N-Body Simulation for Dark Matter Clustering at Different Epochs of the Universe

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Abstract

In this study the cold dark matter particles is simulated at different epochs of the universe using Gadget-2 code for lambda cold dark matter model (ΛCDM). Firstly, the dark matter particles distributed in homogenous form then with time because of the gravity effects the particles collected gradually to construct sub clumps of halo and then big clumps of halo. This process is shown in the simulation from redshift z=17.7 (700Myr.) after the Big Bang of the universe to z=0 (13.3Gyr.).

During these epochs of the universe the clustering of dark matter halo, filaments, and voids are constructed. These clusters of halo which were found from the simulation are the basic parts of galaxy clusters.

In the simulation also the velocity scale of each epoch shows the displacement of the dark matter particles at different directions to construct the halo.

Keywords: N-Body Simulation, Dark Matter Clustering, lambda cold dark matter model**.**

Introduction

Luminous matter is matter that we can detect at any wavelength using any of the telescopes on the earth. This matter, everything we see, seems to make up only about 10 percent of the universe. Gravity gives away the presence of the other 90 percent, what we call dark matter because it is non luminous [1].

Historically, Jan H. Oort 1932[2] explained that there are some missing matter in our galaxy, then this matter discovered by Zwicky 1933[3] during studying the motion of galaxies within Coma cluster of galaxies. In spite of this, the idea of dark matter was not accepted till extensive observational results of Rubin and Ford 1970[4]. After that the existence of a dark matter got further support by the theory of inflation introduced by Guth 1981 [5].

Telescopes are probing the very earliest galaxies and computer simulations can extend our knowledge behind the real world observations. When we notice a pattern in nature, we are curious about it and attempt to investigate it. The numerical tool is often the only one available to the researcher studying the long-term evolution of galaxies. When we perform a computer simulation of galaxies, we hope to learn why real galaxies have the features we observe [6].

According to the current paradigm of structure formation inflation amplifies quantum fluctuations, which are present in the dark matter density field of the early universe, to cosmic scales; at the time of matter and radiation density equality, these fluctuations start growing by gravitational instability. After radiation and ordinary baryonic matter decouple, radiation pressure stops supporting the baryonic density perturbations against self-gravity and against the pull of the dark matter gravitational potential wells that have already formed the dark matter in homogeneities thus accelerate the collapse of ordinary matter. At later times, the dark matter particles, which have sufficient momentum to stream out of the denser regions, set in a characteristic scale in the power spectrum, which is proportional to the typical velocity of the dark matter particles themselves [7].

An N-body treatment of the evolution of the dark matter component is gravitational. The importance of this method is that it tracks galaxy and dark matter halo evolution across cosmic time in a physically consistent way, providing positions, velocities, and other physical properties for the galaxy populations, so this method is used by many researchers for simulating dark matter[8][9].

Cosmological Method

There are many available codes for simulating galaxies formation, but the modern code is gadget-2 code [10] which is used in the present work.

Gadget-2 is a Lagrangian code uses particles to represent dark matter and gas. Here, each dark matter particle in the simulation has a position, velocity, mass and gravitational softening length.

The N-body simulation has been proved to be one of the most versatile methods. In N-body problem we have initial conditions, i.e. initial positions and initial velocities of all bodies in the system. Interactions between all bodies in the system have to be evaluated to receive new positions and new velocities. This evaluation is performed repeatedly so that we are getting information about the time evolution of the system [7].

The best way to understand the evolution of a gravitating system consisting of N particles would be to actually solve the force acting on a given particle due to the remaining particles. In a rather different form, by solving for poisons equation, this precisely the goal which modern versions of N-body simulation codes achieve.

The N-body problem formulated by the system of ordinary differential equations coming from Newton's laws. In the simulation galaxies obey the same laws. Galaxies are controlled by the force of gravity that acts between all bodies except of self interaction, so gravity interaction between all pairs of bodies.

Currently ΛCDM is the popular model of galaxy formation, so depending on the initial conditions of this model Ω=0.25, Ω_Λ=0.75, Ω_{baryon}=0.045, H_0=73 $kms^{-1}Mpc^{-1}$, σ_8=0.9 depended for simulating one million dark matter particles in the present work.

