Virgo Infall and the Mass of Local Supercluster of Galaxies

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Summary

The mass of Local Supercluster (LSC) of galaxies is calculated by analysing a geodesic equation in the expanding universe for the infall motion of Galaxy and Local Group into Virgo cluster center. The result is that the mass of LSC over the background value of corresponding volume amounts to 1.4×10^{15} $M_{\odot}$ which is approximately the same as the background value for the case of the flat universe.

1. Introduction

The distribution of galaxies has been believed to be homogeneous and isotropic on sufficiently large scale. However recent observations reveal large-scale agglomeration of galaxies with linear dimension of 100 Mpc.[1] Those are called supercluster of galaxies as bigger systems than clusters of galaxies. But the detail of superclusters has not been known well because of their great distances. Apart from this, de Vaucouleurs[2] has insisted upon the existence of Local Supercluster of galaxies which contains Milky Way System (Galaxy). Tully[3] has supported the idea of the Local Supercluster (LSC). According to them, LSC's center is at Virgo cluster of galaxies, and the Galaxy locates at the edge of this disk-like system.

The purpose of this paper is to determine the mass of the Local Supercluster from the motion of Galaxy and Local Group, by analysing the geodesic eguations in the perturbed Robertson-Walker line element.

The motion of Galaxy and Local Group has been investigated by many authors, including V. Rubin et al.,[4] who reported that it is a circular motion around Virgo cluster with speed of about 500 km/s from the observation of distant Sb and Sc galaxies. However recent observations confirm that Galaxy and Local Group are falling into Virgo cluster. This "Virgo Infall" enables us to calculate the mass inner from Galaxy which is actually the total mass of LSC.

In section 2, we consider the circumstances of LSC and visualize the relation between LSC and other superclusters. Such a consideration gives us the starting point of the Virgo infall. Formulation of the equation which describes the motion is in section 3, and analysis of the equation and evaluation of the integration is in section 4. Concluding remarks are given in the final section.

2. Circumstances of Local Supercluster

Local Group of galaxies with about 30 member galaxies including Milky Way (Galaxy) is located at the edge of Local Supercluster, outside of which only NGC

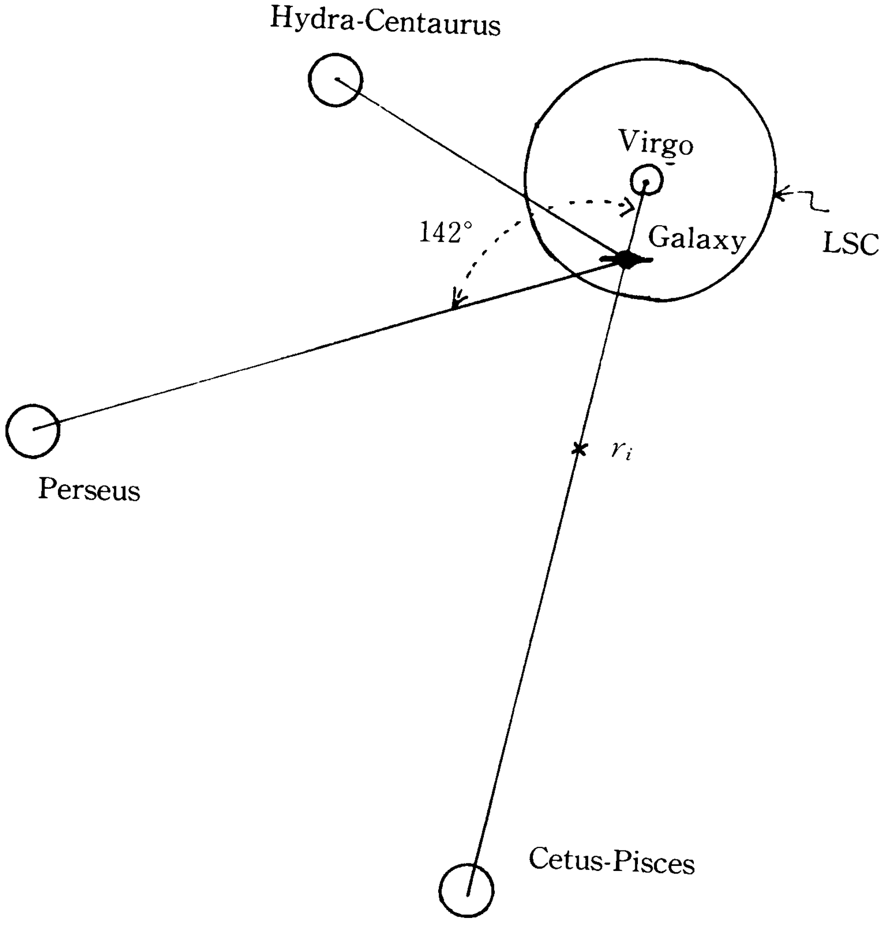

Fig. 1 The circumstance of Local Supercluster of galaxies is depicted schematically.

253 group exists. The distance from LSC center, Virgo cluster, to Local Group is about 20 Mpc.

Around LSC, there exist 5 superclusters named Hydra-Centaurus supercluster, Perseus supercluster, Cetus-Pisces supercluster, and Coma-A1367 supercluster.

