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Unveiling the Cosmic Tapestry: Insights into Galaxy Formation and Evolution

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ABSTRACT

Cosmology's leading edge of observation and theory is galaxy formation. Our comprehension of the cosmic parameters, the universe's contents, and our origins must be furthered, and this requires increased understanding. Astronomers have been fascinated by the intriguing and intricate phenomenon of galaxy creation for many years. A comprehensive survey of all theoretical difficulties is outside the purview of a single review because galaxy formation has grown to be such a broad area in astrophysics. The process by which galaxies, which are vast structures made up of stars, gas, dust, and dark matter, come into being is referred to as galaxy formation. It is a key component of cosmology and astrophysics, trying to comprehend how the universe's structures have changed over the course of billions of years.

Keywords: Galaxy formation, Cosmology, Galaxy Evolution, Galaxy classification

INTRODUCTION

The prevailing theory of galaxy formation is known as the hierarchical model or the cold dark matter (CDM) model, which is supported by observations and computer simulations. According to this model, galaxies form through a series of gravitational interactions and mergers of smaller structures, such as dark matter halos and gas clouds. The process begins shortly after the Big Bang, with the formation of tiny fluctuations in the density of matter across the universe. These fluctuations, seeded by quantum fluctuations during the inflationary period, serve as the seeds for the formation of galaxies. Over time, gravity causes these density fluctuations to grow, leading to the collapse of regions with higher densities.

Dark matter, a mysterious and invisible form of matter, plays a crucial role in galaxy formation. It provides the gravitational scaffolding around which normal matter can accumulate and form galaxies. As the dark matter collapses under gravity, it forms halos, which act as gravitational wells that attract gas and dust. Within these halos, gas begins to accumulate and cool down through radiative processes, allowing it to condense and form stars. The process of star formation is triggered by the collapse of gas clouds, leading to the formation of protostellar cores and eventually individual stars. The stars then cluster together within the dark matter halo, forming a galaxy.

As galaxies evolve, they can undergo mergers with other galaxies, resulting in the growth and transformation of their structures. Major mergers, involving galaxies of comparable mass, can lead to the formation of elliptical galaxies, while minor mergers and interactions can influence the shape, size, and star formation activity of the resulting galaxies. Feedback processes also play a significant role in galaxy formation. Stellar feedback, driven by supernovae and massive star winds, can heat or expel gas from galaxies, regulating their star formation rates. Active galactic nuclei (AGNs), powered by supermassive black holes at the centers of galaxies, can release intense radiation and powerful jets that impact the surrounding gas and influence galaxy growth.

Observational studies of galaxies at different cosmic epochs, combined with sophisticated computer simulations, have provided valuable insights into the mechanisms driving galaxy formation. However, many aspects of this intricate process are still under investigation, and ongoing research aims to further refine our understanding of galaxy formation and unravel the complex interplay of physical processes involved.

In terms of observational studies of galaxy formation, the last few years have been extraordinarily productive. Observations at a wide range of wavelengths, from the far ultraviolet to the submillimetre, have led to significant advancements. The discovery and measurement of the clustering of "Lyman-break" galaxies, a population of bright, metal-producing galaxies at redshifts z, 34 [1,2], estimates of the history of star formation and the associated metal production, from z, 5 to the present [3,4], measurements of the galaxy luminosity function at z, 0:51 [5,6], and z, 34 [7], and the discovery of a population of bright submillimetre sources, some of which, at least, appear to be dusty, star-forming galaxies at z * 2 [8].

Galaxies are gravitationally bound systems consisting of stars, stellar remnants (white dwarfs, neutron stars, and black holes), interstellar matter (gas and dust), and a significant portion of dark matter. They are diverse systems with a variety of morphologies and attributes. For example, their optical luminosities and stellar masses are in the range of 103-1012 in solar units, whereas the typical diameters of their luminous components range from 0.1 kpc to tens of kiloparsecs. The mass budget of galaxies is dominated by roughly spherical dark matter holes.