The introduction of a cosmological constant Λ in the CDM scenario allows for a flat universe [11] [7],

$$\Omega_\Lambda = \frac{\Lambda}{3{H_0}^2} \quad (1)$$

$$\Omega + \Omega_\Lambda = 1 \quad (2)$$

with $\Omega < 1$ as suggested by observations.

Where the density parameter Ω and density parameter for the cosmological constant Ω_Λ are defined by

$$\Omega_\Lambda \equiv \frac{\rho_\Lambda}{\rho_c} \quad (3)$$

Where ρ_c is the critical density,

$$\Omega(t) = \frac{\rho}{\rho_c} \quad (4)$$

Boltzmann equation describes the evolution of dark matter according to the relation:

$$\partial_t f(\vec{x},\vec{v},t) + \vec{v}\cdot\partial_{\vec{x}} f(\vec{x},\vec{v},t) + \vec{a}\cdot\partial_{\vec{v}} f(\vec{x},\vec{v},t) = 0 \quad (5)$$

Results and Discussion

Figs.(1a-e) show different epochs of the universe. Fig.(1a) shows the dark matter particles distribution in the box without any clumps in any place of the box. In Fig.(1b) some sub clumps appears because of the gravitational forces between the dark matter particles. The sub clumps grow gradually at different epochs to construct clusters of dark matter halo as shown from Figs.(1c-e), so the dark matter clustering, voids, and filaments are constructed because of continuous attraction of dark matter particles. These clusters are halos which surround galaxies in the universe. The filaments combine the clusters of the dark matter and the voids which are the spaces without sub clumps and clumps inside surround the clusters and filaments. Developing of these components start from high redshitfs to low redshitfs so in the final snapshot which represent the lowest redshift, z=0, these components are very clearly shown in Fig.(1e).

