State-of-art Simulations and Observations for Star Formation

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Abstract. In recent year, the formation and formation of galaxies is a hot spot in astrophysics which has been widely investigated and discussed. On the basis of the theory of formation and formation of large-scale structures in modern cosmology, this study intends to systematically investigate and analyze the physical characteristics of galaxies in different stages, such as morphological structure, star family structure, gas accretion, stellar formation, black hole growth, chemical elements, stellar and gas movements, and their physical relationships with large-scale structures. According to the analysis and evaluations, it aims to reveal the physical origin and formation of galaxies in different stages, as well as their physical relationships with large-scale structures, and then summarize the universal physical laws affecting galaxy formation. Moreover, the current limitations of the state-of-art results will be demonstrated and prospects will be given accordingly. Overall, these results shed light on guiding further exploration of investigation of star formation.

Keywords: Galaxy, Formation, Universe.

1. Introduction

The basic process of the recognized Milky Way Galaxy formation theory is that in the early universe, cold dark matter produced cold dark matter with different masses due to local gravitational instability; Hot gas enters it, cools and condenses into high-density molecular clouds; Molecular clouds break down and eventually form new stars and even galaxies [1].

The feedback of supernova explosion and AGN plays an important role in cooling the atmosphere and increasing the amount of matter. The formation of the Milky Way Galaxy is a very complicated process, which depends not only on the cosmic model, but also on abundant observation data, such as the measurement and correlation of physical parameters of the Milky Way Galaxy, the change of star coefficient density of galaxies, the clustering of galaxies, the red shift change of galaxies, etc. [2]. With the use of new observation equipment and large-scale computers, the research on galactic formation has developed rapidly in the past decade, in which some hot issues often appear and many new discoveries have been made.

2. Star Formation History in the Universe and Star Formation Main Sequence in Galaxies

In recent ten years, through the observation of multiple bands, people have a clear understanding of the star formation in the universe. During ~1-2, the density of star formation rate in the universe reached its peak in ~1-2, and gradually decreased with the passage of time. There are two main influencing factors: bright red galaxies (LIRG, LIR>10^{11}L$\odot$) or extremely bright infrared galaxies (ULIRGs, LIR>10^{12}L$\odot$) [3]. This type of galaxy is rare in the low redshift universe, but in ~1-2, its density increases sharply, its star formation rate is greater than 10 M$\odot$yr-1, and there are mergers and remnants [4]. However, some recent observations show that galaxies are not the main driving factors for the formation of ~1-2 stars, and the main evidences including following process. There is a strong correlation between star formation rate (SFR) and mass, which is called "Star Formation Main Sequence", and has existed since the redshift of Z=2, indicating that the star formation process of these galaxies is very simple and the similarity is very high [5]. The latest Integral Field Unit (IFU) data show that although some redshifted 2 galaxies have a star formation rate of 10 M$\odot$yr-1, their disk structure is stable and there is no significant interaction and fusion [6]. Through the high-resolution observation of CO molecular spectral lines, it is found that the gas concentraten in closed galaxies about ~1-2 away is enough to maintain their extremely high star formation rate without increasing the formation efficiency by collision and merger. For the detailed study of high redshift galaxies, multi-band image observation is the main method at present, and there will be more large telescopes for beam splitting (such as Subaru/PFS) and larger IFU sky survey in the future [7].