The earliest telescopic views revealed the presence of objects, originally named nebulae, whose light appeared diffuse and fuzzy, which led to the discovery of galaxies (without knowing their nature). C. Huygens made the first telescopic observations of these nebulae in the middle of the eighteenth century, followed by E. Halley and N.-L. de Lacaille in the first half of the century. Intriguingly, T. Wright wrote a book in 1750 that depicted the Milky Way as a flat covering of stars and proposed that distant nebulae might represent analogous systems. certain concepts perhaps served as inspiration for I. Kant, who in 1755 suggested that certain objects, like the Andromeda galaxy, appear nebulous because of their great distances, which make it difficult to distinguish their individual stars. The Milky Way was seen in this perspective as one of these several star systems (island universes).

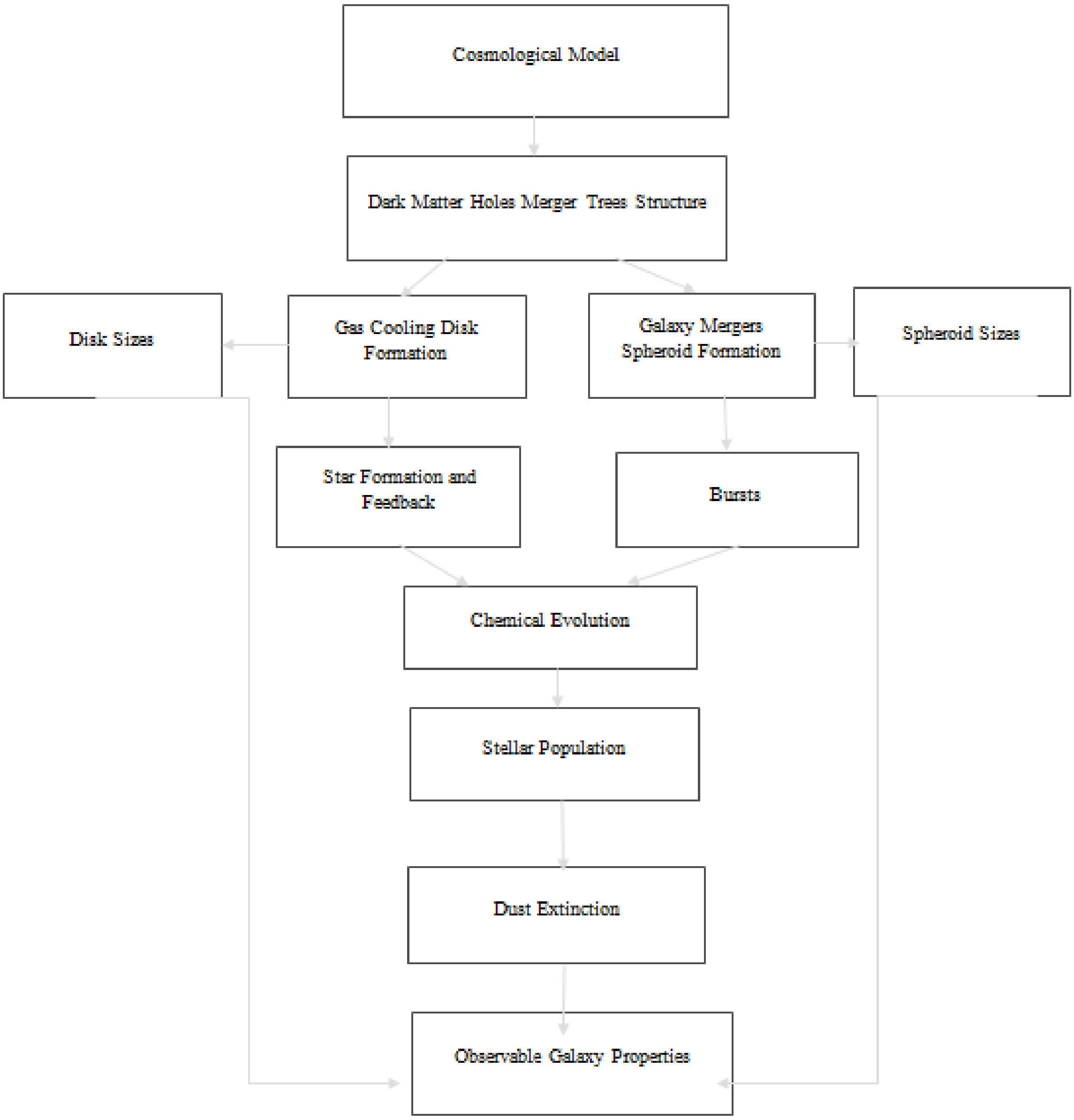

Fig. 1 A schematic showing how different physical processes are combined to make predictions for the observable properties of galaxies, starting from initial conditions specified by the cosmology. The numbers in each box indicate the subsection of the paper in which our method for modelling that process is described

Our model of galaxy formation combines a variety of methodologies, each of which was created to address a specific component of the intricate process of galaxy formation. A Monte Carlo method for creating "merger trees" to depict the hierarchical development of dark matter (DM) haloes forms the basis of the theory. The entire spectrum of elements and activities that we represent in this framework are:

1. Creation and fusion of dark matter haloes caused by gravity;
2. The radiative cooling of gas and its collapse to form centrifugally supported discs;
3. The density and angular momentum profiles of dark matter and shock-heated gas within dense non-linear haloes;
4. The scale lengths of discs based on angular momentum conservation and including the effect of the surrounding halo's adiabatic contraction during the formation of the disc;
5. steric scaling.
6. Feedback, or the regulation of the star formation rate as a result of the injection of supernova (SN) energy into the interstellar medium (ISM);
7. Chemical enrichment of the interstellar medium and hot halo gas, and its impact on both the gas cooling rates and the characteristics of the stellar populations that are formed;
8. The frequency of galaxy mergers caused by dynamical friction acting on galaxies as they orbit within common dark matter haloes;
9. The formation of galactic spheroids, which are accompanied by bursts of star formation, during violent galaxy-galaxy mergers, and estimates of their effective radii;
