

Simulation of Gas and Dark Matter in Galaxy Formation

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Abstract

In the present work the gas and dark matter were simulated in lambda cold dark matter model using gadget-2 code. In the simulation one million gas and one million dark matter particles were simulated from the early universe (redshift $z=30$) to (redshift $z=0$) in a box of size $(80\text{Mpc}/h)^3$. The gravity caused the collection of gas and dark matter particles to construct many clumps, and then these clumps developed with time. The clumps are clusters of galaxies formed in the simulation. The clusters surrounded by voids, while the filaments formed between the clusters. The clusters, voids, and filaments were clearly appeared in redshift $z=0$. In the simulation, the density-temperature plane shows different concentrations of the non cooling and cooling of gas particles in different epochs.

In the simulation sixteen processors of high performance supercomputer of Nottingham University-England were used.

Introduction

Dark matter is the unseen material that does not produce enough radiation to be observed directly. Several independent arguments suggest that the Universe dominated by dark matter. Although it was provided in 1933, but was detected in 2006 by its gravitational lensing. There are three different ways of measuring the amount of dark matter in clusters of galaxies which are galaxy orbit, measuring the temperature of the hot gas in clusters and the gravitational lensing. All of these methods agree on the indication that the total mass of a cluster is about fifty times the mass of its stars, implying huge amounts of dark matter. (Coles, 1998; Ramachers, 2001).

Some of the dark matter could be ordinary or baryonic matter but there does not appear to be enough ordinary matter to account for all the dark matter. Most of it is probably extraordinary or nonbaryonic matter consisting of undiscovered particles that are called weakly interacting massive particles WIMPs (Bennett et al., 2007).

Dark matter is grouped into two general types, the cold dark matter and the hot dark matter. The first is non baryonic and non relativistic particles (Vitorio & Silk, 1984), the second is also non baryonic but it is ultra-relativistic particles (Masayuki & Ikeuchi, 1984). The evolution of the structures refers cold dark matter (Holtzman & Primack, 1993).

According to the current standard paradigm, galaxies form and reside inside extended dark matter halos and the gravitation force of dark matters must be the primary force holding these structures together. Thus, it is strongly suspected that the gravitational attraction of dark matter is what pulled galaxies and clusters together in the first place (Bennett et al., 2007; White & Ress, 1978).

The second component of the universe is the gas. It was predicted that the ratio of protons to neutrons during the era of nucleosynthesis of the Universe should be about 75% hydrogen and 25% helium mass (Bennett et al., 2007).

Simulation

All simulations of large-scale structures and galaxy formations depend on the existence of dark matter and gas particles which are the basic components of the universe. In the present work one million dark matter particles were simulated with one million gas particles in the conditions of cosmological density $\Omega=0.25$, dark energy density $\Omega_{\Lambda}=0.75$, baryon density $\Omega_b=0.04$, fluctuation amplitude $\sigma_8=0.9$ and Hubble constant $H_0=100h \text{ km s}^{-1}\text{Mpc}^{-1}$. Simulation of one million particles of dark matter was run in a box $(80\text{Mpc}/h)^3$. The run time took four hours to complete on two processors. The same dark matter particles with the addition of a non-cooling gas component consisting of another one million particles were simulated in the same box. This run took eight hours to complete using four processors. One million dark matters and one million cooled gases were simulated also. This run took more than forty eight hours to complete on sixteen processors. From the simulations, inside the box clumps of dark matter and gas together constructed which represents clusters of galaxies. The filaments between the clusters and the voids around the clusters are also constructed with time, so the concentration of particles differs at different redshifts.

In the present work, as mentioned above, the Hubble constant is:

$$H_0 = 100 h \text{ km s}^{-1} \text{ Mpc}^{-1} \quad \dots (1)$$

But the uncertainty (h) has the value:

$h=0.73$, so:

$$H_0 = 73 \text{ km s}^{-1} \text{ Mpc}^{-1} \quad \dots (2)$$

The collisionless Boltzmann equation describes the particles motion (Huang 1987):

$$\frac{\partial f}{\partial t} + \frac{\partial f}{\partial x} \cdot \frac{P}{m} + \frac{\partial f}{\partial P} \cdot F = \frac{\partial f}{\partial t} \quad \dots (3)$$

$F(x, t)$ is the force field acting on the particles in the fluid, and m is the mass of the particles. The term on the right hand side is added to describe the effect of collisions between particles; if it is zero then the particles do not collide.

