Proceedings of the 2023 International Conference on Mathematical Physics and Computational Simulation
DOI: 10.54254/2753-8818/10/20230338

Analysis of the functions of cosmology dust in galaxy formation

Xiaoyu Dong

The High School Affiliated to Shaanxi Normal University, Xi'an 710000, China

2021262963@mail.nwpu.edu.cn

Abstract. The physical laws related to star formation in galaxies are the key to understanding the formation and evolution of galaxies. The dust in the interstellar medium has a significant effect on both the star formation and the observational properties of the galaxy. Understanding the properties, effects, and evolution of cosmology dust in galaxies is an essential part of a complete picture of galaxy formation and evolution. In this study, the background of interstellar dust research in galaxy formation will be summarized. Some basic concepts and physical properties of galaxies are introduced. The definition, classification and evolution of galaxies will be discussed. It then states the properties of cosmology dust in galaxies, including the basic concepts of physics, properties, generation, and evolution of dust. It will then focus on the role of interstellar dust in galaxies, including its basic concepts and background. These results shed light on guiding better understanding of the functions of cosmology dust in galaxy formation.

Keywords: galaxy, galaxy formation, cosmology dust.

1. Introduction

Galaxies, as defined in the COSMOS-SAO Astronomical Encyclopedia, are self-gravitating systems of dark matter halos, stars, gas and dust. The dynamics of galaxies research have showed that the glowing baryonic matter (gas, dust, and stars) makes up only a small fraction of the total mass of a galaxy, and it's dominated by a non-glowing substance called dark matter. In addition, much evidence such as dynamics, mass-to-light ratio, strong X-ray, radio radiation, and the theory simulation, indirect proved that the center of most galaxies existed supermassive black hole of quality range of 10^5-$10^9\odot$.

According to their visual appearance under the Hubble classification method, galaxies can generally be classified into two main types: elliptical galaxies and spiral galaxies (Figure 1) [1]. Spiral galaxies can be subdivided into two types, with or without a bar structure in the middle. Hubble thought that galaxies would gradually evolve from elliptical galaxies to spiral galaxies which was called early and late galaxies respectively. Although later studies have shown that there is no such evolutionary sequence between them, on the contrary, early galaxies may have evolved from late galaxies [2]. Those that do not fall into these two distinct categories are collectively referred to as irregular galaxies. The "galaxies" mentioned in this paper all represent galaxies dominated by star formation.

The measurement of galaxy morphology usually includes visual classification, parametric quantitative measurement and non-parametric measurement. Visual differentiation is the classification of galaxies based on distinct morphological features, such as the discovery of the Hubble sequence and

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the modern public science project Galaxy Zoo [1, 3]. In addition, one can quantitatively describe the galaxy morphology by fitting the one-dimensional luminance distribution function which varies with the radius obtained from the measurement at different apertures Eq. (1) [4].

$$I(r) = I_c exp(-n_b[(r/r_e)^{\frac{1}{n}} - 1]) \tag{1}$$

The Sérsic exponent n describes the shape of the distribution, and the value of the constant n_b makes r_e contains just half the luminosity of the galaxy which means the half-light radius or effective radius. Sérsic index and the effective radius of the galaxy are the basic parameters to describe the morphology of the galaxy [5].

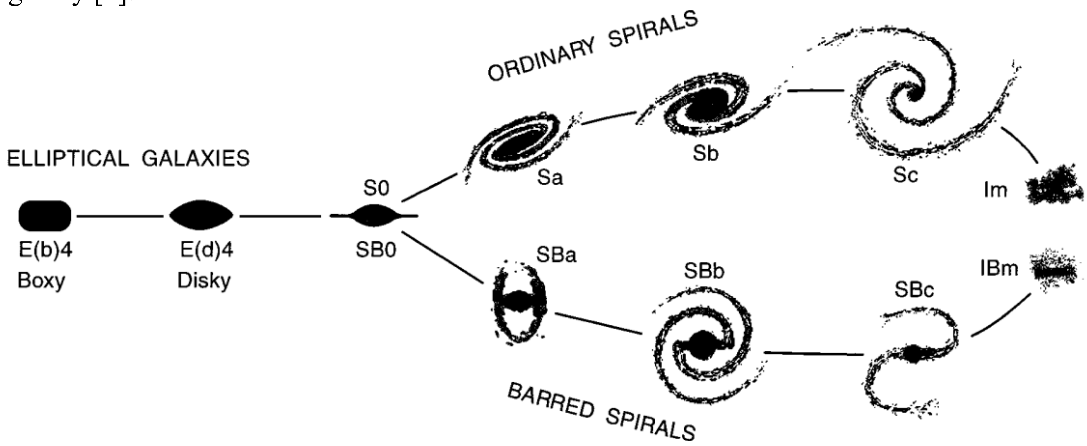

Figure 1. Hubble sequence diagram.

