The impact of the dark matter on galaxy formation

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Abstract. Contemporarily, dark matter exerts dominant impacts on galaxy formation, which is the spine bone of the galaxy. Herein, we investigate the attraction effect of initial dark matter distribution on the normal matter (hydrogen and other gases), which will form the dark matter halos. Subsequently, an introduction to the properties of dark matter halos and some disputes about it are demonstrated. Besides, the cold dark matter (CDM) is chosen to fit the current observation and interpret the influences of dark matter on galaxy formation. Overall, this paper offers a clear procession of the impact of dark matter on galaxy formation, which will be guideline for future development of both galaxy formation theory as well as dark matter detection.

Keywords: Dark matter, dark matter halos, galaxy formation, current observation.

1. Introduction

With the deeper and deeper exploration of universal, plenty of astrophysics and cosmology issues are addressed. However, dark matter remains an unresolved issue, whose properties and components remain unclear. Galaxy formation still has lots of problems needed to be solved. Although there are plenty of scholars that propose various approaches to find out its procession, the formation of galactic disks remains unclear. Therefore, we will give a clear calculation of how dark matter attracts gas to increase its mass based on reviewing articles to delineate the effect of dark matter on galaxy formation [1]. Besides, Millennium N-body simulations will be chosen as the investigation target [2]. In this case, cosmological simulations are carried out to present the distribution of dark matter.

Subsequently, we will compare cold dark matter (CDM) with warm dark matter (WDM) and state the reason for choosing CDM [3]. A major issue with cold dark matter galaxy formation is increasingly severe, which remains an unsolved problem.

The rest part of the paper is organized as follow: Section 2 will introduce the analytical model for galaxy formation and star formation; Section 3 will present some state-of-art experiment results to demonstrate the properties of dark matter for different models; Section 4 will give a brief summary and future guideline eventually.

2. Analytical model

2.1. The mechanisms of dark matter attraction of gas and normal matter

Primarily, we establish a spherical coordinate system where the origin is the singularity of big bang, $M(\vec{r})$ is initial dark matter distribution $\vec{r}$ is a vector. Dark matter attracts the distant matter due to gravity

$$\frac{GM}{\vec{r}-\overrightarrow{r_1}}=\frac{d^2\vec{r}}{dt^2}=\ddot{\vec{r}}_1 \quad (1)$$

Since the dark matter has a certain distribution, we assume that the displacement of distant matter is $\vec{r}_1$

$$\sum\frac{GM}{\vec{r}-\vec{r}_1}=\overrightarrow{r_1} \quad (2)$$

We obtain the acceleration formula of specific position which can in turn extend to all positions in the university

$$\sum\frac{GM}{\vec{r}-\overrightarrow{r_1}}=\overrightarrow{r_1}(r) \quad (3)$$

Owing to large mass of dark matter, the other effects on this matter can be neglected. On this basis, one can assume the matter has its certain speed $\vec{v}$, then we derive the acceleration formula that can find out the time required for the matter fuse with dark matter

$$\int\overrightarrow{r_1}(\vec{r})dt=\overrightarrow{r_1}(\vec{r})+c \quad (4)$$

One can derive the constant c easily because of the specific $\vec{v}$

$$\int_0^z\overrightarrow{r_1}(\vec{r})+cdt=\vec{r}-\overrightarrow{r_1} \quad (5)$$

where z is the time to get then we can obtain the time of all positions fused with dark matter

$$z(\vec{r})=t \quad (6)$$

Dark matter exhibits flesh sheet in large scale but we can assume that it will be spherical symmetric in small scale. Because dark matter has its certain diameters, i.e., we assume its radius is r_d.Therefore, we obtain the mass increases per unit of time

$$\int_{r_d}^{r_d+\Delta r}\frac{4\pi r^2m_1}{\Delta t}dr=\frac{4\pi m_1}{3}\left[\frac{(r_d+\Delta r)^3-r_d^3}{\Delta t}\right] \quad (7)$$

$$\frac{4\pi m_1}{3}\left[\frac{3\Delta rr_d^2+\Delta r^2r_d+\Delta r^3}{\Delta t}\right]=4\pi m_1r_d^2v_d \quad (8)$$

where $m_1$is the matter distribution of matter per unit area. Then, we obtain the formula of increasing mass per unit time because the dark matter does not involve in electromagnetic interaction. In this case, one can assume the radius of dark matter remain unchanged for long time, i.e., we derive relation of $m_1$and t:

$$m_{1end}=(1+4\pi r_d^2v_dt)m_1 \quad (9)$$

However, this formular only makes sense at short time because when the mass increases the radius will shrink.

