GALAXY FORMATION IN LAMBDA COLD DARK MATTER MODEL

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Abstract

The present work adapts the lambda cold dark matter ΛCDM model for simulating 10^6 dark matter and 10^6 gas particles to form galaxies inside a box of size $(70Mpc/h)^3$. The simulation is shown from high redshift z=10(1.2Gyr.) after the Big Bang to the low redshift z=0(13.4Gyr.) which represents the present day. The position of the particles and the temperature-density relations were studied at each epoch. It is found that the galaxies formation start at low redshift z=5 and the gas cooled at 10^4 K. The web construction of voids, filaments and clusters of galaxies were observed clearly at z=0. Sixteen processors of high performance supercomputer of Nottingham University-England were used in the simulation and the run took more than one day.

تكوين المجرات في نموذج المادة الداكنة الباردة

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الخلاصة

في هذا البحث تم استخدام نموذج المادة الداكنة الباردة لمحاكاة مليون جسيم من المادة الداكنة الباردة مع مليون جسيم من الغاز لتكوين المجرات داخل صندوق ذات حجم (70Mpc/h)3 . تم عرض المحاكاة من ازاحة حمراءعالية (1.2Gyr.) z=10 بعد الانفجار الكبير الى ازاحة الحمراء الواطئة (13.4Gyr.) z=0 والتي تمثل الوقت الحاضر. تمت دراسة مواقع الجسيمات وكذلك علاقة درجة الحرارة مع الكثافة لكل عصر. لقد وجد بان المجرات تكونت من الازاحة الواطئة z= 5 ، وكذلك ظهرتبريد الغازعند درجة الحرارة 104 K و شوهد التركيب الشبكي للفجوات والفتائل وكذلك عناقيد المجرات بوضوح عند z=0 .
لهذه المحاكاة تم استخدام ستة عشرة معالجا لسوبركومبيترذات كفاءة في جامعة نوتنغهام البريطانية واستغرق تنفيذ البرنامج اكثر من يوم واحد.

Introduction

Galaxies are the basic building blocks of the Universe. The general term used to describe a physical aggregation of many galaxies is a galaxy cluster. There are clusters of greatly varying size and richness containing many hundreds or thousands of galaxies in a region just a few million light years across. Recent observational surveys have shown that galaxies are not simply in quasi-sphere but also sometimes lie in extended quasi-linear structures called filaments. The clusters are complemented by vast nearly empty regions called voids, many of which appear to be roughly spherical. These voids contain so many fewer galaxies than average or even no galaxies at all [1]. Galaxy formation began when gravity collected hydrogen and helium gas into protogalactic clouds. All galaxies developed as gravity pulled matter together in regions of the Universe that started out slightly denser than surrounding regions. And dark matter which is unseen and

non baryonic matter is thought to drive galaxy formation. The gravity of dark matter seems to be what pulled gas into protogalactic clouds. It continues to cause galaxies to cluster. So the astronomers believe that the galaxies are constructed from cold dark matter and gas [2].
Cosmological simulation is the suitable method for investigation of galaxy formation, radiative cooling, feedback processes and mechanical processes of galaxy formation[3]. Two complementary techniques are available for theoretical modeling of galaxy formation and evolution, numerical simulations and semi-analytical modeling. The strategy in both cases is to calculate how density perturbations emerged from the Big Bang turn into visible galaxies [4].
The idea of cosmological numerical simulation is to represent a part of the expanding Universe as a box containing a large number of point masses interacting through their mutual gravity. This box, typically a cube, must be at least as large as the scale at which the Universe becomes homogeneous if it is to provide a fair sample which is representative of the Universe as a whole [5].Although there are four main models for simulating galaxies formation, viz. standard, lambda, tau, and open, the cold dark matter model is more acceptable than the others because it is nearer to the real universe. Hence, researchers [6,7,8,9] concentrate on this model.
In the present work, the same model was used with new number of particles inside a new box size at different redshifts.