10. Evolution of the star populations as measured by spectroscopy;
11. The impact of galaxy inclination and dust extinction on galaxy luminosities and colours, as well as
12. The process whereby new born stars ionise interstellar gas and produce emission lines.

A comprehensive survey of all theoretical difficulties is outside the purview of a single review because galaxy formation has grown to be such a broad area in astrophysics. Historically, simulations of mergers and idealised galaxy models have been used to test numerical implementations of "feedback" processes. Important discoveries on star formation, morphological and kinematic changes, merger-driven gas flows, star formation's initiation, the effect of accreting black holes on the process' termination, and size evolution have been made as a result of these models. We provide an introduction to these feedback models and discuss how they are applied in current cosmological simulations of galaxy formation.

There are cosmic galaxy formation simulations face significant theoretical challenges. How galaxies accumulate their gas is one of them. Despite being a crucial and basic step in galaxy formation, gas accretion has shockingly not yet been convincingly seen. It is still unknown from computer simulations whether the gas is accreted onto the cold filaments of galaxies [9, 10] or if the filaments disintegrate in the halos and accretion is smoother [11].

SEVERAL PERTINENT OBSERVATIONS

Stars

A flattened, rotationally supported disc or spiral component, which is typically somewhat larger (aside from the highest mass systems), and has a roughly exponential profile [13–15], makes up the majority of the mass in the visible parts of galaxies. Spheroidal parts typically have scale lengths of only a few kpc to a few tens of kpc. Since isolated systems tend to be disc dominated and those in areas of high galaxy density likely to be dominated by the spheroidal component, these two components appear to be unique, and environmental considerations must be crucial in explaining their creation [16–19].

Gas

Typically, the cold interstellar medium gas (. 104K) makes for around 10% of the mass of spiral galaxies like the Milky Way. The so-called "circumgalatic medium," which is the region extending from the star-forming interstellar medium towards the galaxy halos, may include an even greater amount of gas (part of it hotter and more ionised) [20, 21]. Contrary to the conventional view, more massive early-type galaxies often have considerably lower fractions of cold gas, while they nevertheless contain cold gas [22–25].