From 3-dimensional configuration of these superclusters, we can readily see that unless Virgo infall ocurrs, Local Group would fall into Perseus supercluster (see Fig.1). Hence the condition of Virgo infall is that the starting point must be inside of 64 Mpc radius from LSC center. We assume that each supercluster has the same mass. In Table 1, we give coordinates (α, δ) of each superclusters.

Name of Supercluster	Distance(Mpc)	R.A.(h)	Decl.(°)
LSC	20	12.5	+12
Hydra-Centaurus	58	12.0	−40
Perseus	100	2.0	+40
Hercles	200	16.0	+20
Cetus-Pisces	300	0.	0

Table 1. A list of the superclusters with their distances and position (α, δ).

3. Description of the motion in the expanding perturbed universe

The motion of Galaxy and Local Group through gravitational attraction will be expressed in terms of general theory of relativity, because cosmological expansion must be taken into account. Moreover we adopt the following perturbed Robertson-Walker (flat) line element.

$$ds^2=c^2\left(1+\frac{2\Phi(r,\ t)}{c^2}\right)dt^2-a^2(t)\left(1-\frac{2\Phi(r,\ t)}{c^2}\right)(dr^2+r^2d\theta^2+r^2\sin^2\theta d\varphi^2), \tag{3. 1}$$

where Φ denotes the local gravitational field due to LSC. The origin of the coordinates ($r,\ \theta,\ \varphi$) is taken as LSC center.

The motion of a particle is expressed by the geodesic eqation

$$\frac{d^2x^i}{d\tau^2}+\Gamma_j{}^i{}_k\frac{dx^j}{d\tau}\cdot\frac{dx^k}{d\tau}=0,\ (i,\ j,\ k=1,\ 2,\ 3), \tag{3. 2}$$

where the Chrstoffel symbols are calculated from Eq. (3. 1).

We take 1 as r, 2 as θ, and 3 as φ. The plane of θ = constant is taken as supergalactic plane. After rather tedious calculation under Newtonian appoximation, we obtain the following equation of motion for radial and tangential direction in the supergalactic plane,

$$\left.\begin{aligned}&\frac{d^2r}{dt^2}+2H\frac{dr}{dt}-r\left(\frac{d\varphi}{dt}\right)^2=-\frac{1}{a^2}\frac{\partial\Phi}{\partial t}\\&\frac{d^2\varphi}{dt^2}+2H\frac{d\varphi}{dt}+\frac{2}{r}\frac{dr}{dt}\frac{d\varphi}{dt}=0\end{aligned}\right\} \tag{3. 3}$$

where $H\equiv\dot{a}/a$.

As we consider infall motion, that is the case of φ = const., we treat the first of the equations only.

We put

$$u_r=\frac{dr}{dt}$$

then Eq. (3. 3) is rewritten as

$$u_r+2Hu_r=-\frac{1}{a^2}\frac{\partial\Phi}{\partial t} \tag{3. 4}$$

We use the following relation

$$\Phi(r,\ t)=-\frac{GM}{a(t)r} \tag{3. 5}$$

where M denotes the excess mass of LSC.

This equation is integrated formally as follows.

$$\left[\frac{1}{2}(u_r a_0^2)^2\right]_{t=t_0} = -\int_{r_i}^{r_0} \frac{GMa(t,\ r)}{\gamma^2} d\gamma \tag{3. 6}$$

4. Estimation of the excess mass of LSC.

The excess mass of LSC can be calculated by solving Eq. (3. 4) with Eq. (3. 5) or, in other words, integraton of Eq. (3. 6). However the integration cannot be performed analytically because the scale factor a depends not only t, but also r along the trajectory of the infalling particle. Instead of integrating Eq. (3. 4), we evaluate the integration (3. 6), taking into account the consideration in section 2.

If we assume that the scale factor a obeys power law, $a \propto r^n$, $n = 6$ holds from the relation $(r_i / r_0)^n = 10^3/1$. Hence we perform the integration as follows.

$$\int_{r_0}^{r_i} \frac{a}{r^2} dr \approx \int_1^{60/26} \frac{dr_*}{r_*} \approx \frac{1}{2} \tag{3. 7}$$

Here $r_* = r_i / r_0$.

As a result, we obtain the excess mass M of LSC of as

$$M \approx 7 \int_{r_0}^{\infty} \frac{ar}{r^2} G(u_r)_0^2 \tag{3. 8}$$

By substituting the Virgo isfall velocity into $(u_r)_0$, we get

$M = 1.4 \times 10^{15} \mathbf{M}_\odot$

This value is to be compared with the mass M of the same volume as LSC occupies, that is $M = 2.3 \times 10^{15}$ $M_\odot$ for the case of flat universe.

5. Concluding remarks.

The excess mass estimated in the previous section suggests that at least $10^{15} M_\odot$ exists in LSC. This value corresponds to 10^4 galaxies which is 10 times greater than visible mass. Hence we interpret our results as follows:

(1) hidden mass of 10 times greater than observed galaxies exists.[7]

or

(2) initial proper motion exists.

The latter interpretation is more natural if we assume the existence of the primordial turbulence. As had been proved by present author,[8] such a turbulence is die out before the epoch of plasma recombination ($z = 1000$). But larger scale vortical motion can survive against viscous dissipation. In this sense, such a rapid infall velocty is a possible remnant of the primordial cosmic turbulence.

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