2.2. An introduction to dark matter

The backbone for the development of galaxies is dark matter, anticipated to develop at the cores of dark matter over densities, known as halos.

2.2.1. The properties of dark matter. Theoretically, CDM or WDM must be invoked to clarify relatively small-scale features in the observable Universe. Apart from this, hot dark matter is introduced, which is no longer possible to use hot dark matter as the only explanation for cosmic galaxy formation. As a result, the production of greater mass aggregates that surround entire galaxy clusters should correspond to the formation of hot dark matter. However, evidence from the cosmic background explorer (COBE) satellite shows that the cosmic microwave background radiation is remarkably uniform.

The energy scale of hot dark matter is about 30 eV, and the dark halo scale is about the size of a large galaxy cloud; the energy scale of warm dark matter is about 2 keV, and the dark halo scale is comparable to that of small galaxy; the energy scale of cold dark matter is 100 GeV, and the dark halo scale is comparable to that of Earth. Since then, the hot dark matter theory has been abandoned, even though it is completely incompatible with experimental findings. The cold dark matter model and the warm dark matter model are now two rival ideas. Cold dark matter models: in the more prevalent cold dark matter model, first form scale and the earth's dark matter halo, then produce more and bigger dark matter halo through an accretion process. Thus, according to the cold dark matter concept, the universe is full of dark matter halo spanning 21 orders of magnitude from Earth to the size of clusters. Because dark matter is substantially more than ordinary baryonic matter, the universe’s large-scale structures are all generated by dark matter gravity.

2.2.2. The gravity of dark matter. Cosmological simulations are frequently run with periodic boundary conditions to simulate the large-scale homogeneity and isotropy of the Universe’s matter distribution, i.e., the cosmological principle Collisionless Bolzman equations:

$$\frac{df}{dt} = \frac{\partial f}{\partial t} + \vec{v}\frac{\partial f}{\partial \vec{r}} - \frac{\partial \phi}{\partial \vec{r}}\frac{\partial f}{\partial \vec{v}} = 0 \qquad (10)$$

and Poisson’s equation:

$$\nabla^2 \phi = 4\pi G \int f \, dv \qquad (11)$$

2.3. The impacts of dark matter on galaxy formation

Baryons are supposed to discover the dark matter dissemination on scales since they are originally distributed nearly uniformly. As shown in Fig. 1. We predict baryons to gravitate towards the great potential wells of dark matter halos in particular. As a result, these should be the places where galaxies develop.

The cosmos began to cool a little less than 14 billion years after the big bang, and hydrogen helium began to form. Since hydrogen is the most basic element, it is made up of only one proton and one electron. Then there was dark matter, which was the initial prompt since dark matter is the galaxy’s spine bone. It will pull the first gas to agglomerate. Then, it will attract an increasing amount of matter. During this time, there will be some high density areas where the star will form. The system will form as a result of a large number of stars forming. The creation of numerous systems will eventually result in the formation of a galaxy. It’s known as a supernova. Globular clusters make up the burnt-out materials. The rotating disk will draw more and more gas and dust as it rotates. The reason one should be aware of is that galaxies will have an impact on neighbouring galaxies. The various shapes of the galaxy will merge into a single integral. The irregular galaxy then merges.