3. Semi-analytical Model

The semi-analytical model (SAM) of the Milky Way Galaxy has made great progress, including the following research results. Because of the addition of supernova explosion and energy feedback from AGN, this model can well simulate a large number of low redshift galaxies [8]. Based on SDSS as shown in Fig. 1 and Fig. 2, HIPASS, ALFALFA, COLDGASS and other observation data, the applicant realized the 2D spatial distribution of galaxy star composition, neutral hydrogen gas and molecular gas, and incorporated these spatial distributions into the formation process of galaxy stars. The observation data of constrained mode is no longer limited to low redshift, and the existing mode can well satisfy the consistency of quality function under each redshift [9]. Combining Bayesian statistics with Markov chain Monte Carlo (MCMC), the model can describe the parameter space faster and more completely, and give more reasonable parameter distribution and degradation [10]. There are still many problems to be solved in this method, such as serious degradation caused by too many free parameters. As an important physical mechanism, the feedback of AGN lacks sufficient observational evidence for a long time. These models predict a large number of dark red galaxies, among others. This project plans to further improve the new generation of high redshift galaxy survey (such as Subaru/PFS), and further improve the existing semi-analytical model in combination with more bands of high redshift galaxy survey data.

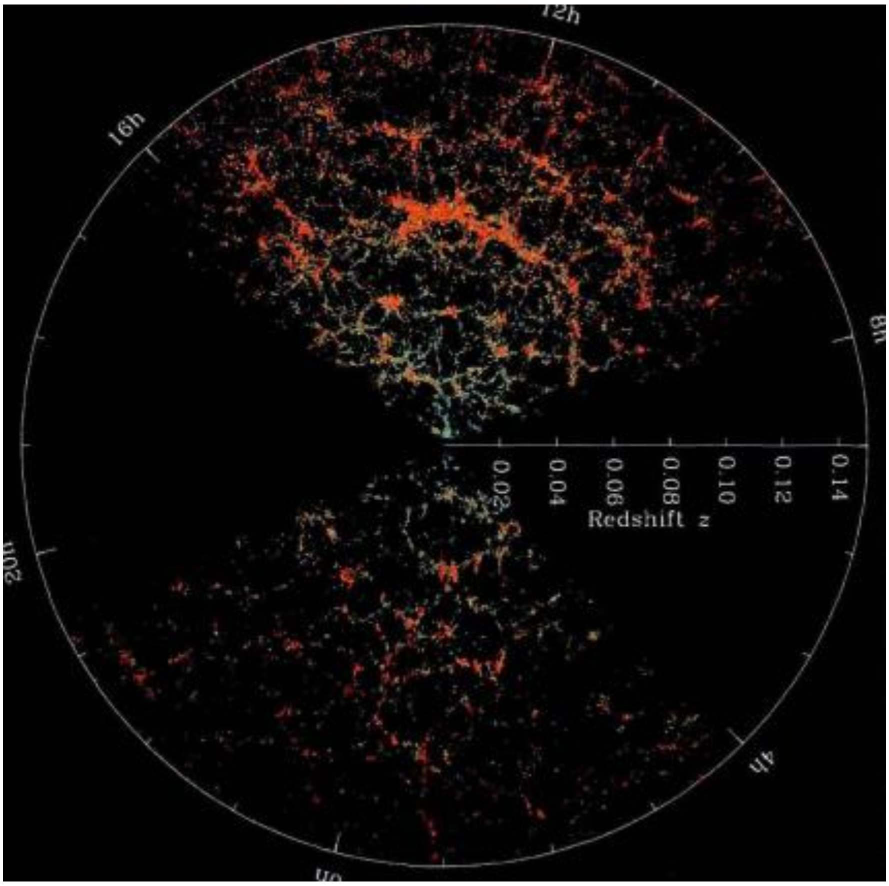

Fig. 1 Distribution of galaxies in the universe observed by SDSS

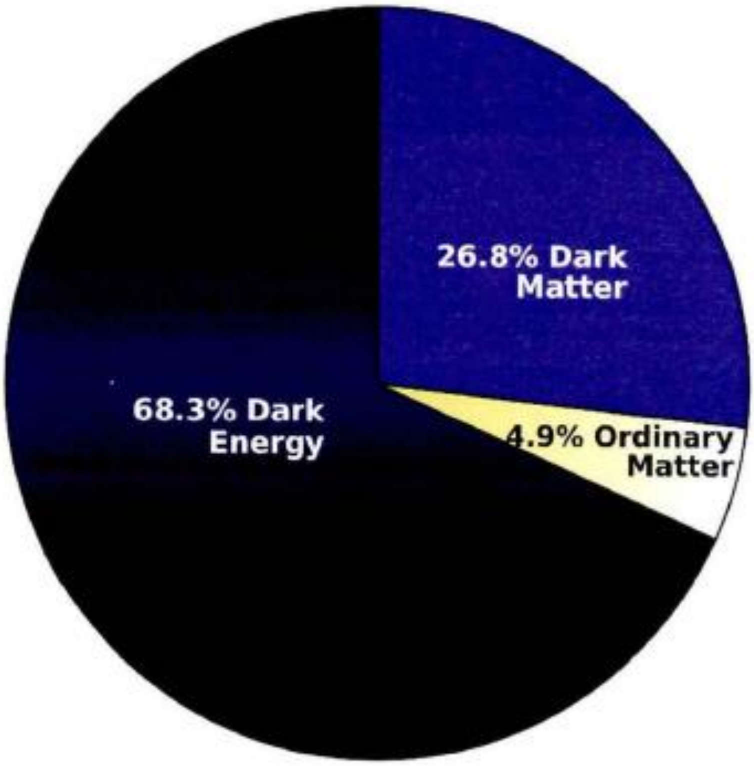

Fig. 2 Mass rate of each component of the universe measured by satellite.

4. Observational Study of High Redshift Galaxies

