THE JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
23; 112~115, 1990

EVOLUTION OF AN ASPHERICAL VOID*

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(Received October 17, 1990)

ABSTRACT

We test an evolution of a giant void using an N-body simulation. We find the void expansion is faster than the rest part of the universe and the shape of an isolated aspherical void becomes more spherical as it evolves.

I. INTRODUCTION

The recently observed large scale structures such as the giant voids, large scale galaxy distributions (de Lapparent, Geller and Huchra 1988; Giovanelli and Haynes 1985) and large scale streaming velocities (Gorski *et al.* 1989; Lynden-Bell *et al.* 1988) are confronting puzzling features which are not compatible with most of existing theoretical models. In the last decade, several redshift surveys of galaxies have revealed the three-dimensional distribution of galaxies on scales greater than tens of megaparsecs. In particular, the first result of the extension of the CfA survey showed a bubble-like distribution of galaxies (de Lapparent, Geller, and Huchra 1986; Huchra *et al.* 1988): the universe is filled with nearly spherical voids and galaxies seem to be distributed on the surfaces of the voids.

Most of theories for the formation of large-scale structures and galaxies are based upon the idea that these structures in the universe were produced by gravitational growth of primordial density perturbations imprinted in the early universe. The most succesfull scenario to explain the observed large scale structure is the biased galaxy formation with cold dark matter (White *et al.* 1987). A recent N-body simulation with this biased cold dark matter scenario succesfully revealed the large scale void structure which is compatible with the observations (Park 1990). Another scenario explaining the void structure is the explosion model. In this model shock waves produced by explosive energy release from a small number of seeds such as first generation objects (Ostriker and Cowie 1981) or superconducting cosmic strings (Ostriker, Thompson, and Witten 1986) sweep up ambient intergalactic gas into spherical shells, which fragment into new objects.

*This work was fully supported by the Ministry of Education through Korea Research Foundation.

Galaxies from on these large shells, and thus the bubble-like structure of the galaxy distribution is naturally produced.

We present an N-body simulation to test an evolution of an isolated void, particularly for an aspherical one. Our aim is not to simulate the details of large scale structures, but to show whether the initial seed of a void with arbitrary shape in the primordial universe would grow to form a present giant void having nearly a spherical form. For this purpose we build a particle-particle (PP) code with certain symmetrical initial conditions. Although the particle number in the code is limited to a few hundreds, it meets our purpose to show qualitative features of a void.

II. DESCRIPTION OF THE CODE

Instead of the usual periodic boundary conditions in most of other simulations (for example, see Hockney and Eastwood 1981), we incorporates a spherical boundary condition. Particles are distributed inside a spherical region of which radius is $58.8h^{-1}$Mpc and follows the pseudoNewtonian equation of motion (Peebles 1980). Then a particle inside the sphere obeys the dimensionless equation of motion in the proper coordinate.

$$\frac{d^2\vec{r}_i}{dt^2} = -G\frac{m_0 t_0^2}{r_0^3} \sum_{j \neq i} \frac{m_j}{|\vec{r}_i - \vec{r}_j|^3} (\vec{r}_i - \vec{r}_j).$$

Here the summation goes over all the particles in the sphere. The particle position $\vec{r}$ is expressed in the unit of r_0, time t in t_0 and particle mass m in m_0. For the simplicity, we set $Gm_0t^2_0/r^3_0 = 1$ by choosing the following values.

$$m_0 = 4 \times 10^{44} g \ (typical\ galaxy\ mass),$$

$$t_0 = 4.7 \times 10^{17} s \ (Universe\ age),$$

$$r_0 = 1.8 \times 10^{24}\text{cm} = 0.588\text{Mpc}.$$

We take the radius of the sphere $R = 58.8h^{-1}$Mpc comparable to a giant void size at the present epoch.

We apply the Numerov algorithm to determine particle's position at the time $t_{n+1} = t_n + \Delta t$ with the informations at time t_n *and* $t_{n-1} = t_n - \Delta t$.

$$\vec{r}_{n+1} - 2\vec{r}_n + \vec{r}_{n-1} = \frac{(\Delta t)^2}{12} \{\vec{g}(\vec{r}_{n+1}) + 10\vec{g}(\vec{r}_{n-1})\} + O((\Delta t)^6)$$

where $\vec{g}(\vec{r}_n)$ is the peculiar gravitational field at the particle position $\vec{r}$ at time t_n. We omit the particle index i. This formula is an implicit one because of the term $\vec{g}(\vec{r}_{n+1})$. Therefore we employ the predictor-corrector algorithm to evaluate $\vec{r}$.

$$\vec{r}^{\,(k+1)}_{n+1} = 2\vec{r}_n - \vec{r}_{n-1} + \frac{(\Delta t)^2}{12}\{\vec{g}(\vec{r}^{\,(k)}_{n+1}) + 10\vec{g}(\vec{r}_n) + \vec{g}(\vec{r}_{n-1})\},$$

with $\vec{r}^{\,(0)}_{n+1} = \vec{r}_n$. In the actual calculation we do the iteration up to $k = 4$.