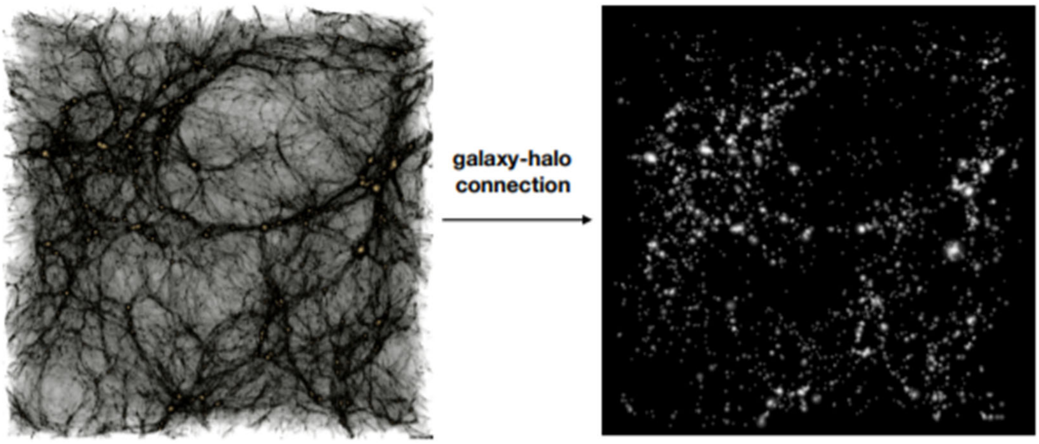

Figure 1. The initial bone of dark matter [4].

2.3.1. The start formation. Usually, a large number of stars with varying masses arise from a collapsing cloud of gas. It is natural to believe that stars with low mass are more likely to develop since they require less material. The initial mass function (IMF) is a relative power-law function that describes the relationship between a star's mass and the number of stars with that mass. Its formula is [5]:

$$\xi(M) = (\frac{M}{M_S})^{-\beta} \tag{12}$$

$$\xi(M) = (\frac{M}{M_S})^{-2.35} \tag{13}$$

Expressing the number of stars as a multiple of the number of stars with a mass of one solar mass The exponent, according to modern theories and observations, is not constant, but varies with the mass of the stars. The IMF's formula is still a hot issue of discussion today.

$$\xi(M) = B(\frac{M}{M_S})^{-\beta(M)} \tag{14}$$

With B as a pre-factor, the pre-factor does not have a unit since the mass is given in multiples of the solar mass. For masses less than 0.08 sun masses3, the exponent (M) is 0.3; as for masses between 0.08 and 0.5 solar masses, it is 1.3; and it is 2.3 with regard to masses more than 0.08 solar masses. The pre-factors B are computed using the constraint $\xi_{up}{}^{1}$ (M) = $\xi_{low}{}^{2}$ (M) to obtain a continuous function, hence the values of the two portions of the function must be the same at the limiting mass.

$$\xi(M) = 2(\frac{M}{M_S})^{-\beta(M)} \tag{15}$$

2.3.2. Some feedback to star formation. We concluded that star formation could not take place in all dark matter halos with 100% efficiency. There is evidence for this in a number of observable phenomena, but the two most important are demonstrated in [6, 7].

This second argument may be emphasized further: even if all dark matter halos converted a consistent proportion of their mass to stars, there would still be an excess of dim galaxies in comparison to brilliant galaxies. A plethora of additional observable constraints suggest that the efficiency of galaxy formation is greatly influenced by halo mass. Apparently, a mechanism that selectively inhibits the development of stars in smaller mass dark matter halos is required. Energy/momentum input from supernovae explosions, maybe boosted by star winds, is the most common explanation for this process. In the most large dark matter halos, a similar issue arises. Even while cooling in such halos is inefficient, they can nonetheless cool a large amount of gas over cosmic time. If left unchecked, which will result in the development of galaxies that are far more bright than any that have been observed. The problem's energy needs imply that AGN might be a viable solution.