With the application of ground-based 8-10m optical/near infrared telescopes (such as Keck, Subaru, VLT), 4 m class (such as UKIRT), space medium-far infrared telescopes (Spitzer, Herschel), Hubble Space Telescope (HST), etc., as well as the selection of high redshift galaxies such as Riemann Blake (LBG) and BzK (BzK) based on ultraviolet/optical/infrared broadband selection; Sub-Millimeter (SMG) and ULRG (ULR) with submillimeter wave/infrared flux selection; Ly alpha (LAE), HAE etc for narrowband photometry selection [11]. One can also use multi-band energy spectrum fitting to retrieve some important parameters of high redshift galaxies, such as redshift, star mass, star formation rate, dust content and so on. HST carried the third generation wide field camera (WFC3) with high resolution for the first time in 2009, which made great progress in the study of the structure and shape of the high redshift Milky Way Galaxy. Several deep field surveys (such as CANDELS, CLASH, HubbleFrontier-Field) were carried out, which provided a lot of new data and new achievements for the study of galaxy formation in the future, and raised new doubts about some existing theories (such as critical velocity in mass-radius relationship). In the search for the first generation galaxies, it has also been reported that galaxies with redshifts above Z~10 have been found [12]. Redshift survey (VVDS, DEEP2, zCOSMOS, VVDS, DEEP2, zCOSMOS, etc.) can observe tens of thousands of Z~1 accessory galaxies in a few square ranges, and Subaru/PFS was launched in 2019, which was the first time to conduct a super-large-scale spectral survey of galaxies in the $1 < Z < 2$ energy region. It brings new formation to the Milky Way Galaxy [13]. Some typical results are shown in Fig. 3 and Fig. 4.

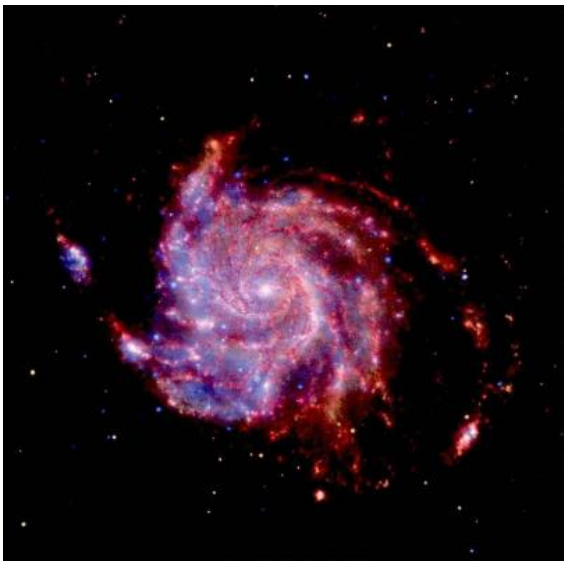

Fig. 3 M101 multiband composite image combining Spitzer (infrared), Hubble (optical) and Chandra (X-ray) observations