III. RESULTS AND DISCUSSIONS

The initial and final states of the void are show in Figs. 1. and 2. The horizontal coordinate in the figures corresponds to the X-coordinate of the simulation. One the other hand the vertical coordinate corresponds to $\pm\sqrt{Y^2 + Z^2}$. Total number of particles is 288. But many of them are overlapped in the figures. The initial distribution of the particles has a regular cubic lattice structure except in the void region. It is symmetric under each coordinate reflection and also under the exchange of y and z coordinates. This symmetric structure reduces the numerical instability. The radius chosen in the spherical region is $58.8h^{-1}$ Mpc in Fig. 2. We assume there is only Hubble expansion at the redshift $z = 21.5$ at which the simulation starts.

We assume $\Omega = 1$ on average in the sphere. But the void region has lower mass density and its local Ω is smaller thus the void expansion rate should be higher than the overall Hubble expansion. As apparent in Fig. 2, we see this effect. Of course the particle density is high near the void surface. While we cannot estimate it quantitiatively due to the small number of particles in use, this catch-up effect would help galaxy formations in the primordial universe. We also find that the void becomes more spherical as it evolves. The inital ratio of the semiminor axis to the semimajor axis is $b/a = 0.47$ at $z = 21.5$ and the final value $b/a = 0.69$ at $z = 0$.

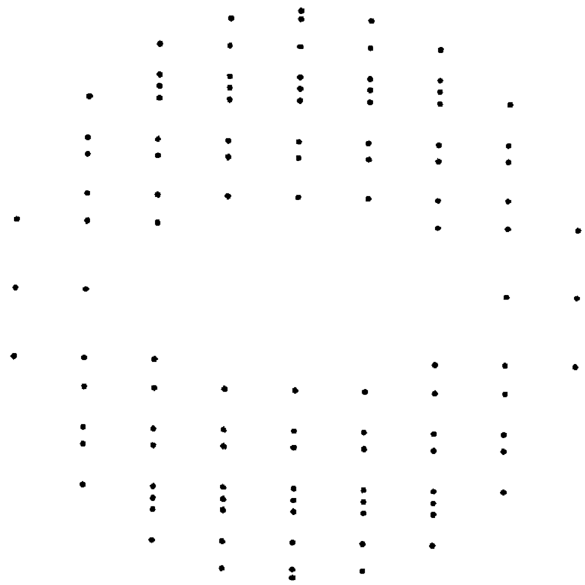

Fig. 1. An initial state of particle distribution in comoving coordinate at $z = 21.5$. The horizontal axis corresponds to the X-coordinate of the simulation and the vertical axis to $\pm\sqrt{Y^2 + Z^2}$. The total number of particles here is 288. Many of them are overlapped in the figures. The ratio of the semiminor axis to the semimajor axis is $b/a = 0.47$.

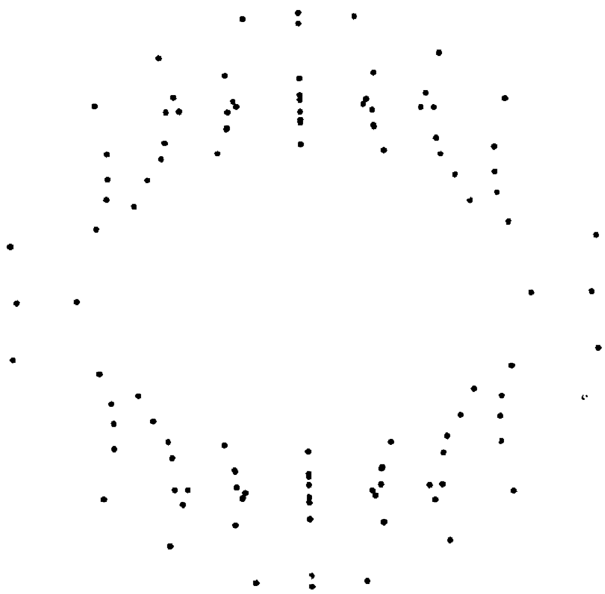

Fig. 2. The final state of particle distribution in comoving coordinate at $z = 0$. The ratio of the semiminor axis to the semimajor axis is $b/a = 0.69$.

ACKNOWLEDGEMENT

We thank to K.-T. Kim for useful discussions.

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