For the galaxy clusters the thermodynamic equation of state can be written as follows (Sonntag et al., 2003):

$$P = \frac{\rho k_B T}{\mu m_p} \quad \dots (4)$$

Where k_B is Boltzmann's constant, ρ is density, T is the temperature in Kelvin degrees, μ is the mean molecule weight, and m_p is the mass of the proton, this quantity is more often used in galaxy clusters.

Results and discussion

a- Simulation of non-cooling gas

In Fig.(1a,b,andc), the box $(80\text{Mpc}/h)^3$ at different redshifts $z=30,1.2,$ and 0 is shown within two million particles, one million dark matter particles and one million gas particles. The gas was simulated in non-cooling condition. As shown in Fig. (1a), the dark matter and the gas particles are distributed homogenously inside the box and there is no attraction between the particles. In this initial step, the dark matter and the gas particles have the same spatial distribution, and each gas particle collects with each dark matter particles.

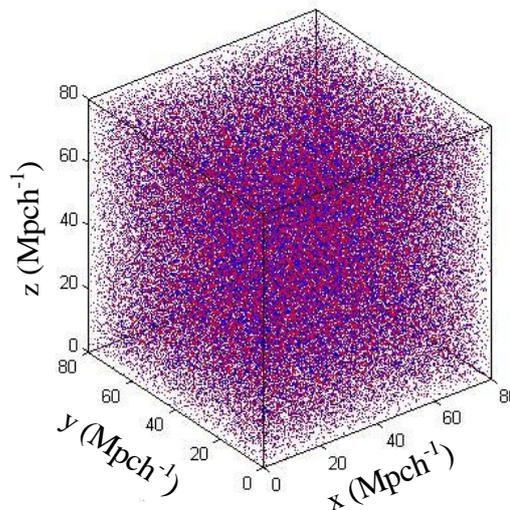


Fig. (1a): Non-cooling gas in box $(80\text{Mpc}/h)^3$ at $z=30$.

In Fig. (1b), another epoch of the universe of $z=1.2$ is shown. From the figure, it is clear that the position of the dark matter and the gas particles were changed because of the influence of the gravity force between the particles. These collections of particles represent the galaxies and some protogalaxies but there are still no large numbers or huge collection of clusters of galaxies, filaments and voids.

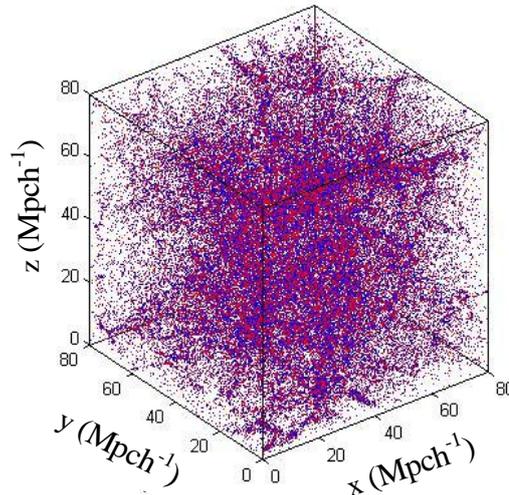


Fig. (1b): Non-cooling gas in box $(80\text{Mpc/h})^3$ at $z=1.2$.

In Fig. (1c), these clusters are more dense, and also the voids are less dense than the other epochs.

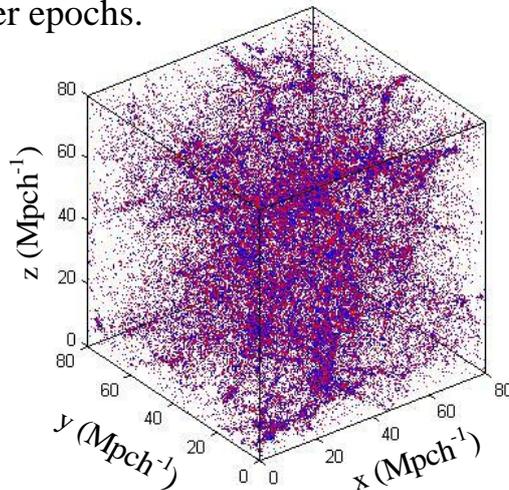


Fig. (1c): Non-cooling gas in box $(80\text{Mpc/h})^3$ at $z=0$

Fig. (2) shows the xy, xz and yz planes of each epochs $z=30, 1.2$ and 0 of the non-cooling gas respectively. In Fig. (2a), the xy, xz and yz planes of $z=30$ show initial conditions of distribution of dark matter and gas particles. Figs (2b and c) indicate $z=1.2$ and $z=0$ respectively, in which the gravitation influence is shown.