2.3.3. Galaxy evolution. Galactic development is shifting from hierarchical clustering-dominated early Universe to internal secular processes-dominated future. These are the results of interactions with collective phenomena including bars, oval disks, spiral structure, and triaxial dark halos. As shown in Fig. 2, gas has accumulated form an outside ring, an inner ring around the bar's end, and a dense core concentration after 7 bar revolutions. ESO 426-2 [8] and NGC 3081[9] are barred galaxies with similar properties, which diagram is based on Ref. [10].

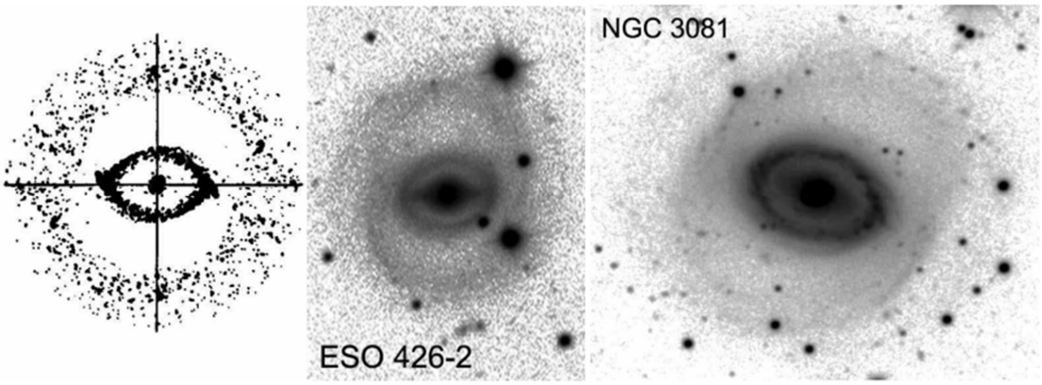

Figure 2. Secular evolution's products include: (left) Gas particle dispersion at the end of a sticky-particle simulation of gas growth in a horizontal but not depicted spinning bar potential.

2.3.4. The discussion of galaxy disks. Numerical simulations are emerging as one of the most significant theoretical methods for investigating the difficult subject of galaxy formation. More advanced treatments of supernova feedback, chemical enrichment models, and approaches to "zoom in" on galaxies of interest within cosmological simulations were used in current studies.

While these research were only partially successful in producing rotationally supported disks, the simulated galaxies seldom matched their observed counterparts. Furthermore, the models' star formation was extremely efficient, transforming an excessively large proportion of the gas into stars by the present day. Plenty of the early modelling flaws may be traced back to the simulations' coarse resolution and the way in which feedback was handled. Furthermore, if star formation in low-mass halos is particularly efficient at high redshifts, a significant number of dense, compact galaxies would develop. If the angular momentum of these baryonic clumps is lost to black halos, the resultant objects will be less in size than if the baryons were accreted smoothly. As a consequence of the early collapse of baryons, a route for gas to lose angular momentum opens, resulting in galaxies that are excessively compact, lack angular momentum, and create stars more efficiently than seen. Following that, greater types of feedback and changes to the cosmological framework were used to try to address these flaws. The above-mentioned issues were aggravated in certain circumstances. Photoheating by a diffuse UV backdrop, for example, was shown to lower the angular momentum content of the simulated galaxies even further. The impact of preheating and gas blowout from tiny halos as well as the development of galaxies in a WDM cosmology were also investigated. Direct comparisons with observation can be realized based on incorporating spectral synthesis techniques into the modelling and employing the Tully-Fisher relation to restrict the hierarchical origin of galaxies. The galaxies in these simulations, however, were still excessively dense. Recent research on disk creation has provided some more encouraging results, which created disk galaxies with angular momentum deficits of less than an order of magnitude. It provides in-depth assessments of simulated galaxies with kinematic and photometric features that are comparable to those seen in observed Sab galaxies. Although different simulations of disk creation have yielded some amazing results, the fundamental physics underpinning this process is still unknown. It also suggests that the low angular momentum of previously simulated galaxies was due, at least in part, to insufficient resolution. Moreover, other scholars argue that implementing feedback that can govern star formation is a critical component for building appropriate disks. [11]

2.3.5. Disputes on dark matter. The major features of dark matter haloes as observed from observations are discussed. More than a thousand galaxies now have detailed rotation curves, demonstrating that they are not so flat in the outer sections, but rise for late-types and decline for early-types according to a well-established finding. More than a thousand galaxies now have comprehensive rotation curves, revealing that they are not as flat in the outer parts as previously thought, but rather increase for late-types and fall for early-types. According to a well-established result, dark matter does not dominate most luminous galaxies' optical disks. LSB are dark matter-dominated galaxies that can be dwarfs or giant galaxies with a lot of HI gas. Their rotation curves can also be used to restrict dark matter theories.