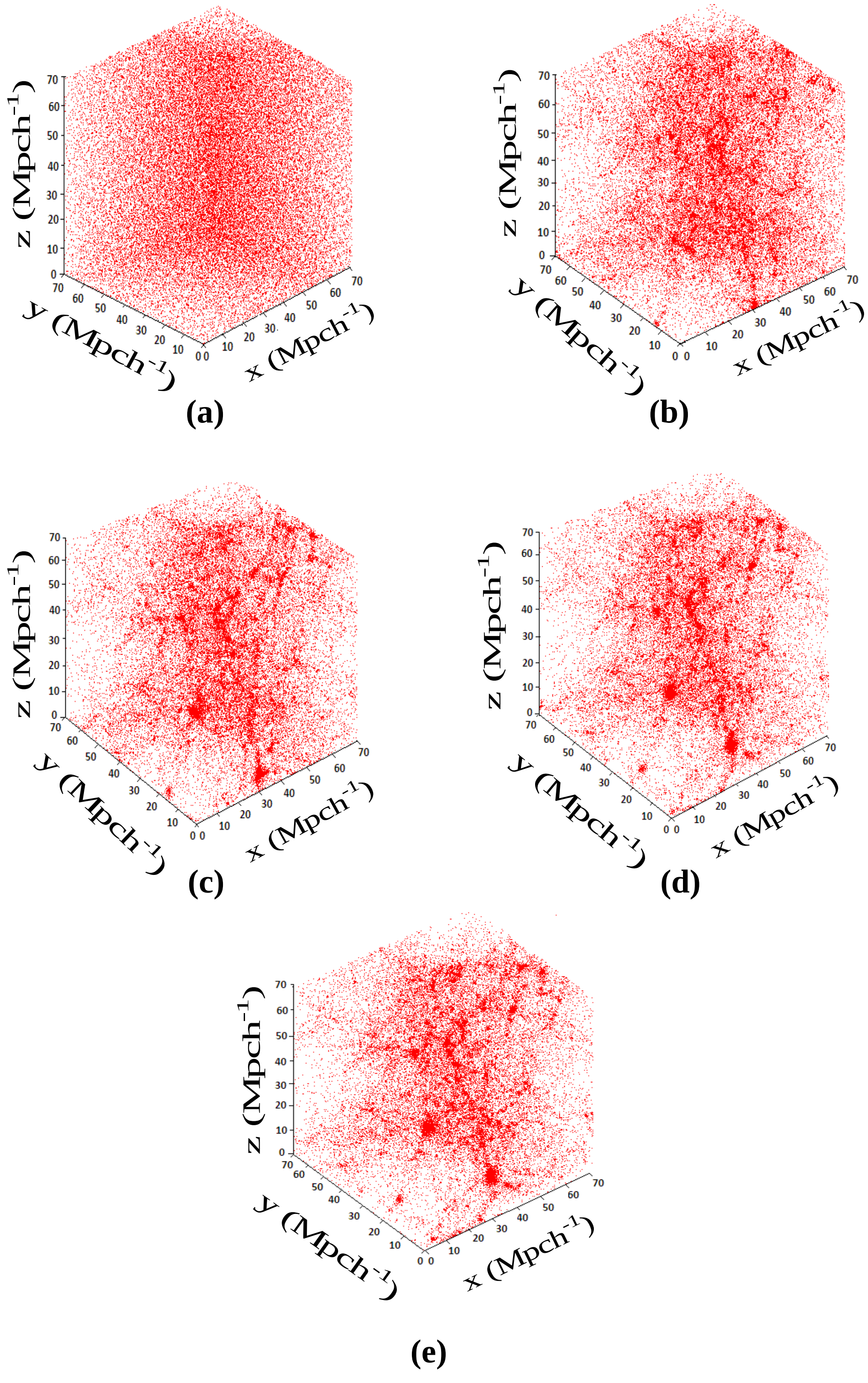


Fig.(1) Dark matter in box $(70\ Mpc\ h^{-1})^3$ at five epochs:
a)z=17.7 b)z=1.15 c)z=0.5 d)z=0.1 and e) z=0.

To observe the components of such simulations a slice of each box is taken. A slice of 0.1 Mpc^{-1} of the box at previous redshifts were shown in Figs. (2a-e). These figures represents the simulations in the xy plane. Fig.(2a) is a slice of particle distribution with based on an originally glass like particle distribution. After that in each slice the dark matter clusters, filaments, and voids appear very clearly especially in Fig.(2e) which represents the lowest redshift.