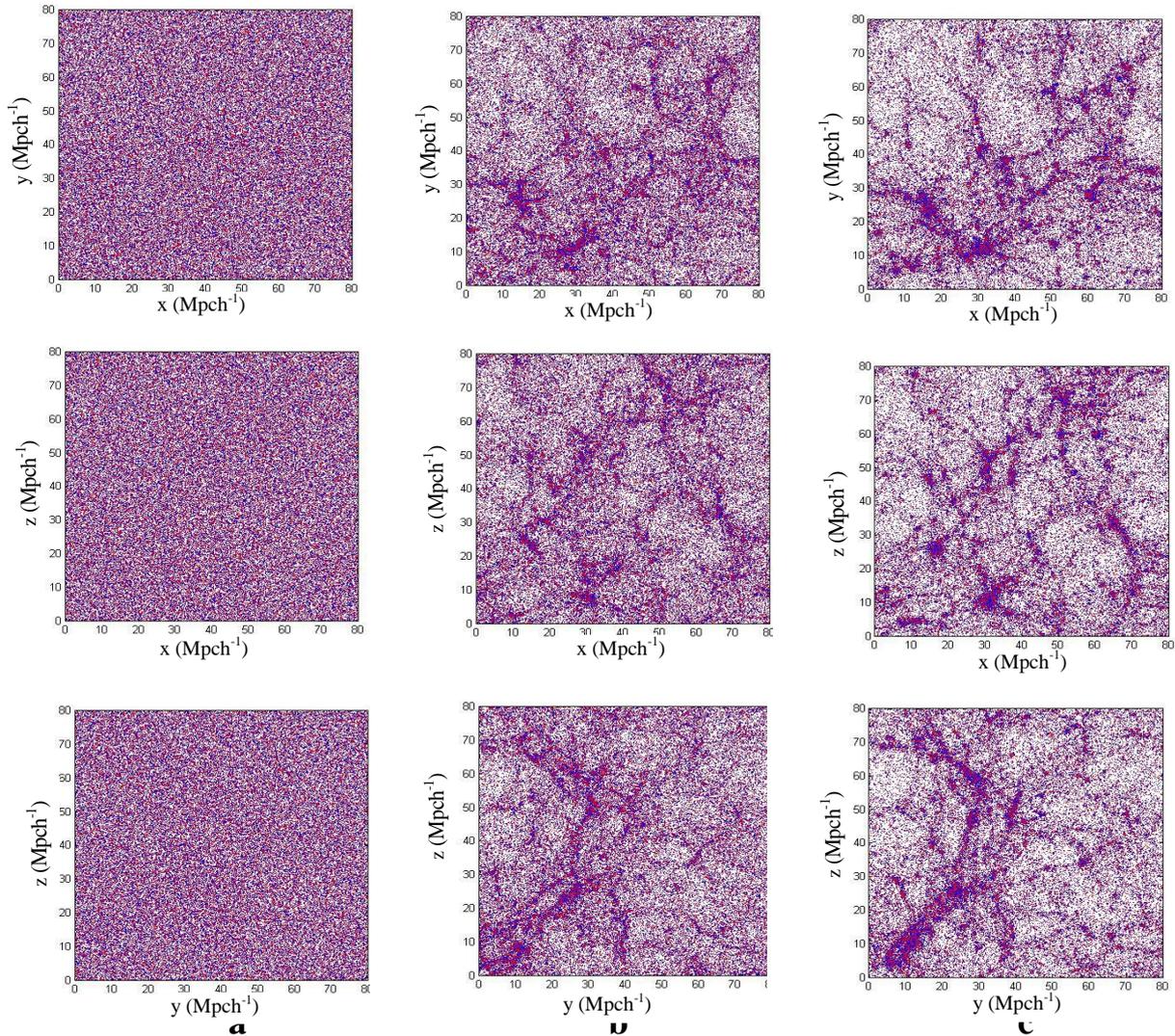


Fig. (2): Non-cooling gas in xy, xz and yz planes at three epochs: a) $z=30$ b) $z=1.2$ and c) $z=0$.

