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Exploring the Impacts of Accelerated Expansion on Galaxy Dynamics

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Abstract:

The contribution of this work is an in-depth analysis of the effects induced by the accelerated expansion of the universe on the dynamics of galaxies, paying particular attention to the contribution of dark energy and alternative cosmological models. It analyzes the role that these ingredients play in the formation and evolution of galaxies within hydrodynamical simulations and by using theoretical modeling. It gives, in detail, the rather insignificant contribution of dark energy towards the process involved in galaxy formation, emphasizing that the action takes effect only in relatively late stages of cosmic developments. The role of black hole feedback is critically reviewed and demonstrates its contribution towards the quenching of star formation in high-mass galaxies. The paper also discusses, as an alternative, a theoretical model based on Tsallis entropy, which shows another approach to explaining both cosmic acceleration and the phenomenon of flat galactic rotation curves without the use of traditional dark matter or dark energy. The Grüneisen parameter is also presented as a thermodynamical tool that connects cosmic expansion to condensed matter physics, allowing new insights on the physical processes that underlie galaxy dynamics. Combining these models, in this paper we deepen the knowledge on the complex interaction of forces at play for driving galaxies towards their observed behavior.

Keywords: Accelerated expansion; dark energy; galaxy dynamics.

1. Introduction

The expansion of the universe is accelerating, and this constitutes one major reason for remodeling our present understanding of cosmic structures especially galaxies [1].This came as one of the major discoveries from distant Type Ia supernovae observations and a congregational accomplishment for modern cosmology [2]. Evidently, such findings have had very important implications for our basic understanding of the evolution of the universe.

Not withstanding this progress, it is clear that the interplay of forces which provides this acceleration, generally termed as dark energy, is one of the biggest puzzles in cosmology [3]. Currently, all sets of cosmological data are consistent with a cosmological constant or a source of energy whose density does not evolve with time. What is relevant is to properly interpret the effects produced by the acceleration epoch on galaxy dynamics if the general course of evolution of the Universe is to be deciphered.

This review discusses how acceleration expansion affects the processes of galaxy formation and evolution and places particular emphasis on dark energy, as well as alternative cosmological model-inspired influences, on these processes. Centrally, there will be a discussion about the interplay between these forces and their impact on the behavioral aspects of galaxies. Dark energy is assumed to drive the acceleration in the expansion of the Universe. However, the influence of dark energy on galaxy formation is much less direct.

Hydrodynamical simulations, such as those coming from the EAGLE project, show that dark energy itself plays a minor role in the early stages of galaxy formation and only later becomes an increased concern. Besides, other factors become very relevant, such as black hole feedback, when it comes to galaxy evolution and, in particular, in suppressing star-forming activity in high-mass galaxies. These results are indicating that only by an integrated approach—it means, in other words, cosmic expansion combined along with internal galaxy processes—can detailed insight into galaxy dynamics be possible. In addition to the role of dark energy, some alternative models based on Tsallis entropy are investigated as explaining cosmic acceleration without employing dark energy or dark matter. These models depict the change in gravitational dynamics from a thermodynamical perspective, such that it could account for the observed acceleration in expansion and flatness in the galactic rotation curves. The project explores both traditional and alternative models in an attempt to derive a complete understanding of how the accelerated expansion of the universe affects galaxy dynamics.

2. Theoretical Framework

2.1 Cosmic Expansion

The discovery of cosmic accelerated expansion fundamentally reshaped our understanding of the universe and revolutionized modern cosmology. This unexpected finding challenged the previously held belief that gravitational forces would eventually slow down the expansion of the universe. Instead, it led to the introduction of dark energy, an unknown and mysterious force that appears to be driving this acceleration. Dark energy, which is represented as the cosmological constant (Λ) in the standard cosmological model, ΛCDM, is often characterized by its equation of state, ω=P/pc^2, where w is the ratio of pressure to density.