2. Basic description of galaxy formation and evolution

The formation and evolution of galaxies is one of the fundamental problems in astronomy. Modern standard CDM cosmological simulations suggest that the Big Bang happened more than 10 billion years ago. Observations from the COBE, WMAP and Plank probe satellites show that the proportion of dark matter in the mass density of matter in the universe is much higher than that of baryonic matter [6, 7]. Dark matter thus takes main effect in the galaxy's formation and evolution. According to the model, there are small density perturbations (or fluctuations) in primordial matter very early in the universe. In the first stage, these initial subtle density fluctuations are continuously strengthened due to gravitational instability, and the dispersed matter continuously condenses and contracts to form dark matter hallows of different scales. Then these dark matter halons undergo processes such as coalescence and accretion to further form larger dark matter halo structures. Galaxies form in such systems of large and small, gravitationally bound halos of dark matter. When the baryonic material (mainly gas clouds) in the dark halo cools and accumulates to a King mass, it collapses to form stars, the first generation of stars. The initial angular momentum of the dark halo and the baryonic matter in the dark halo is obtained by the tidal action during the merger of the dark halo. Subsequently, as the gas falls toward the centre, a disk of rotational support is gradually formed owing to the conservation of angular momentum. If the star formation time scale is smaller than the gas falling time scale, stars will form on the disk. This gradually forms the proto-spiral galaxy. Proto-spiral galaxies evolve by consuming their own gas, merging through dark halos, and interacting with other galaxies. Some evolved into the kinds of spiral galaxies one sees today, while others underwent major mergers, lost angular momentum, triggered central starbursts and AGN activity, and eventually evolved into elliptical galaxies [2].

Large sample statistical observations of galaxies show that the color, age, specific star formation rate (SSFR) and other aspects and characteristics of galaxies tend to present bimodal distribution [8, 9]. Figure 2 depicts the relationship between color and mass of a star. The distribution of galaxies on the color map shows two distinct sequences of red and blue (the larger the U-B, the redder). Galaxies can then be divided into blue galaxies and red galaxies, as shown in the red lines. These two sequences are correspondingly called blue sequence and red sequence, and the middle area between them is vividly called green valley. Reddish galaxies are mainly early galaxies such as lenticular galaxies and elliptical galaxies. Reddish galaxies indicate weak star-forming activity, so they are also called quiet galaxies. The bluer galaxies are composed of late galaxies, mainly spiral and irregular galaxies. The bluer color indicates that the galaxy has very active star formation activity and is therefore also known as a star forming galaxy [10]. The evolution process of galaxies from blue sequence to red sequence is called "star formation termination" [3, 8, 11]. The DEEPS and COMBO 17 survey data are used to study the evolution of galaxies from redshift 1 to the present. The results show that the galaxies evolution from blue sequence to red sequence can occur in multiple ways and approaches. A series of studies show that star formation and termination in galaxies are affected by multiple mechanisms such as cosmic environment, galaxy morphology, stellar mass, active galactic nuclei and angular momentum [8].