Figs. (3a, b, and c) show the temperature - density planes at three different epochs, $z= 6.3, 1.2,$ and 0 which are the time sequence of temperature changing according to the density changes. The gas particles are gravitational, and in addition they may collide with each other. Therefore, according to increasing the density of the gas by the gravitational force which causes pressure to increase on one hand and to collide with each others on the other hand, the temperature of the gas increases.

Fig. (3a) shows the temperature-density plane at $z=6.3$ (this redshift chosen because it is more clear than the other high redshifts). From the figure, it is observed that increasing the density of the fluid causes the temperature to increase. In the figure, it is clear that the density of some particles is limited to more than 10^2 gm/cm^3 while the temperature is nearly 10^5 K .

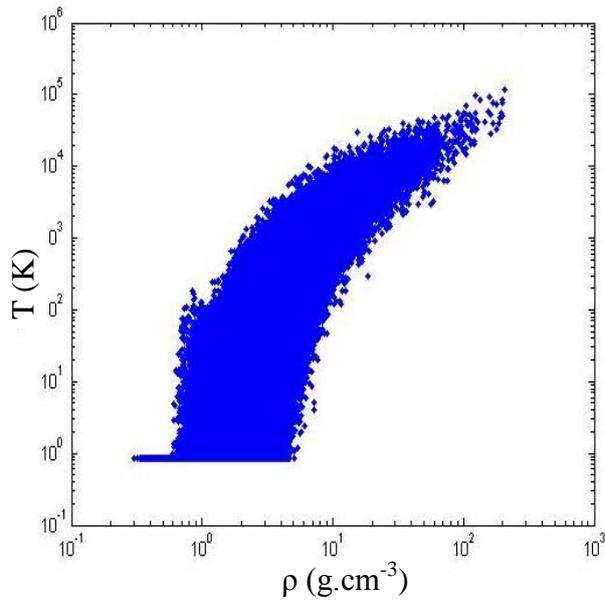


Fig. (3a): Temperature-density plane of non-cooling gas at $z=6.3$.

In Fig.(3b) which indicates another epoch of the universe $z=1.2$, the density is limited to more than 10^4 gm/cm^3 and the temperature is increased to about 10^6 K . This result differs from that of Fig. (3a) because with time the attraction between the particles and the clumps increases, and so the density and the temperature increase.

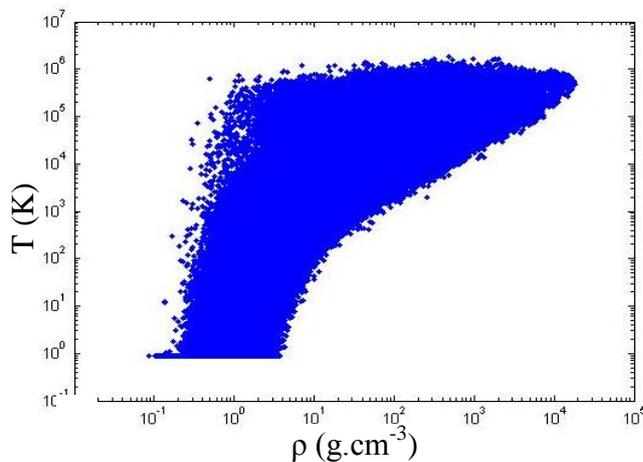


Fig.(3b): Temperature-density plane of non-cooling gas at $z=1.2$.

Fig. (3c) shows the density temperature plane at redshift $z=0$. The density increased to more than 10^5 gm/cm^3 , while the temperature increased to more than 10^6 K . This epoch of the Universe is denser than the others because of increasing the attractions of the clumps.

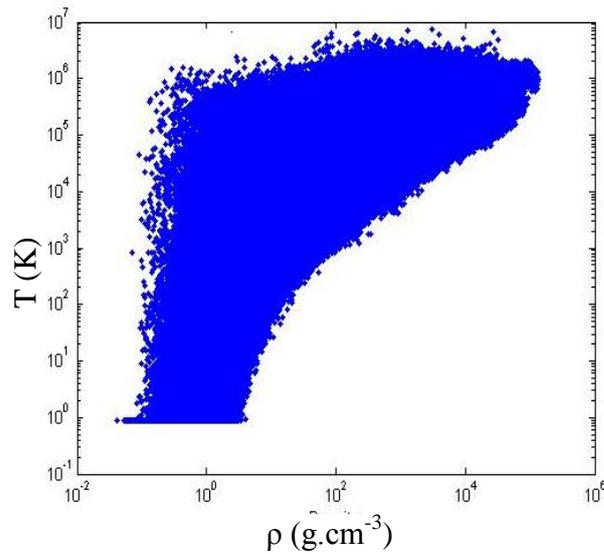


Fig. (3c): Temperature-density plane of non-cooling gas $z=0$.

b- Simulation of gas cooling

Gas cooling is simulated from redshifts, $z=30$ to $z=0$. Figure (4a) shows the initial state of one million dark matters and one million gas particles.