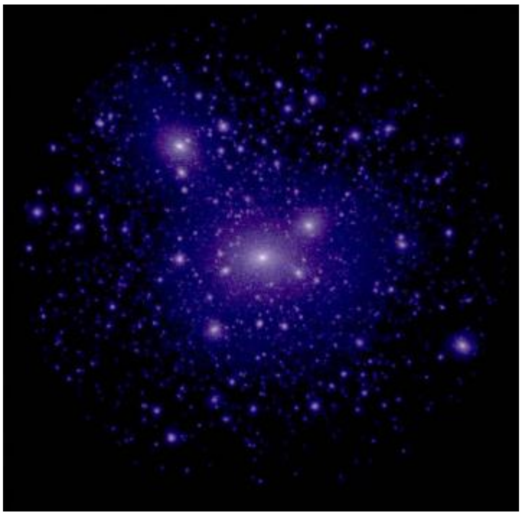

Fig. 4 A dark matter halo the size of the Milky Way Galaxy in numerical simulation under ΛCDM model, and the area in the map is an area with a radius of 250kpc centered on the center of mass of the dark halo.

5. Outlook

As a frontier subject in astronomy and cosmic science research, the formation of the Milky Way Galaxy has both great challenges and great opportunities for development. It has always been one of the difficult problems that puzzle the formation of the Milky Way Galaxy on how to accurately measure the physical characteristics by Spectral Energy Distribution (SED). For low redshift galaxies, people generally use star family synthesis method to study their full spectrum or local spectrum, so as to obtain their star mass, average age, metal abundance, inherent extinction and other parameters. For galaxies with high redshift, there is usually only SED, and the parameters such as photometry redshift and stellar mass can be obtained by fitting SED. Therefore, this project uses the method of energy spectrum diffraction to study these parameters. Due to the degeneracy of stellar age, stellar mass, metal abundance and other factors, these factors lead to great uncertainty in the observation results. In recent ten years, the importance of thermally pulsating AGB stars (TP-AGB) is still debated endlessly, and many major theoretical models give different parameters such as stellar mass.

Scholars are making improvements from the following aspects. Updating the stellar spectrum library to greatly improve the coverage of spectral number and parametric space (MaStar Project).

The analysis and fitting of spectra have been improved. Many foreign scientific research teams have used Bayesian statistics methods; 93 to improve the measurement method of intrinsic extinction, such as simplifying intrinsic extinction and other physical properties, so as to obtain a median extinction curve, thereby breaking through the relationship between intrinsic extinction and other physical properties. These methods and IFU surveys, such as MaNGA and SAMI, will improve our understanding of the physical characteristics and 2D distribution of the Milky Way Galaxy.

6. Conclusion

To sum up, China's research on the formation of the Milky Way Galaxy has continued to develop in recent ten years. A group of young scholars have returned from abroad and made important contributions in some important fields. They have gradually formed a young team with both observation experience of large-caliber astronomical telescopes and high theoretical research level. In recent years, with the implementation of the "B Pilot Program" (TAP) of Chinese Academy of Sciences, China has cultivated a number of outstanding observation talents, among which BASS, CLAUDS, JINGLE, MALATANG, etc., which are mainly TAP, are mainly Chinese scientists, and their international influence is increasing day by day. The newly completed FAST radio telescope is expected to carry out large-scale observation of the Milky Way Galaxy in the next few years, and international cooperation such as "SKA" directly initiated by Chinese officials will also support the research on the formation of the Milky Way Galaxy.

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