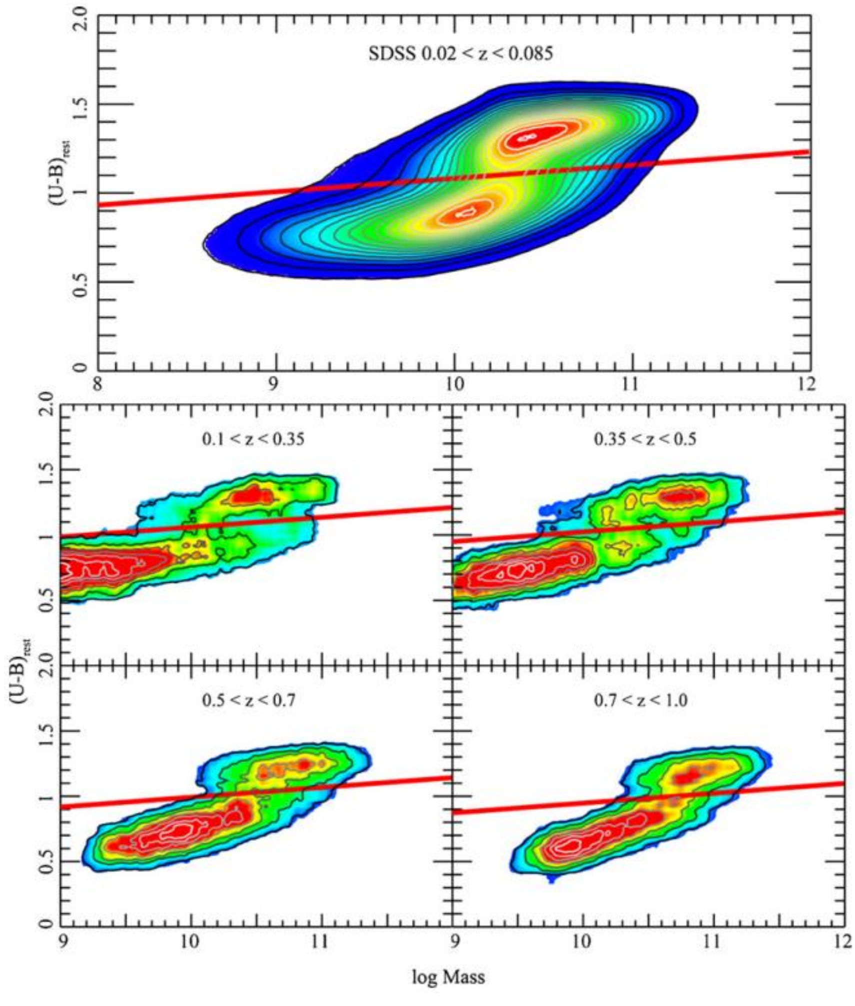

Figure 2. Mass-color (U-B) diagrams of nearby SDSS galaxies and ZCOSMOS galaxies at different redshifts. The two types of galaxies were separated by the red line [8].

As galaxies evolve, the baryonic matter within them goes through a cycle as presented in Figure 3. Firstly, the gas in the galaxy cools and collapses to form stars. During the evolution of stars, heavy elements are produced by internal nuclear reactions. Some heavy elements are released into the interstellar medium (ISM) by star wind or supernova explosion in the late evolution of stars (mainly massive stars). Some of the heavier elements in the gas phase condense into small solid particles called dust. Then the gas, newly created heavy elements, and dust in the galactic medium slowly condense into molecular clouds that take part in the next round of star formation. Unlike the first stars, the gas that formed them now contained heavy elements. So as galaxies evolve and star formation cycles, they get

DOI: 10.54254/2753-8818/10/20230338

a higher and higher proportion of heavy elements in the galactic medium, a process called chemical enrichment. In addition, galaxies exchange material with the outside world through accretion and outflow, including gas, heavy elements and dust. Figure 3 is just a simple demonstration of the evolution of galaxies. Galaxy formation and evolution involve the structure of galaxy distribution, the connection between central galaxy and dark matter halo, the evolution of black hole and host galaxy, accretion and outflow of gas, formation and termination of stars, AGN/stellar feedback, galaxy merger, galaxy morphology, chemical enrichment and dust evolution.