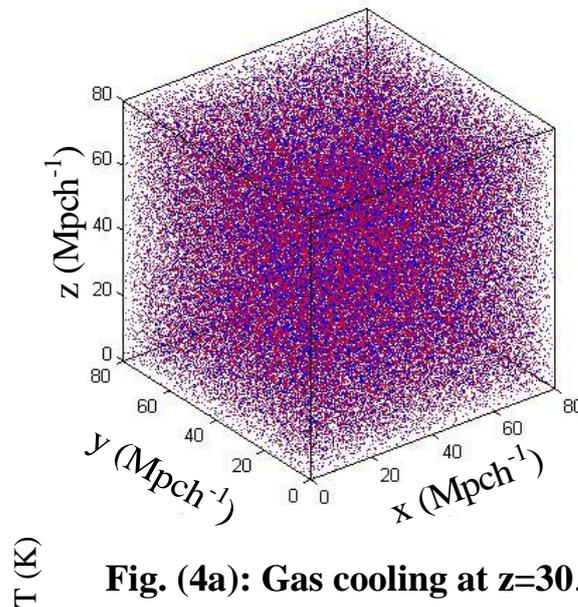


Fig. (4a): Gas cooling at $z=30$.

Fig. (4b) shows how the cooling in each epoch was done. The positions and the shapes of the collection differ from each other because in each epoch the cooling is different and it increases with time.

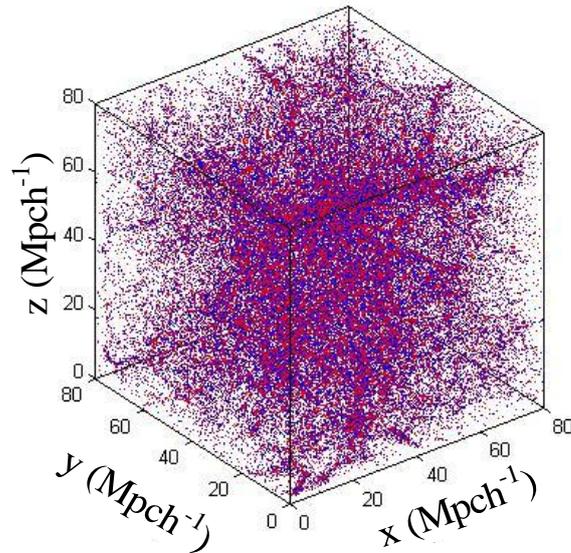


Fig. (4b): Gas cooling at $z=1.2$.

So the collapse affected by cooling and the cooling process gives compact configuration at the lower redshift, $z=0$ as shown in Fig. 4c.