The Simulation

In this work the gadget-2 code [10] depended with tree-particle mesh (TREE-PM) method for simulating galaxy formation of a flat Lambda Cold Dark Matter ΛCDM model with the parameters: the cosmological density Ω=0.25, dark energy density ΩΛ=0.75, baryon density Ωb=0.045, fluctuation amplitude σ8=0.9 and Hubble constant H0=100 km/s/Mpc. Inside the box of length 70Mpc/h, 106 dark matter particles were simulated with 106 gas particles together. The mass of each dark matter and gas particles were (1.95 and 0.43) ×1010M sun respectively. The run took more than one day to complete on 16 processors of high performance supercomputer of Nottingham University–England.
Because the dark matter is the collisionless matter that has no hydrodynamic force but have only gravitational effect. So in addition to Newton's law of gravitation, the collisionless Boltzman equation and the Poisson's equation depended in the gadget-2 code which treats the characteristic of the dark matter as given below [11]:

$$\partial_t f(\vec{x},\vec{v},t)+\vec{v}\cdot\partial_{\vec{x}} f(\vec{x},\vec{v},t)+\vec{a}\cdot\partial_{\vec{v}} f(\vec{x},\vec{v},t)=0 \quad ....(1)$$

Where: $\vec{x}$, $\vec{v}$ and $\vec{a}$ are the displacement, velocity and acceleration of the particles in the time (t) repectively.
The Poisson's equation is given by[4]:

$$\vec{\nabla}^2\Phi(x)=4\pi G\rho(x) \quad ....(2)$$

where $\vec{\nabla}\Phi(x)$ is the gravitational potential filed generated by density ρ .

Because the gas particles are collisional fluid and gravitational in addition to the modeling and gas dynamic the code treats the thermal processes of the gas, such as the gas cooling by radiation and Compton cooling.

Equation of state in galaxy clusters can be written as follows[12]:

$$P=\frac{\rho k_B T}{\mu m_P} \quad ....(3)$$

where K_B is Boltzmann's constant, T is the temperature, μ is the mean molecule weight, and m_p is the mass of the proton, the quantity is more often used in astrophysical theory of galaxy clusters.
From the Friedman equation the relation between the density parameter and geometry of the Universe can be written as follows [13]:

$$\Omega+\Omega_\Lambda-1=\frac{k}{a^2H^2} \quad ....(4)$$

where K is the curvature factor.
In the flat Universe model, k =0, so equ. (4) becomes :

$$\Omega+\Omega_\Lambda=1 \quad ....(5)$$

In the present work, the Hubble constant:
$H_0=100$ h km s-1 Mpc-1 the uncertainty (h) has the value:
h=0.73, so :
$H_0=73$ km s-1 Mpc-1
Thus the age of the Universe (t0) is:
$t_0=H_0^{-1}=13.4$ Gyrs.

Results and Discussion

A: Dark matter and gas cooling

Inside the box 106 dark matter particles with 106 gas particles were simulated at different redshifts. For z=10 The xyz direction of these particles are shown in Figure.(1-a).

In Figures. (1-b) , (1-c), and (1-d) which represent the redshifts z=5 and z=4, a small change of collection of the particles can be seen in collection of particles with the effect of gravitational force because these epochs are early epochs for massive clumping and galaxies formation.

As shown in Figures. (1-e), (1-f), and (1- g) the clumping starts gradually because of the effect of the gravitation force. So the time sequence of galaxy clustering formation can be seen more clearly from the low redshift z=2 (Figure.1-e)

From the redshift, z=0 (Figure.1-g) which represents the present epoch, less dense regions appear, which are voids, between the cluster of galaxies, and the walls which are filaments surrounding those voids. These results are in a good agreement with that obtained by Davis et al. [14] and Springle et al. [7], and the difference in positions and sizes of clumping return to the differences in number of particles and the size of the boxes.

B: Temperature-density relation of gas cooling

It is important to study the time sequence of gas cooling in temperature-density plane to investigate different densities of gas particle distributions in different temperatures.

Figures (2-a to g) show how the shapes and also the values of temperature and density change with time in the gas cooled inside the boxes. In Figures.(2-a), (2 -b), and (2-c) the major parts of gas cooled adiabatically to less than 100K when the density increased from nearly 10 (g/cm3) as in Figure. (2-a) to more than 106 (g/cm3) as in Figure.(2-c).

In Figure. (2-d), (2-e), and (2-f) much cooling of the gas caused to distribute some gas particles which construct the over dense part of the gas. At this part little number of cooled particles reach to near 106 (g/cm3) as shown in Figure.(2-f).