Dark Matter

It was discovered that the stars in the majority of normal galaxies are embedded in massive halos composed of some unidentified type of dark matter with a total mass and size that is roughly 10 times that of the stellar component after Zwicky and Babcock's work in the 1930s and the subsequent work of many authors on the rotation curves of normal galaxies in the 1970s and 1980s [26]. An essential test for cosmological formation hypotheses is the essentially flat observed rotation curves of spiral galaxies [27].

Super-Massive Black Holes

According to a number of studies, super massive black holes are typically found in the centres of normal galaxies (with stellar masses & 1010.3M), and their masses are closely correlated with the masses (and stellar velocity dispersions) of the galaxies' spheroidal components, with the ratio being roughly 5:1000 [28, 29].

The Milky Way

In the latter half of the 20th century, a convincing history of our own galaxy, the Milky Way, was reconstructed using the archaeology method. The Sun is an example of a typical star in the disc portion, having developed gradually from relatively metal-rich gas. The typical stars in our cosmic neighbourhood evolved just 3-6 billion years ago, rather late in the history of the Universe. As rotationally supported gas was systematically converted into stars over cosmic time, it appears that this disc component increased slowly, in size and mass. Only a very small portion of the stellar mass comes from stars created in other galaxies that were added to our system through galactic mergers. The majority of the stars in our galaxy (the fraction may be as high as 95%) were made from gas that was added to the galaxy and formed into stars within the system [30]. Therefore, it's possible that "major mergers" had little to do with the late development of our Galaxy or those with very comparable structures.

Galaxy formation and evolution refer to the processes by which galaxies, vast systems of stars, gas, and dust, come into existence and change over time. Our current understanding of these processes is based on observational data, computer simulations, and theoretical models. Here's a general overview of galaxy formation and evolution:

1. **Initial Conditions**: Galaxies are believed to have formed from small fluctuations in the density of matter in the early universe, as predicted by the Big Bang theory. These density fluctuations eventually led to the formation of structures known as dark matter halos.
2. **Halo Assembly**: Dark matter halos provide the gravitational framework for galaxy formation. As gas and dust fall into these halos, they accumulate in the densest regions, where the first stars and galaxies begin to form. This period is often referred to as the "epoch of reionization."
3. **Star Formation**: Within these protogalactic clouds of gas, star formation occurs. The gas collapses under its gravity, forming dense cores that eventually ignite nuclear fusion, giving birth to stars. The interplay between gravity, gas dynamics, and feedback processes (such as stellar winds and supernova explosions) determines the rate and efficiency of star formation.
4. **Galaxy Mergers and Interactions**: Over time, galaxies can interact and merge with one another due to their mutual gravitational attraction. These interactions can dramatically influence the morphology, size, and composition of the galaxies involved. Major mergers between galaxies often trigger bursts of star formation and the formation of massive black holes at their centers.
5. **Galaxy Types and Morphology**: Galaxies come in various types, including spiral galaxies (like the Milky Way), elliptical galaxies, and irregular galaxies. The morphology and structure of a galaxy are shaped by its history, the amount of gas it contains, and the presence of ongoing mergers or interactions.
6. **Stellar Populations**: Galaxies have distinct populations of stars, each characterized by their age, composition, and location within the galaxy. Over time, galaxies tend to evolve, with the oldest stars found in the central regions and younger stars in the outer regions.
7. **Active Galactic Nuclei (AGN)**: Some galaxies harbor supermassive black holes at their centers, which can accrete large amounts of gas and dust. This process releases enormous amounts of energy, leading to the formation of an active galactic nucleus (AGN). AGNs can have a profound impact on the evolution of their host galaxies by affecting star formation rates and expelling gas.
8. **Dark Matter and Dark Energy**: Although invisible, dark matter is thought to play a crucial role in the formation and evolution of galaxies. Its gravitational effects provide the scaffolding for galaxy formation. Dark energy, on the other hand, is a mysterious force responsible for the accelerating expansion of the universe and has implications for the long-term fate of galaxies.

