Simulation of Large Scale Structure Formation

Mariwan A. Rasheed

Department of Physics, Faculty of Science and Science Education, School of
Science, University of Sulaimani. Sulaimani, Kurdistan Region-Iraq.
E-mail: mariwanrasheed@yahoo.com

Mohamad A. Brza

Department of Physics, Faculty of Science and Science Education, School of
Science, University of Sulaimani. Sulaimani, Kurdistan Region-Iraq.
E-mail: mohamadphysics@yahoo.com

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Abstract

Large scale structures were studied in simulation using gadget-2 code for Lambda cold dark matter model. The dark matter and gas which are the main components of the large scale structures are simulated. At redshift $z=0$, the group and clustering of dark matter and gas particles were shown differently and then at the same redshift. The construction of cluster and super clusters are shown clearly.

In the present work we focused on the history of star formation and the number of stars formed at different redshifts.

During the study it appeared that stars born as a result of gas cooling process. It also appeared that the stars construct groups and clusters gradually from relatively high redshift $z=3.04$ to the redshift $z=0$.

Keywords: Large scale structure, stars, dark matter and gas.

1. Introduction

Current observational and theoretical studies of the formation and evolution of large-scale structure suggest that cold dark matter is the predominant matter in the universe. A CDM dominated universe would suggest that galaxies were built from the aggregation of smaller structures, in a sort of “bottom-up” construction approach. In fact the closer galaxies are detected to the time of the big bang [1]. In addition to the large surveys probing the cosmic evolution of global properties of

galaxies, large improvements in the resolution and quality of the imaging and spectroscopy of nearby galaxies have allowed a better understanding of one of the key physical processes in galaxies: star formation. This new set of observations has allowed us to identify with great detail the places where star formation is taking place and the role played by the different phases of the interstellar medium in setting the star formation rate [2]. The presently favored theory of galaxy formation, within the framework of Λ cold dark matter (CDM) cosmology, hypothesizes that small quantum fluctuations lead to dark matter ‘halos’. Subsequently, halos cluster and merge into larger halos while simultaneously collecting gas. These structures form the seeds of galaxies that grow via further merging [3]. Galaxies remain the best candidates to explain the enrichment of regions at larger overdensities, such as filaments, groups and clusters as for the enrichment of the lowest density regions, it is still not clear what is the contribution from the first populations of stars [4].

In hierarchical clustering, the largest structures forming at a given time do so via the amalgamation of many smaller structures which has been long time ago. This is owing to the form of the initial density perturbation spectrum in which small-scale perturbations have higher initial amplitudes than large-scale perturbations. In contrast, non-hierarchical clustering involves structure formation from the collapse of large structures with smooth density distributions. The results of numerical simulations compared with observations support the theory that we live in a Universe in which structure is formed hierarchically. The degree to which the hierarchical nature affects the baryon distribution in galaxy clusters is not entirely clear [5].

Some outcomes of star formation processes that are particularly important to understand include the rate at which the gas in galaxies is turned into stars, and the distribution of masses with which the stars are formed. The structures of galaxies depend on the circumstances in which stars form and the rate at which they form, while the evolution of galaxies depends on the spectrum of masses with which they form, since low-mass stars are faint and evolve slowly while massive ones evolve fast and release large amounts of matter and energy that can heat and ionize the interstellar gas, enrich it with heavy elements, and possibly expel some of it into intergalactic space [6].

Several groups have presented analysis of baryon fractions in simulations that include gas cooling and star formation. These simulations have shown that cooling can increase the total baryon fraction (gas and stars) compared to the adiabatic simulations [7].

2. Simulations

The Lambda Cold Dark Matter (Λ CDM) model is the standard modern theoretical framework for understanding the formation of structure in the universe. With initial conditions consisting of a nearly scale-free spectrum of Gaussian fluctuations as predicted by cosmic inflation, and with cosmological parameters determined from

observations, Λ CDM makes detailed predictions for the hierarchical gravitational growth of structure [8].

One of the basic astrophysical problems to be studied numerically, following the widespread introduction of computers and numerical techniques into the academic world in the 1960s, was the formation of stars by the gravitational collapse of interstellar gas clouds. This problem involves both gravity and gas dynamics, and in general it can be solved only numerically, despite the fact that the basic physics involved is classical and well known; only a few of the simplest problems in star formation theory can be solved analytically. Numerical simulations of star formation currently constitute a sizeable and growing research area, and much of the recent progress as well as ongoing debates in star formation theory have come from the results of numerical work [9].

The assumption of a homogeneous and isotropic Universe holds on scales larger than 100 Mpc and only at such large scales are the Friedmann equations sufficient to describe the dynamical evolution. On smaller scales, however, the Universe is far from homogeneous. Rather it is full of structures, like walls, filaments and clusters. In the CDM paradigm, structure grows from primordial fluctuations generated during inflation. The evolution of the massive, weakly interacting dark matter particles is only governed by gravity. This makes it easier to study their dynamics whether analytically or numerically. It is usually convenient to separate the structure formation into two regimes: the linear growth regime where the fluctuations are small and the equations of motion can be linearized around the homogeneous solution; and the non-linear regime where the perturbation is large and the non-linear objects emerge. The first case applies to the early Universe and to the evolution of structures on very large scales (>100 Mpc), while the latter is important for the evolution of the dark matter halos within which galaxies form [10].