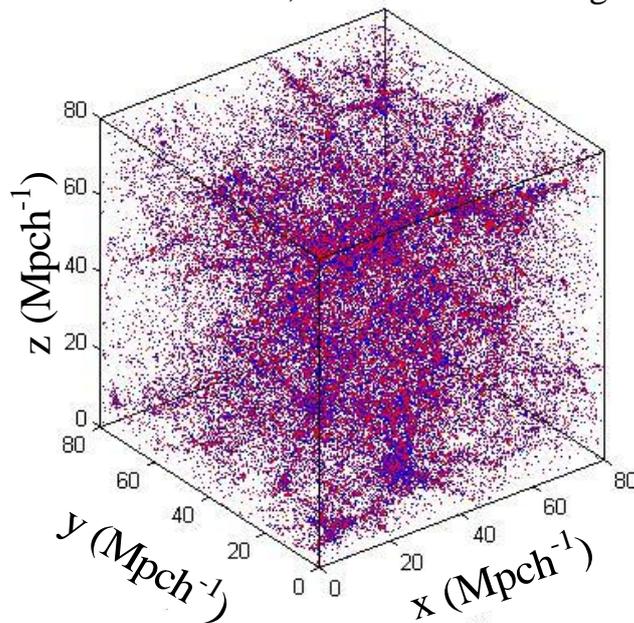
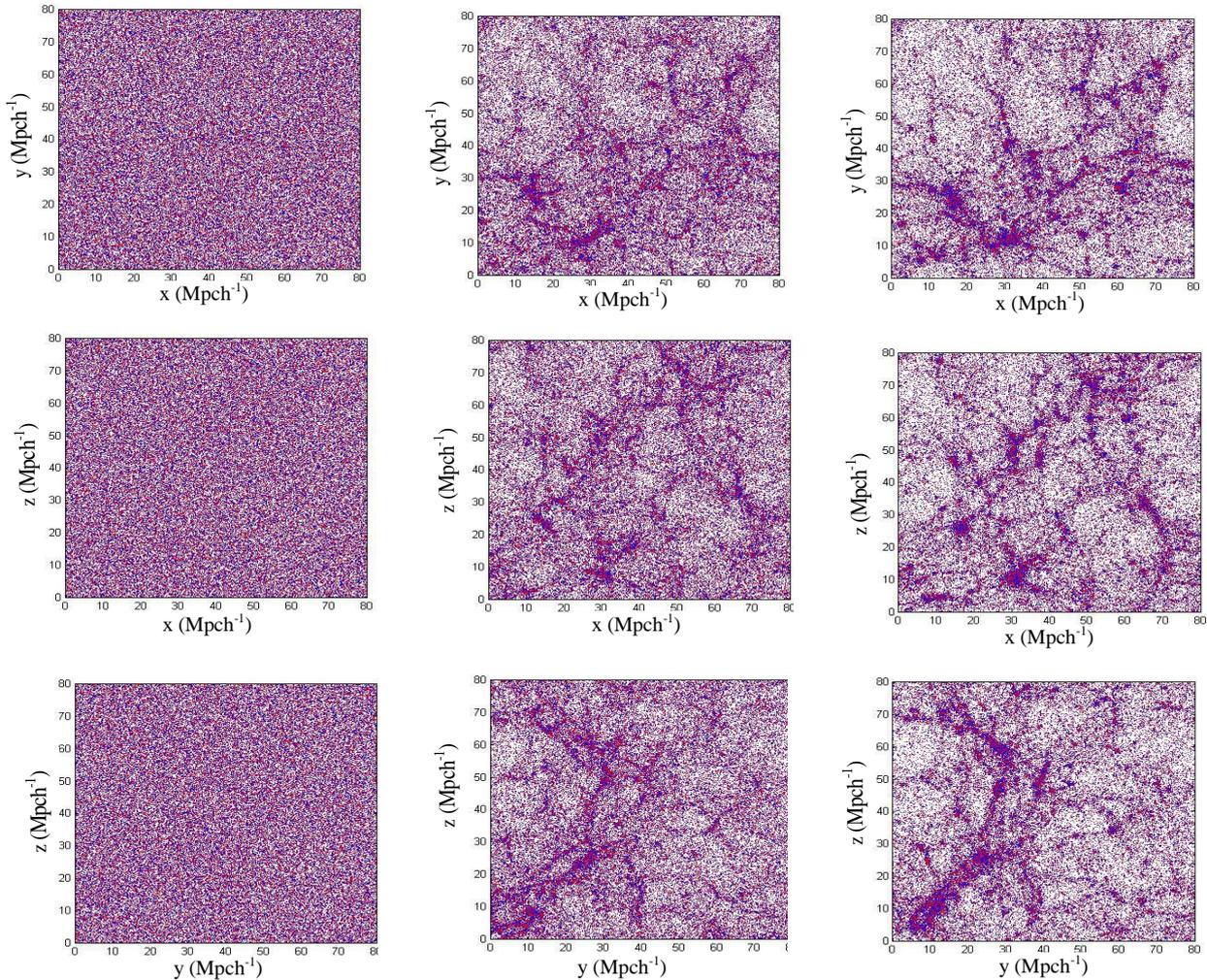


Fig. (4c): Gas cooling at $z=0$.

The process of the gas cooling is governed by radiation mechanism that causes the baryonic fluid to lose energy and pressure. By this mechanism the condensing and collapsing particles and clumps move from their original positions. All of these thermodynamically processes are followed in the simulation from the early Universe to the present day.