If α is an arbitrary length scale in the universe, then the density of some component of the universe evolves as p∝α^−3(1+ω). Normal matter has w=0, meaning it dilutes with volume as space expands. If dark energy has an equation of state ω =−1, corresponding to Einstein's cosmological constant Λ, then it has the strange property that its energy density does not dilute as the universe expands, implying it is a property of the vacuum. Other possibilities exist: if $w<-1$, the dark energy density is ever growing and could ultimately result in a "big rip," destroying galaxies and even subatomic particles. However, dark energy could also be modeled as a scalar field with $w>-1$ (generally known as quintessence), where w can evolve over time.

Despite the importance of dark energy in explaining the accelerated expansion, its nature remains elusive. Various theoretical models have been proposed to explain what dark energy could be, ranging from a constant energy density that permeates all of space to more exotic explanations involving modifications to general relativity or the existence of new fundamental fields. Observational evidence, such as that gathered from the Cosmic Microwave Background by missions like the Planck satellite, continues to support the presence of dark energy, but it has yet to be definitively understood. As the universe continues to expand, the influence of dark energy becomes more pronounced, particularly in the large-scale structure of the cosmos. This acceleration affects not only the rate of expansion but also the evolution of galaxies and galaxy clusters. The study of cosmic expansion remains an active and evolving field, as researchers seek to uncover the true nature of dark energy and its role in shaping the universe's future.

2.2 Galaxy Dynamics

The understanding of galaxy dynamics has to be made within the context of an expanding universe if one is ever going to be able to predict their future behavior and that of their large-scale interactions. Galaxies do not evolve in isolation in this accelerated expansion-dominated universe but are continuously subjected to internal and external forces due to dark energy, gravitational interactions, and feedback from supermassive black holes. On the other hand, hydrodynamical simulations have indeed given much deeper insight into forming and evolving galaxies within an expanding universe. Simulations follow a variety of physical processes including gas dynamics, star formation, supernovae feedback, and black hole activity that allow researchers to see both small and large

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scale behaviors of galaxies. As galaxies grow and their central supermassive black holes become more active, they release copious amounts of energy into space. Such energy heats up the surrounding gas, which in turn stops it from cooling down and forming new stars. In this way, star formation is strongly reduced in massive galaxies. Besides internal processes like black hole feedback, the expanding universe itself brings about some mechanisms. It is dark energy that drives the accelerated expansion of the universe; it makes them move away from each other—a reason why galaxy mergers and large-scale interactions will be less possible. This may be due to what will be called 'cosmic isolation' in the future, where galaxies become increasingly isolated, with star formation slowing down because the gas supplies get depleted. Meanwhile, the large-scale structure of the universe—depending on the role of dark energy—determines the distribution of the galaxies and their clustering properties, that is, a description of how they form groups and clusters.

Ultimately, the study of galaxy dynamics in an expanding universe provides critical insights into the long-term evolution of galaxies and the large-scale structure of the cosmos. By combining observational data with advanced simulations, researchers are better equipped to predict the future behavior of galaxies and the forces that govern their interactions in a universe dominated by dark energy.

3. Methodology

This study builds on the findings of previous research using advanced cosmological models and simulations to investigate the impact of accelerated expansion on galaxy dynamics. Hydrodynamical simulations are employed to model galaxy evolution and star formation under the influence of dark energy. These simulations take into account the interactions between galaxies, the role of black hole feedback, and the suppression of star formation as the universe expands.