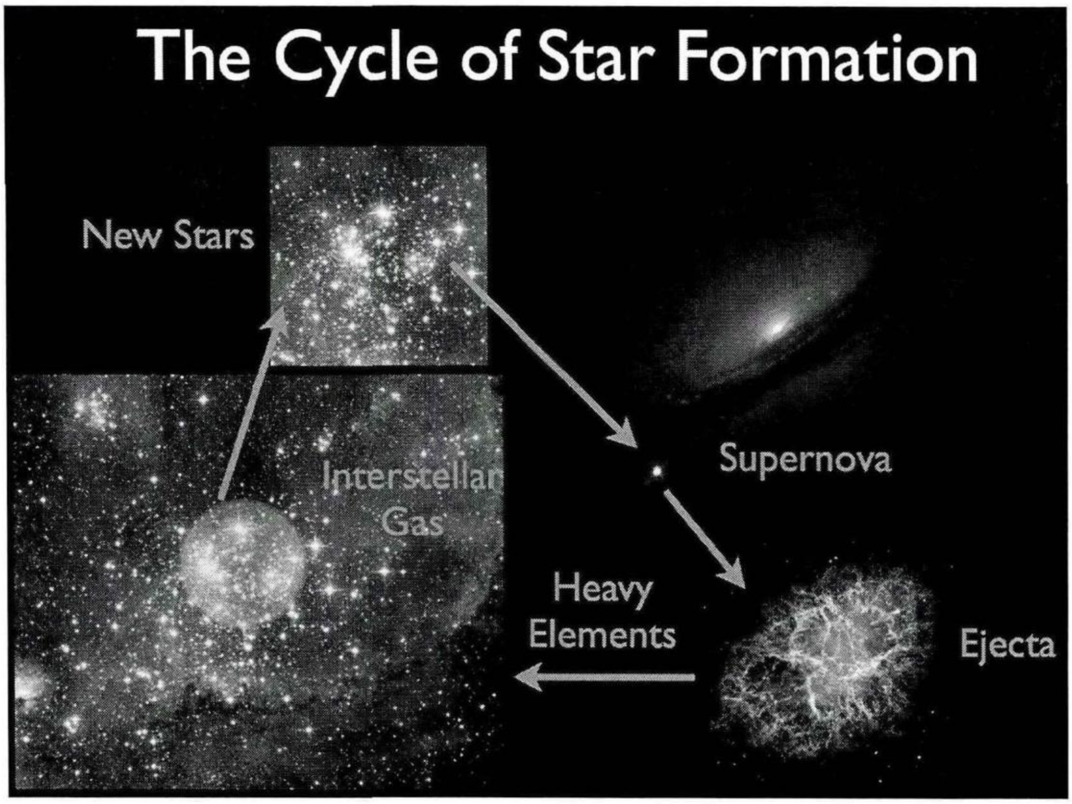

Figure 3. The cycle of baryonic matter in galactic star formation.

3. Introduction of cosmic dust

In the vast universe, most of the space is filled with interplanetary matter, interstellar matter, intergalactic matter and diffuse nebulae, except for planets, stars, galaxies, galaxy clusters and other massive objects forming cosmic islands in a very small area. These nebulae of interstellar matter and gas are composed mainly of H and He gas, and about 10% of them are dust. These are particles ranging in size from a few micrometres to a few centimetres or even larger, and since these particles fill the universe, they are appropriately called cosmic dust (given in Figure 4). Cosmic dust can be divided into intergalactic dust, interstellar dust, interplanetary dust (as in the zodiacal cloud), and circumplanetary dust (as in a planetary ring) by its astronomical location.

The analysis of the composition and structure of the samples of interplanetary dust and meteorites taken from the vicinity of the Earth shows that most of the elements contained in the interplanetary dust are those found on Earth. The composition is similar to that of minerals on Earth: both hydrous and anhydrous minerals. There are aggregates, metal spheres, and single mineral particles in the dust. These minerals of the dust include silicates, carbonates, phosphates, magnetite, etc., as well as water ice, ammonia ice, and methane ice. According to the elemental abundance analysis, the dust also contains elements including H, He, O, and N, but the proportion of H and He is rather small.

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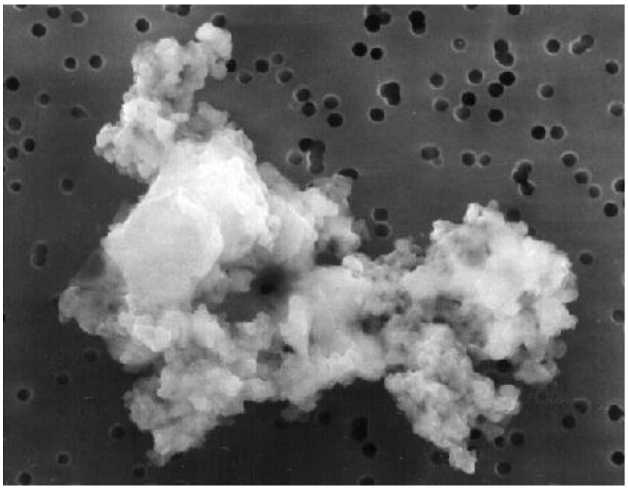

Figure 4. A microscope view of a dust grain given Herschel Observatory.