Figures (2-e), (2-f), and (2-g) show the three main parts of cooled gas in each figure which are the low adiabatic density, the over dense and the very over dense parts. At z=2, the particles of the overdensity part, which is the shock heated gas region , increase because of cooling the gas, this increasing continues at z=1 and z=0 , as shown in Figures.(2-f) and (2-g) respectively. In Figure.(2-g) some over dense particle densities reach more than 106 (g/cm3). The third part is the very overdense gas region that has cooled radiatively from the temperature near 104K which is the cutoff location of the curve . This region is grown because of cooling continuously until some very overdense particles reach more than 1010 (g/cm3) as shown in Figure. (2-g). The increase of gas density by cooling on the one hand, and the gravitation force on the other hand, cause the construction of molecular clouds in the galaxies .

These results are in a good agreements with that obtained by Yoshida et al. [15].

Conclusions

1- Simulation is the best method for studying the properties of galaxies formation because the telescopes till now can not observe the galaxies formation at the early epochs such that depended in the present work.
2- The size (70Mpc/h)3 is a proper size for simulating two million particles which are the seeds of the huge number of galaxies formation.
3- The galaxies formation starts at low red shifts z=5, and the gravitation force is the basic force that affects the particles to clump the components of the dark matter and gas causing the formation of galaxy clusters, filaments and voids with the existence of expansion from the Big Bang.
4- The ΛCDM model depended in the present work gives suitable view of galaxies formation which is called the cosmic web as it exists in the real sky.
5- Cooling the gas in the simulation caused the increase of the density and collecting the particles to construct the clumps with the help of gravity.

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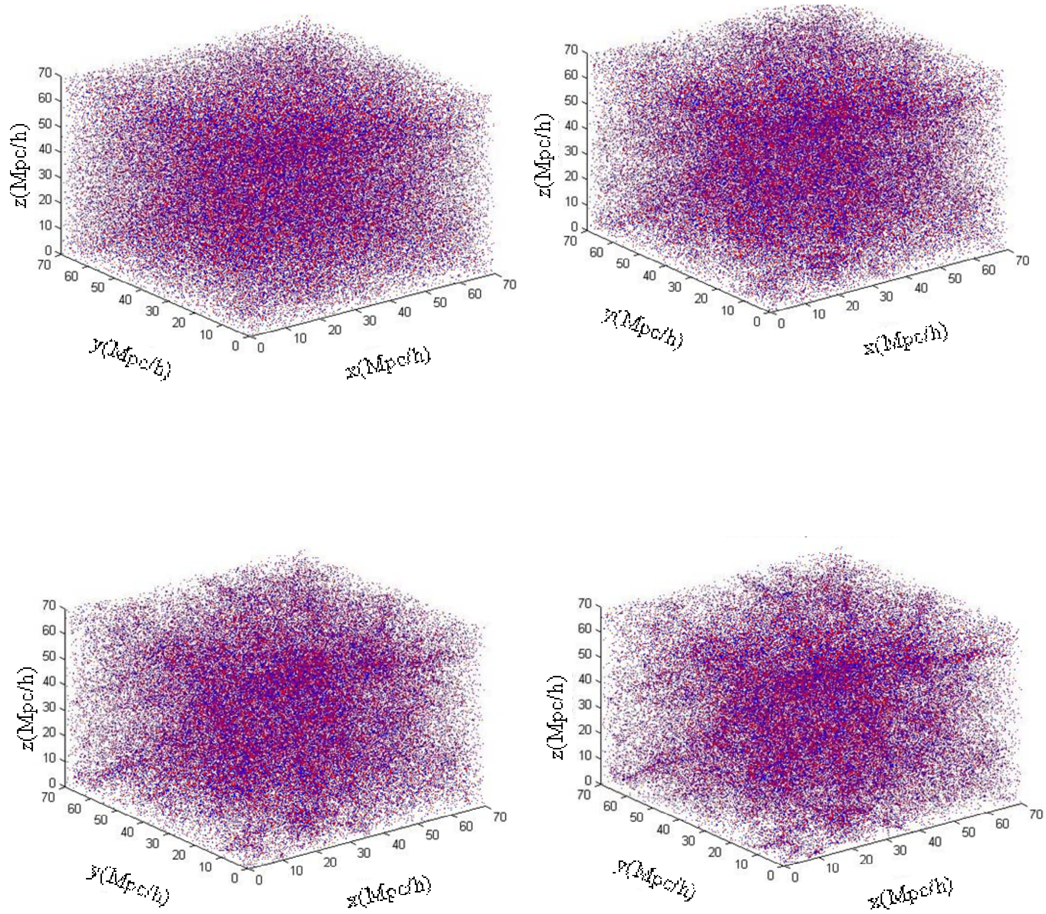