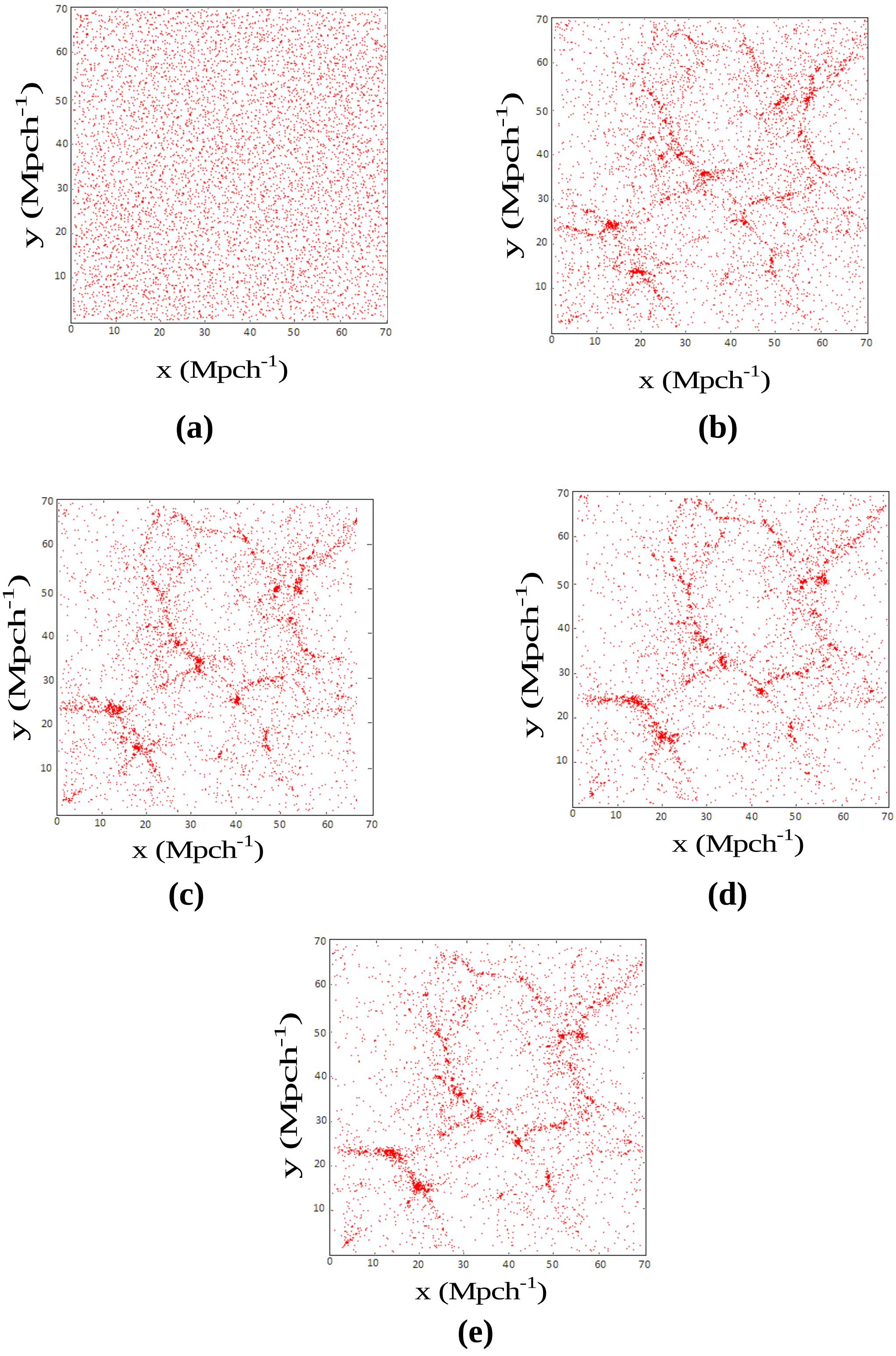
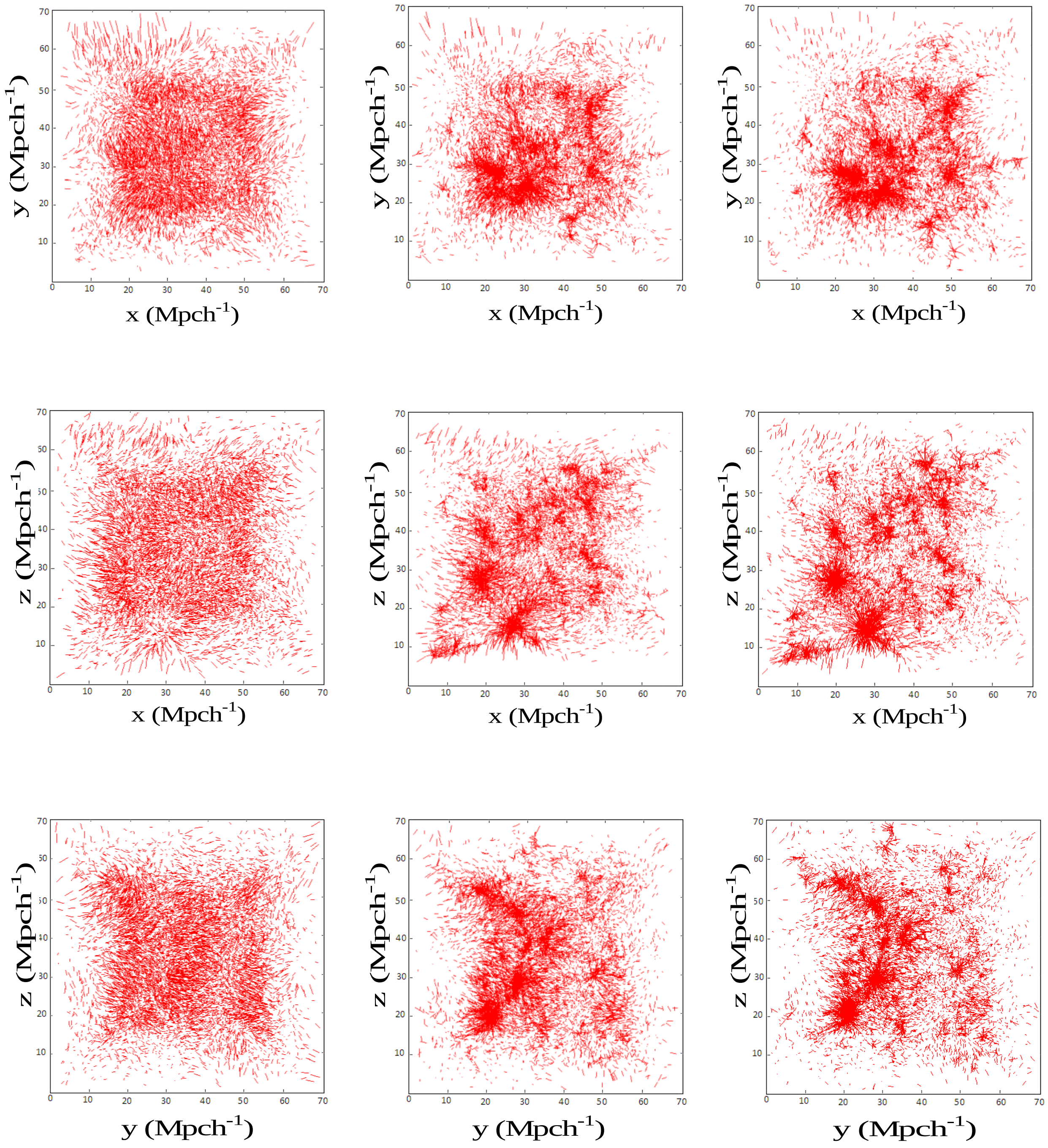


