for the Solar system motion.

The fact of existence of an essential bulk flow of the substructures revealed above, is a remarkable property of LG and can be a common feature of subgroups of clusters of galaxies (Gurzadyan&Mazure, 1998) – galaxy associations.

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References

Ambartzumian V.A., 1936, MNRAS 96, 172

Branchini E., Plionis M., 1996, ApJ 460, 569

Gurzadyan V.G., Kocharyan A.A., 1994, in '*Paradigms of the Large-Scale Universe*', Gordon and Breach

Gurzadyan V.G., Harutyunyan V.V., Kocharyan A.A., 1994, A&A 281, 964

Gurzadyan V.G., Kocharyan A.A., Petrosian A.R., 1993, Ap&SS 201, 243

Gurzadyan V.G., Mazure A., 1998, MNRAS 295, 177

Gurzadyan V.G., Pfenniger D. (Eds.), 1994, *Ergodic Concepts in Stellar Dynamics*, Lecture Notes in Physics, vol.430, Springer-Verlag.

Gurzadyan V.G., Rauzy S., 1997, Astrophysics 40, 308

Gurzadyan V.G., Savvidy G.K., 1986, A&A 160, 203

Kogut A. et al., 1993, ApJ 419, 1

Lynden-Bell D., 1996, private communication

Peebles P.J.E., 1994, ApJ 429, 43

Rauzy S., Gurzadyan V. G., 1998, MNRAS 298, 114

Yahil A., Tammann G.A., Sandage A., 1977, ApJ 217, 903