Figs. (5 a, b and c) show the gas cooling in xy, xz and yz planes at different redshifts, $z=30$, 1.2, and 0 respectively. At each epoch the

collections of the gas and the displacement which are caused by cooling of the gas in these different redshifts are shown.



**Fig. (5): Gas cooling in xy, xz and yz planes at three epochs:
a) $z=30$ b) $z=1.2$ and c) $z=0$**

Figs. (6a, b and c) show the temperature-density planes of gas cooling at three different epochs of the Universe in the box. From the figures, it is shown that the distributions and positions of some particles change with time.

Fig. (6a) indicates the temperature-density plane at $z=6.3$. The main part of gas distribution in the figure is low density gas cooled to low temperature and most of the gas particles are cooler than 100K. This process is done by Universe expansion and the lowest density gas cooling is done by voids expansion. The density of some gas is increased to more than 10^3 gm/cm^3 at temperature of nearly 200K. Over this temperature many particles left their positions to the new positions inside the clusters. Therefore, the particles above this temperature which are shown in Fig. (3a) been missed in Fig. (6a).

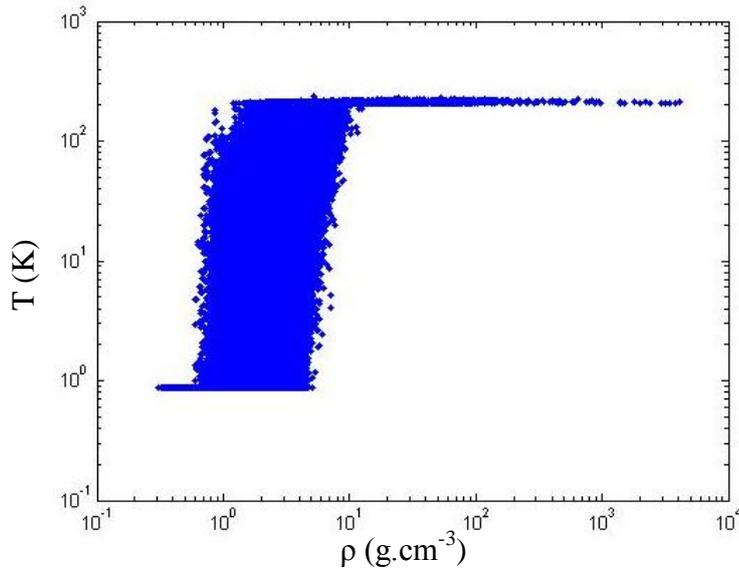


Fig. (6a): Gas cooling in temperature-density plane at $z=6.3$.

Fig. (6b) shows the temperature-density plane at $z=1.2$. From the figure it is clear that the gas distribution has three main components. First, the adiabatic cooling to very low temperature. The second component is overdensity which is called shock heated gas at which the temperature reaches to more than 10^5 K. The third component is the very overdense gas that has cooled radiatively from the temperature near 10^4 K which is the cutoff location of the curve. At the very overdense component the gas density of some particles increases and reaches to near 10^9 gm/cm³. When this compared with Fig. (3b), one can observe that the particles shown in this figure have left their positions in Fig. (6b).

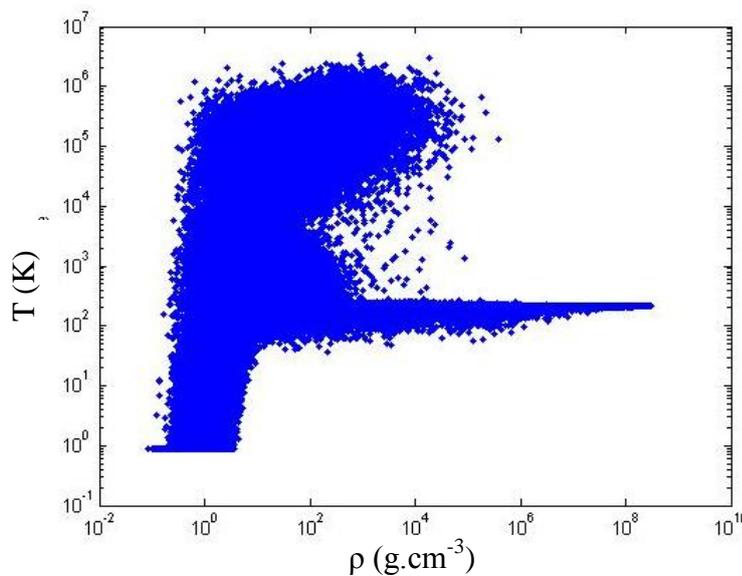


Fig. (6b): Gas cooling in temperature-density plane $z=1.2$.