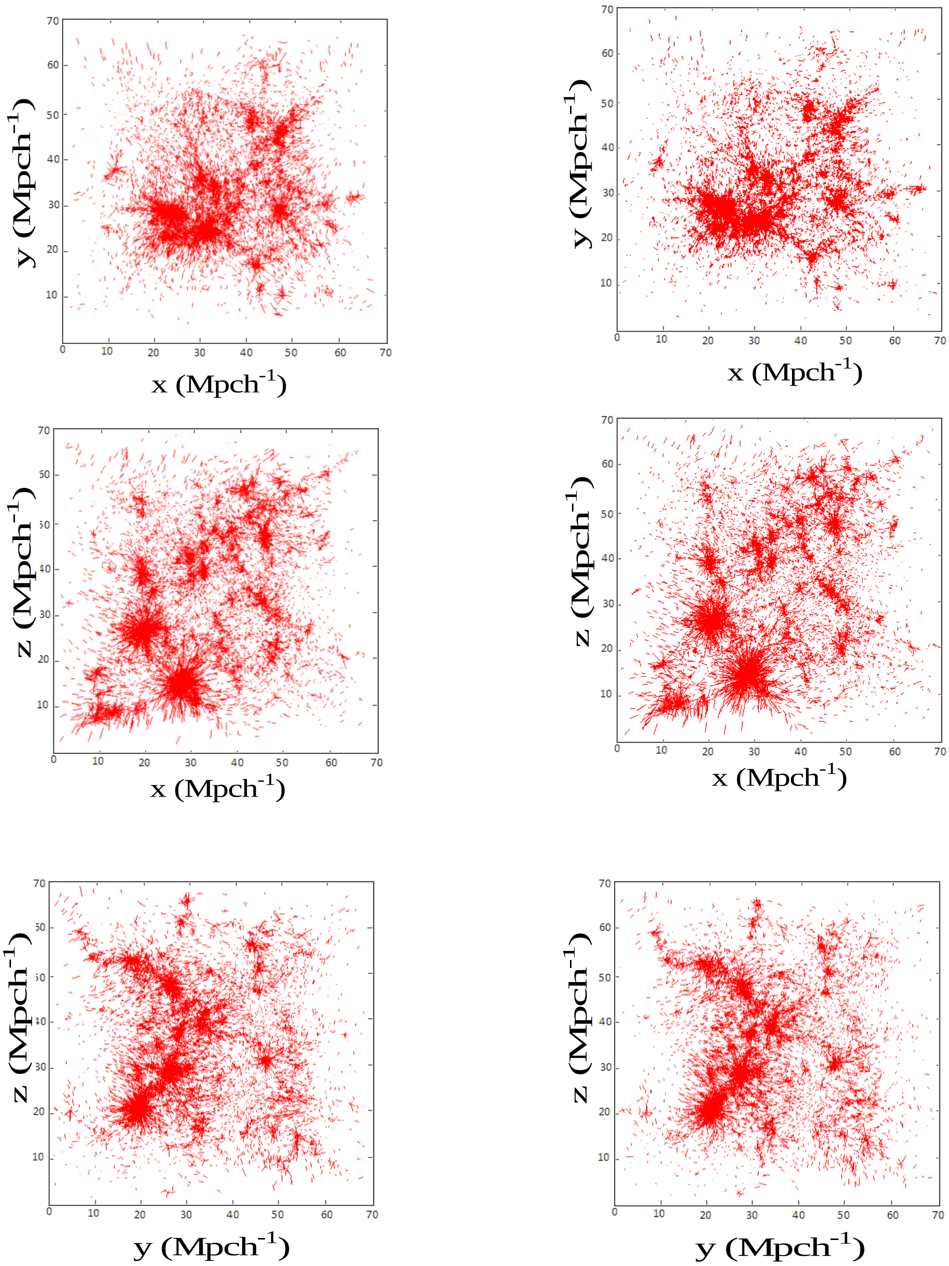
Fig.(2) Dark matter in a slice of thickness 0.1 the box size at five epochs: a) z=17.7 b) z=1.15 c) z=0.5 d) z=0.1 and e) z=0.