4. Formation and evolution of cosmic dust

Dust undergoes a complex evolutionary process, which includes: 1. Dust is produced by ejections of material from stars late in their evolution; 2. Collapse of dust; 3. Accretion and growth of dust particles; 4. Adhesion and fragmentation of dust particles. Finally, with a new round of star formation, the dust enters the next cycle of evolution. Among the physical processes listed, the changes in dust particle size are different. Hirashita divided particles into two size categories based on the 0.03-micron boundary, and then systematically evaluated the effects of these physical processes on dust and particle size changes, respectively [12]. The results are shown in Table 1.

Table 1. Processes considered in this paper.

Process	Small Grains[a]	Large Grains[b]	Total
Stellar ejecta	△	↗	↗
Shock destruction	↘	↘	↘
Accretion	↗	△	↗
Coagulation	↘	↗	→
Shattering	↗	↘	→

Note: ↗, ↘, and →indicate that the process increases, decreases, and keeps constant the dust mass, respectively. △means that the process has little influence on the dust mass. The large and small grains are divided at a ~ 0.03 μm [12].

Dust is first produced by the evolution of massive stars, mainly by the condensation of heavy elements thrown out by the winds of progressive giant branching stars and by supernova explosions [13, 14]. These two processes generally produce large particles of dust. If it happens to be the shock of a supernova explosion, large particles of dust may be directly destroyed. However, large and small particles are affected by this mechanism, so the relative distribution of large and small particles does not change. In addition, dust grows in dense environments by accreting gaseous metals. It increases the dust content. Owing to the larger surface area of small dust particles per unit volume (or mass) and more efficient accretion growth, accretion will increase the proportion of small dust particles in relative terms [12]. Finally, the dust will also undergo the process of adhesion and fragmentation in dense ISM, but this is only the change of dust particles on the physical scale, which does not change the total dust mass. The complexity of dust formation and evolution can be seen from the fact that all the physical processes listed in the above table change dust content or particle size distribution to a greater or lesser extent. The dust cycle described above is local and short in time. In fact, galaxies have gone through countless cycles of star formation, dust production, dust evolution and star formation. In the time scale of galaxy evolution, the results of dust evolution mainly show the correlation between dust related properties and galaxy physical properties [13]. The dust is dependent on the star mass, SFR, gas content and metallicity of the galaxy [15].

5. Dust in the galaxies

As an important product of stellar evolution in the galaxy, dust permeates the entire interstellar medium. Although it accounts for only a small percentage (1%) of the galactic medium, it seriously affects the observable properties of galaxies [13]. Dust absorbs energy in the ultraviolet spectrum (ultraviolet is the most absorbent) and is heated to emit radiation in the mid-to-far infrared. In addition to darkening celestial bodies, dust extinction also makes celestial bodies red, which affects the observable properties of galaxies. Half of the ultraviolet radiation in the universe is absorbed by dust and re-radiated in infrared [16]. On the other hand, dust also plays an important role in the formation and evolution of galaxies. Dust helps to cool the gas, and hydrogen atoms tend to form molecular gas on its surface, the stuff stars are made from [17, 18]. Dust is produced late in the life of massive stars and is part of the chemical evolution of galaxies. The study of dust evolution in galaxies is of great significance for testing the theory of galaxy formation, galactic chemical evolution and restoring the intrinsic properties of galaxies.

6. Conclusion

In summary, the dust has a significant effect on both the star and galaxy formation. In this study, the interstellar dust research in galaxy formation was summarized. The definition, classification, evolution and physical properties of cosmic dust and galaxies was introduced. It will then focus on the role of interstellar dust in galaxies, including its basic concepts and background. The study of dust evolution in galaxies is of great significance for testing the theory of galaxy formation, galactic chemical evolution and restoring the intrinsic properties of galaxies. Overall, these results offer a guideline for understanding of the functions of cosmology dust in galaxy formation**.**

Through the previous introduction, it’s a certain understanding of the basic concepts of galaxies, the scale relationship of the main parameters in the evolution of galaxies, and the formation and evolution of dust in galaxies. Due to the complexity of dust and its geometric distribution, the effect of dust on galaxy formation is a complex process with multiple parameters. Its complexity also means that the effect of dust can be used as an important tool to study the evolution of dust and its geometric distribution in galaxies. At present, considerable progress has been made in the research on this aspect in the academic circle. However, limited by observational data and research methods, the understanding of dust effect is still very limited, and needs to be studied in future.

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