In the present work eight million dark matter particles and eight million gas particles were simulated inside a box of size $(240\text{Mpc}h^{-1})^3$. The parameters are $\Omega_m = 0.25, \Omega_b = 0.045, h = 0.73, \Omega_\Lambda = 0.75, n = 1$ and $\sigma_8 = 0.9$. The Hubble constant is $H_0 = 100h^{-1}\text{kms}^{-1}\text{Mpc}^{-1}$. Gadget-2 code, which includes gravitational dynamics, gas cooling, and a simple scheme of star formation is used [11].

The star formation rate, $\dot{\rho}$ for each SPH particle is given by:

$$\dot{\rho}_* = C_* \rho_{\text{gas}} / t_{\text{ff}} \quad (1)$$

Where

$$t_{\text{ff}} = 1 / \sqrt{4\pi G \rho_{\text{gas}}}$$

If we assume spherical symmetry, the pressure required for hydrostatic support may be obtained from,

$$dP(r) = - \frac{GM(r)\rho(r)}{r^2} dr \quad (2)$$

Where $P(r)$ is the gas pressure at a radius (r) , G is the gravitational constant, $M(r)$ is the total mass interior to the radius r , and $\rho(r)$ is the gas density as a

function of radius. The expected gas temperature, $T(r)$, may then be obtained from,

$$P(r) = \frac{\rho(r)K_B T(r)}{\mu m_H} \quad (3)$$

3. Results and Discussion

Figs. 1(a, b, and c) show the 0.1 thick of the box at redshift $z=0$. Fig. 1a represents the dark matter particles which clumped in many regions. Fig. 1b represents cooled gas particles which clumps also in same regions of the dark matter. In Fig. 1c of the simulation it is clear that the dark matter and cooled gas clumps construct large clumps, these large clumps represent super clusters of galaxies while the smaller clumps represent clusters and groups of galaxies. The main force for the clumps construction is the gravitation force which is the most effective force in large scale structure.

Fig. 1a: a slice at $z=0$ of dark matter

Fig. 1b: a slice at $z=0$ of cooled gas

Fig. 1c: a slice at $z=0$ of dark matter and cooled gas

Figs. 2(a, b, c and d) shows number of stars which are formed at different redshifts, $z=5.19$, 3.04 , 1.95 and 0 . In Fig. 2a it is shown that more stars formed, but the groups of stars are still not observed. Fig. 2b shows that more stars born at $z=3.04$ than the previous redshift, and groups of stars are gradually weakly construct at this epoch of the universe. Fig. 2c represent a number of new stars formed at $z=3.04$ in addition to the stars formed at redshifts before. In the Fig. the cluster of stars is constructed because of the effect of the gravity. At $z=0$ as shown in Fig. 2d the clustering of stars are appeared clearly in the simulation. Because of much number of stars at this epoch the gravity among them is stronger than the other epochs.

Fig. 2a: stars formed at $z=5.19$ Fig. 2b: stars at $z=3.04$ Fig. 2c: stars at $z=1.95$ Fig. 2d: stars at $z=0$

Although, till now, the process of star formation remains complex, but Houjun et al 2010 [12] gave the best explanation of the processes. According to this explanation, as the gas in a dark matter halo cools and flows inwards, its self-gravity will eventually dominate over the gravity of the dark matter. Thereafter, it collapses under its own gravity and in the presence of effective cooling, this collapse becomes catastrophic. Collapse increases the density and temperature of the gas, which generally reduces the cooling time more rapidly than it reduces the collapse time. During such runaway collapse the gas cloud may fragment into small, high-density cores that may eventually form stars thus giving rise to a visible galaxy.

Fig. 3(a, b, c and d) shows the gas particles (green colored) and the stars (blue colored) at different redshifts. The cooled gas was gradually converted to stars at different redshifts in many positions inside the box. Here for redshifts of the simulation are shown $z=5.19$, 3.04 , 1.95 and 0 .

Figs. 3: The gas particles (green colored) and the stars (blue colored) at different redshifts: a) $z=5.19$ b) $z=3.04$ c) $z=1.95$ and d) $z=0$.

Figs. 4(a, b, c, d, e and f) show the number of stars formed in the range of red-shifts. In Fig. 4a, at $z= 5.19-3.04$ number of new stars is 17214. In Fig. 4b, at $z=3.04-1.95$ number of new stars is 43162. Number of new stars at $z=1.15-0.99$ is 12207 stars as shown in Fig. 4c, but at $z= 0.1-0.07$, the number of new stars is 3940 as shown in Fig. 4d. At $z= 0.07-0.025$ which is represented by Fig. 4e the number of stars is 7196 stars. Fig. 4f shows that the number of new stars formed is 4189 at $z= 0.025-0$. From the fig.s it is clear that number of stars forms is different at different redshift.

Figs.4: History of star formations as a function of redshift.

(e)

(f)

Figs.4: Continued

4. Conclusion

The dark matter and cooled gas construct large scale structures in the box. The constructions include, groups, clusters and super clusters of galaxies. In the simulation also large numbers of stars were born as a result of gas cooled at different redshifts. In the redshift $z=5.99$ many stars were simulation seen in the simulation but they were not made clumps and clusters yet. At $z=3.04$ clump of stars were seen. After this epoch more clumps and clusters were constructed. At $z=0$, the clusters of stars were seen clearly. From the simulation it appeared that the number of stars born is different from one epoch to another.

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