There is an unequal distribution of galaxies in space. While some exist in couples that orbit each other, others have no close neighbours. The majority of galaxies are located in clusters, which can include anything between a few hundred and thousands of members. Superclusters are even larger formations that can form from galaxy clusters.

THE HUBBLE SEQUENCE

Edwin Hubble developed a system for categorising galaxies based on their shape as seen from Earth in 1926. Regular galaxies are divided into three broad types by the Hubble sequence: spiral, lenticular, and elliptical. For galaxies that have an irregular appearance, a fourth class is used.

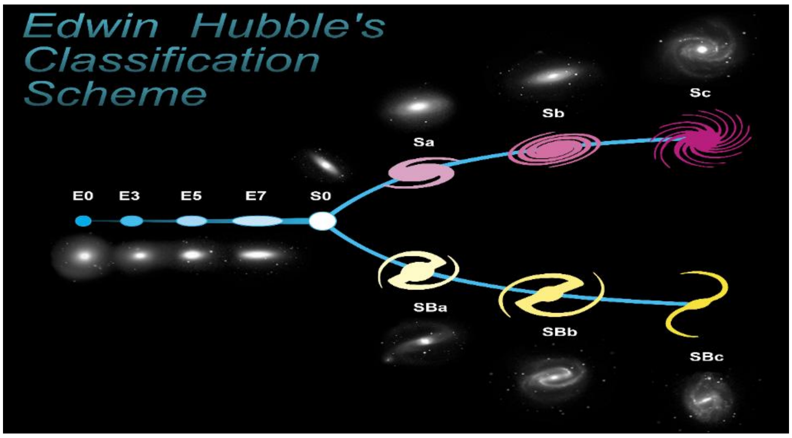

Fig. 2 Edwin Hubble's classification scheme credit: NASA/ESA, PD, en.wikipedia.org/wiki/File: HubbleTuningFork.jpg.

Elliptical Galaxies

Elliptical galaxies appear as ellipses in photographic photographs and have uniform, featureless light distributions. There is minimal indication of young stars, gas, or dust in them. Compared to spiral galaxies, elliptical galaxies have stars that move more randomly.

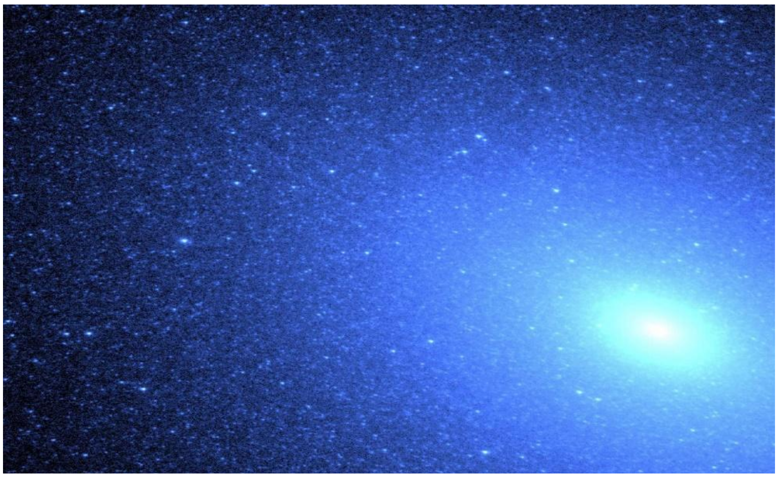

Fig. 3M 32, an elliptical galaxy in the constellation Andromeda credit: NASA and T. Brown, apod.nasa.gov/apod/ap991103.html.

Lenticular Galaxies

Where the elliptical branch connects the two spiral arms on the Hubble sequence are lenticular (lens-shaped) galaxies. These galaxies feature an extended disk-like shape encircling a bright central bulge.Some lenticular galaxies resemble spiral galaxies in that they have a bar. Barred lenticular galaxies are what they are known as.