Table 1. The Millennium N-body simulations' selected parameters.

Ωm	Ωb	n_{spec}	h	σs	L_{box} h^{-1} Mpc	Np	Mp h-1 M_0	Mh $h^{-1}M_0$	Label
0.25	0.0455	1.0	0.73	0.9	500	2160^3	8.61×10^8	1.72×10^{10}	MSI
0.25	0.0455	1.0	0.73	0.9	100	2160^3	6.88×10^6	1.37×10^8	MSII
0.272	0.0455	0.97	0.70	0.81	500	2160^3	9.34×10^8	1.87×10^{10}	WM7
0.307	0.04825	0.96	0.68	0.83	542	5040^3	1.06×10^8	$2.12^*\times10^9$	PMILL

3. Experiment measurement

3.1. The Millennium N-body simulations

Cosmological simulations of galaxy formation have been critical in increasing our knowledge of the structure and creation of galaxies in the Universe during the last few decades. These simulations explore the nonlinear history of galaxies across a wide range of sizes, representing a variety of physical processes. Improved numerical approaches, increasing computer capacity, and a better knowledge of the physics important to galaxies have resulted in simulations, which can recreate a significant number of observable galaxy features. Millennium N-body simulations will be used in this article. Some of the simulations results are presented in Table 1 and Figure 3.

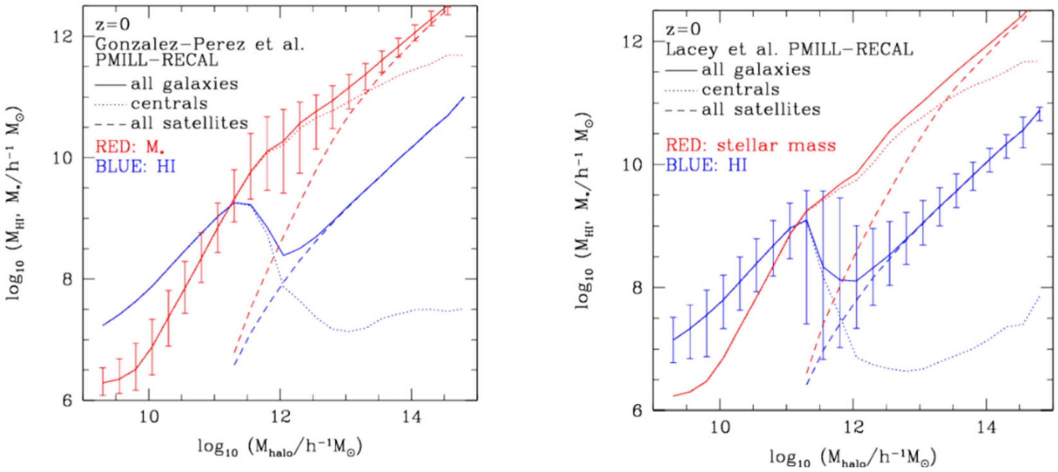

Figure 3. The median stellar mass (red) and HI (blue) contents of dark matter halos in the models as a function of halo mass, showing contributions from all galaxies (solid), centrals (dotted), and satellites within a halo (satellites). (It's worth noting that the specific value of the median mass for satellite galaxies depends on the resolution.) The bars represent the distribution's 10-90 percentile range, and are only given for the total HI content of the haloes in the left panel and the total stellar mass in the right panel for clarity. The predictions of the recalibrated version of the models are shown in the left panel, while the recalibrated model is shown in the right panel.