Figs.(3a-e) show velocity scale of the dark matter particles. The figures represent the motion of dark matter particles at different redshifts with gravity pulls particles into regions of the universe where the density is relatively high. Each line represents the amount by which a galaxies actual velocity different at different epochs of the universe. These displacements are random as shown in the figures at high redshifts and the displacements are high as in Fig.(3a). But the displacements of galaxies are low at low redshifts because the clusters constructed and the individual galaxies are now very less compeering with high redshift epochs, so the velocity is low. This is clearly appears in Fig.(3e).



(a) (b) (c)

Fig.(3) Velocity of dark matter particles in xy, xz and yz planes at five epochs: a) z=17.7 b) z=1.15 and c) z=0.5.



(d) **(e)**

Fig.(3) :Continued
d) z=0.1 and e) z=0.

Conclusion

From the present work one may conclude the following:

1- Simulation of dark matter particles shows how the dark matter particles is clustered in the universe at different epochs.

2- Dark matter clustering results fromthegravitational forces between thedark matter particles from the early universe till now which is clearly started from z=0.1.

3- Although the dark matter is amysterious unseen matter, but the N-body simulations gives sufficient knowledge about some important characteristics of it.

4- The lines of galaxies displacement in the simulation explain that the velocity of galaxies is large in the high redshifts such as z=17.7 but low at redshifts below that.

At redshift z=0 the velocity has the minimum value.

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الخلاصة

في هذه الدراسة تمت محاكاة المادة الداكنة الباردة في عصورمختلفة للكون وذلك باستخدام Gadget-2 code لنموذج Lambda cold dark matter. في البداية، تم توزيع جسيمات المادة بشكل متجانس بعدها بمرور الزمن وبسبب تأثير الجاذبية تجمعت الجسيمات تدريجيا لتكوين كتل ثانوية من الهالة وبعدها الكتل الكبيرة من الهالة.هذه العملية قد تمت إظهارها في المحاكاة من الإزاحة الحمراء (700Myr.) z=17.7 بعد الأنفجار الكبير للكون الى(13.3Gyr.) z=0.

خلال هذه العصور من عمر الكون تشكلت العناقيد ،الفتائل،ولفجوات. هذه العناقيد من الهالة التي وجدت في المحاكاة هى اجزاء اساسية من عناقيد المجرات.

في المحاكاة ايضا أظهرت مقايس السرعة إزاحة جسيمات المادة الداكنة بإتجاهات مختلفة لتكوين الهالة في كل عصر.