Fig. 4NGC 5866 (the Spindle Galaxy), a lenticular galaxy in the constellation of Draco credit: NASA, ESA and The Hubble Heritage Team (STScI/AURA)

Spiral Galaxies

A flattened disc of stars makes up spiral galaxies, which have a spiral structure. Typically, there are two arms, which may be more or less tightly wound, and a bulge, or grouping of stars, in the centre. A bar-like structure that extends from the central bulge and leads to the spiral arms is present in over half of all spiral galaxies. Spiral galaxies' arms stand out because they are areas of active star formation and are home to a large number of hot, youthful, blue and blue-white stars. The colour of a spiral galaxy's nucleus, in comparison, tends to be redder, which denotes the presence of numerous ancient stars. In spiral galaxies, stars often revolve around the galactic centre.

Fig. 5 M 83, a spiral galaxy in the constellation of Hydra credit: SPIRIT

Irregular Galaxies

A subclass of irregular galaxies that lack regular structure also exists. According to astronomers, gravitational influence from nearby galaxies may be the source of the deformed shapes of irregular galaxies. Unusual galaxies known as the Large and Small Magellanic Clouds orbit the Milky Way galaxy.

Fig. 6The Large Magellanic Cloud (LMC), a dwarf irregular galaxy. credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA)- ESA/Hubble Collaboration

The Milky Way

Our galaxy, the Milky Way, is a massive spiral galaxy with a diameter of 100,000 light years and a mass of roughly 1 trillion solar masses. The Milky Way contains hundreds of billions of stars, including our Sun. The Large and Small Magellanic Clouds, two dwarf galaxies that are only a few hundred thousand light years apart, are our closest neighbours. The Andromeda Galaxy (M 31), our closest big neighbour and located approximately 2.5 million light years away, is also a spiral galaxy. The Local Group is the name given to the collection of the about 50 galaxies that are closest to us.

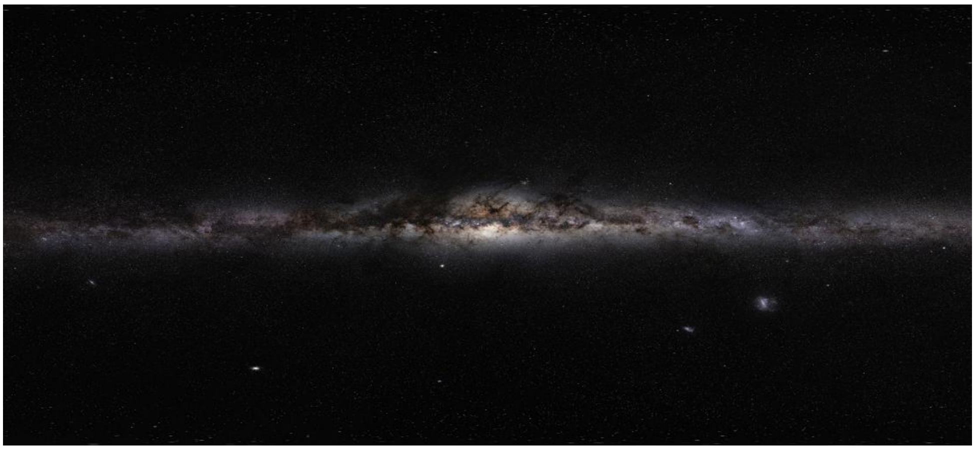

Fig. 7 360° photographic panorama of the Milky Way by Digital Sky LLC, CC-BY-SA-2.5, en.wikipedia.org/wiki/File: Milkyway_pan1.jpg.

CONCLUSION

Studying galaxy formation and evolution is a complex and ongoing field of research. The study of galaxy formation and evolution has deepened our understanding of the cosmic processes that shape the universe. It continues to be an active area of research, combining observational discoveries, theoretical models, and advanced simulations to unlock the mysteries of how galaxies are born, evolve, and interact throughout the vast expanse of the cosmos.

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