Figure 1 : Cold dark matter and cooled gas particles at different redshifts :
a) z=10 b) z=5 c)z=4 and d) z=3

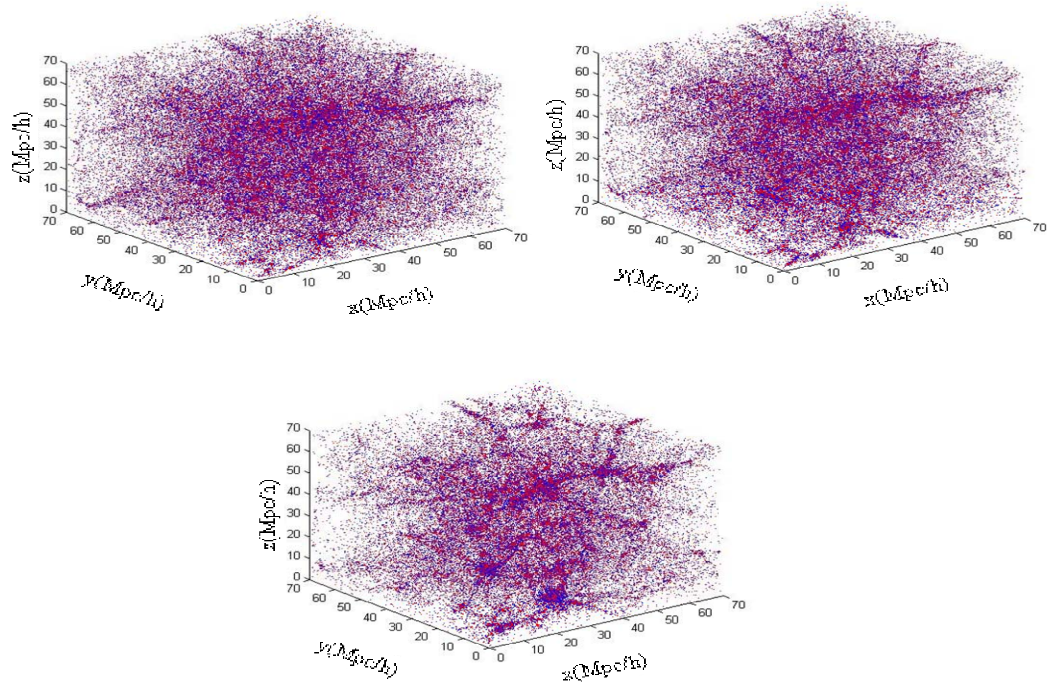

Figure 1: Continued for :
e) z=2 f) z=1 and g) z=0

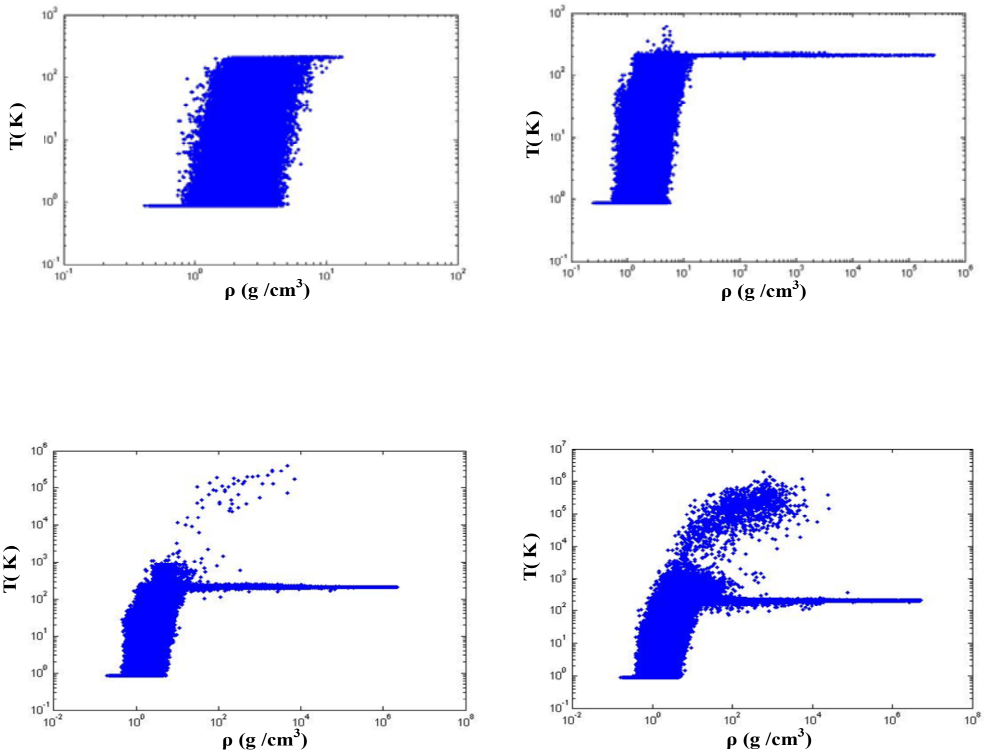