Fig. (6c) shows the gas cooling in the temperature-density plane at $z=0$. In this figure also the three main components of gas distribution are shown, but with different ranges of density and temperature. In the overdense component, some particles density reaches to more than 10^{10}g./cm^3 . Also the gas particle distributions in the low density and the shock-heated components differ from Figs. (6a and b).

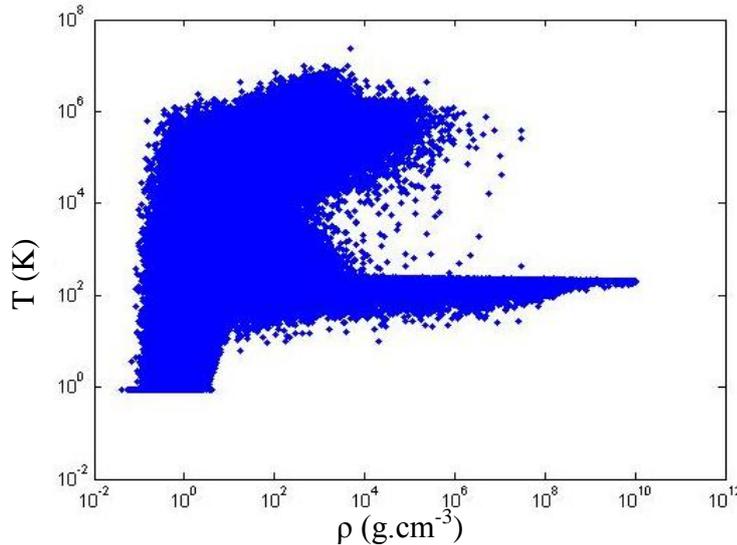


Fig. (6c): Gas cooling in temperature-density plane at $z=0$.

Comparing Figs. (3a, b, c and 6 a,b,c), it is clear that some particles have left their positions because of gas cooling.

The general shapes of clusters construction, voids, filaments in the present work is in a good agreement with Millennium simulation (Springle et al., 2005; Rasheed & Ameen, 2009). The changing of locations of cooling gas is in a good agreement with that found by (Pearce et al., 2001) who obtained the new locations of gas in simulation of galaxy formation after gas cooling.

Conclusion

- 1- From the simulation, it was found that the gas and dark matter are the two main components of galaxy formations.
- 2- The gravity causes the construction of galaxy clusters, voids and filaments.
- 3- The density- temperature plane shows different concentrations of the non cooling and cooling of gas particles in different epochs. The gas particles cooled at nearly 10^4 K in low redshifts $z=1.2$ and $z=0$.
- 4- In the simulation the galaxy formation growth with time. At redshift $z=0$ which represents the present day, and the galaxies formation obtained very clearly.

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محاكاة الغاز والمادة الداكنة في تشكيل المجرات

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الخلاصة

في هذا البحث تمت محاكاة الغاز والمادة الداكنة بواسطة موديل (Λ CDM) وذلك باستخدام كود gadget-2. مليون جسيم من الغاز مع مليون جسيم من المادة الداكنة الباردة تمت محاكاتها سوية من الماضي السحيق للكون من الازاحة الحمراء (redshift $z=30$) الى الازاحة الحمراء (redshift $z=0$) داخل صندوق ذي حجم $(80 \text{ Mpc/h})^3$. الجاذبية تسببت في تجميع جسيمات الغاز و المادة الداكنة لبناء عدة مجاميع، بعدة ذلك تتطور هذه المجاميع مع الزمن. هذه المجاميع عبارة عن عناقيد المجرات تشكلت في المحاكاة. العناقيد محاصر بواسطة الفجوات بينما الفتائل تكونت بين العناقيد. العناقيد، الفجوات، و الفتائل ظهرت بوضوح عند الازاحة الحمراء (redshift $z=0$). في المحاكاة، مستوى درجة الحرارة – الكثافة يظهر تجمعات مختلفة لجسيمات الغاز المبردة وغير المبردة في ازمان مختلفة. تم استخدام ستة عشرة معالجا لسوبر كومبيوتر جامعة نوتنغهام البريتانية في المحاكاة.