3.2. Parallel N-body, smoothed particle hydrodynamics

We explain star-forming gas using a "multiphase model". Our technique, when implemented in a sub-resolution way, allows for numerically convergent findings. This is especially relevant in CDM cosmology simulations, where early generations of galaxies might be difficult to resolve.

To avoid the difficulties, the parallel N-body, smoothed particle hydrodynamics (SPH) algorithm GADGET2 is utilized in its "conservative entropy" formulation. The initial displacement field is then generated using a typical zooming approach, which involves correctly adding small-scale disturbances in the high-resolution area. It is worth noting that the high-resolution zone doesn't focus on a specific object, with the goal of avoiding bias caused by picking halos that are fundamentally favourable for disk galaxy formation. The high-resolution particles can be divided into two categories: dark matter (HRDM) and gas. As shown in Fig. 4, the volume is adequate for our needs, given our current research does not involve large-scale galaxies or the global mass function, for example. The interesting points are in solitary, galactic-scale objects here, which are mostly unaffected by simulation box size. We include a UV backdrop and radiative cooling and heating, as well as star formation, supernova feedback, and metal enrichment. To characterize the star-forming gas, we use the multiphase model. Without explicitly spatially resolving the distinct phases, our method accounts for some of the important elements of the ISM's multiphase structure. Two fundamental difficulties in understanding star formation on cosmic scales drive our technique. To begin with, there is no underlying explanation for this procedure. Second, large-scale models lack the resolution needed to accurately define the ISM. [11]

Table 2. List of some necessary Parameters

Parameter	Symbol	Value
Supernova evaporation	A_0	1000
Mass Fraction of stars >8 M	β	0.1
Cold cloud temperature (K)	T_{clouds}	1000
Effective supernova temperature (K)	Tsn	10^8

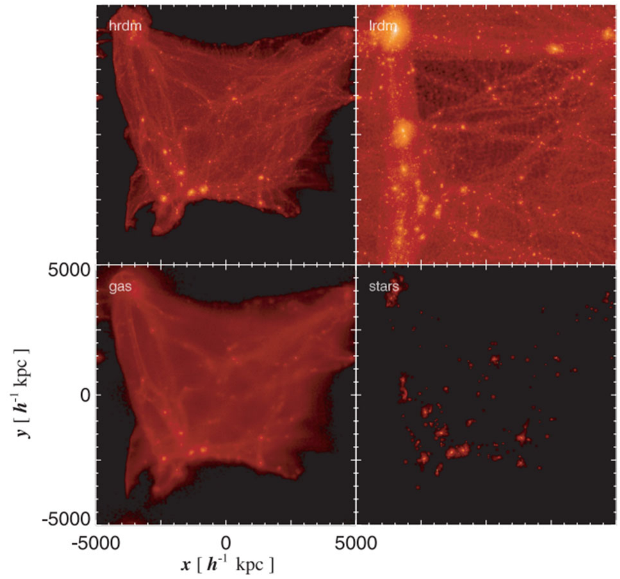

Figure 4. The whole simulation volume projected onto a 10 h^{-1} Mpc square region at z = 0, illustrating the simulation's final state. The HRDM and LRDM particles are shown in the top left and top right panels, respectively. The gas and star particles are depicted in the bottom left and right panels, respectively. The low- and high-resolution particles have mixed at the high-resolution zone's boundary due to gravitational influences, but the LRDM particles have not infiltrated the inner high-resolution region. In areas where the gas density has beyond the threshold density for star formation, star particles have spawned. [11]

4. Conclusion

In summary, we derive the formulae for the attraction force between dark matter and normal matter and choose the CDM model to demonstrate the impact of dark matter on galaxy formation. As a matter of fact, the real properties of dark matter are still unobserved since the solution is obtained based on CDM model, which is under plenty of assumptions and approximations. In the future, it is pursued to construct and propose more accurate model that can be verified based on state-of-art detectors. Overall, these results pave a path for dark matter detection and development of analytical models for dark matter.

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