Figure 2 : Temperature-density planes of cooled gas at:
a) z=10 b) z=5 c)z=4 and d) z=3

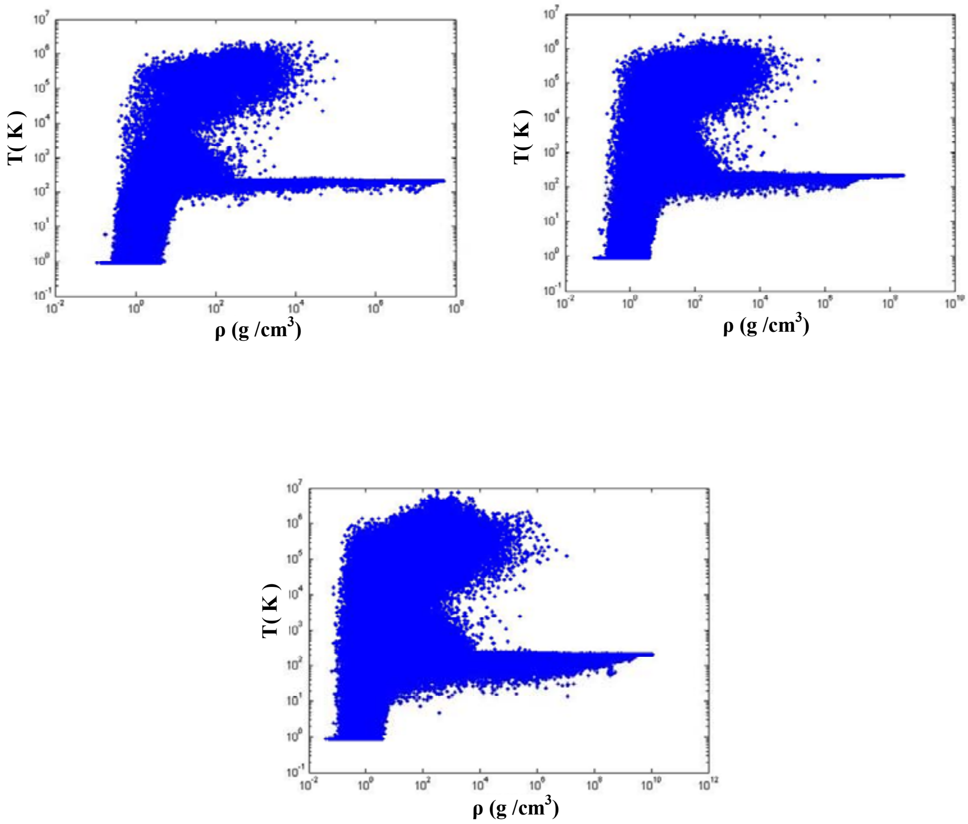

Figure 2: Continued for :
e) z=2 f) z=1 and g) z=0

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