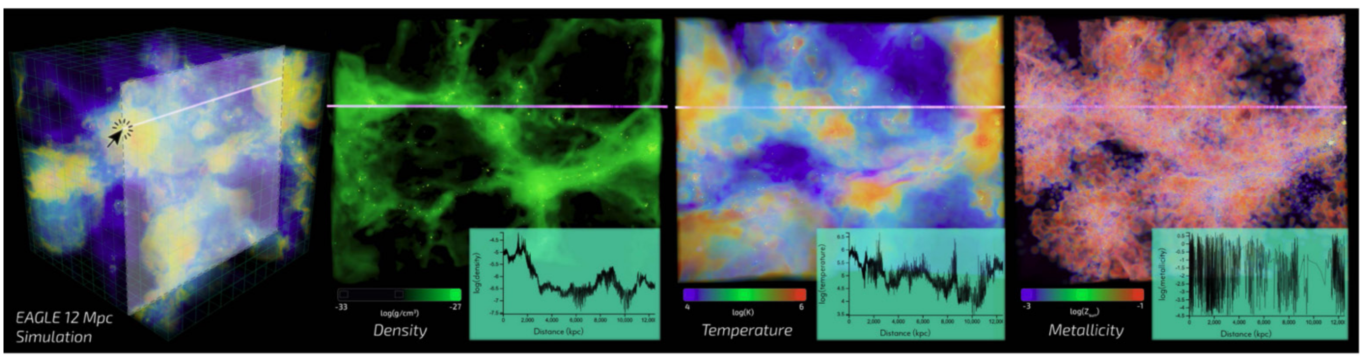

Fig. 1 Hydrodynamical simulation [4]

Visual representation of a hydrodynamical simulation showing density, temperature, and metallicity. which illustrates the hydrodynamical simulation results, where density, temperature, and metallicity are key factors in understanding galaxy formation and evolution. These simulations are crucial in visualizing how different factors impact galaxy structure as the universe expands.

As shown in the Fig. 1, Multiple volume renderings within the CosmoVis software illustrating the various types of gas attributes that can be retrieved from cosmological simulations.

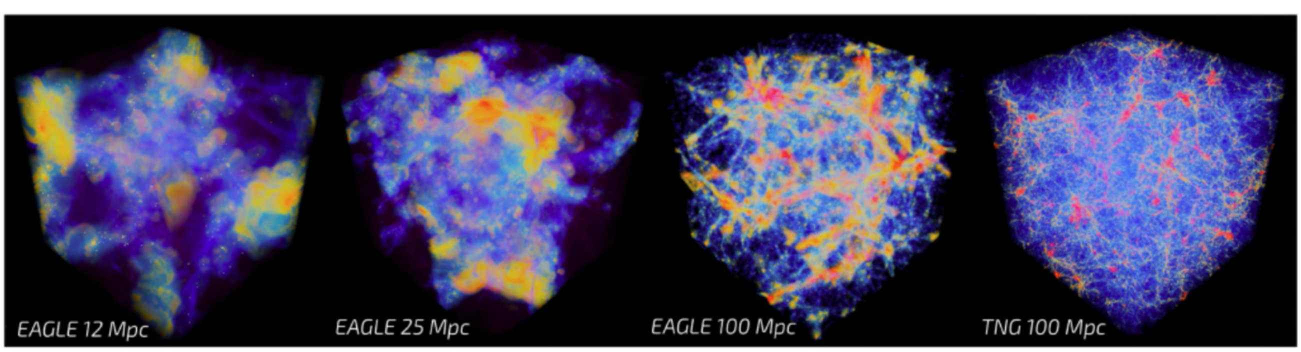

Fig. 2: EAGLE simulation [4]

Comparative visualization of EAGLE simulation volumes across different scales (12 Mpc, 25 Mpc, 100 Mpc). It showcases how different scales of the simulation, ranging from 12 Mpc to 100 Mpc, evolve [4].

As shown in the Fig. 2, these Gas temperature volume renderings in simulations of various sizes. These simulations help scientists understand galaxy clustering and cosmic structure formation, revealing how cosmic evolution occurs at different scales.

In addition to dark energy, this study incorporates an alternative model based on Tsallis entropy, which offers insights into how galaxy behavior might change without the influence of dark energy. This approach modifies gravitational dynamics at large scales, providing a compelling explanation for flat galactic rotation curves and late-time accelerated expansion in the absence of dark matter or dark energy.

This equation presents the Tsallis entropy equation, which underpins the alternative cosmological model used in this study. This model challenges traditional views of dark energy and offers a thermodynamic approach to explaining the universe's accelerated expansion.

4. Results

Results from hydrodynamical simulations, which show that dark energy takes a very minor part in galaxy formation and becomes significant only after most stellar mass has formed. Instead, black hole feedback emerges as the main agent of star-formation quenching, notably in high-mass galaxies. While the cosmological constant contributes significantly to the overall dynamics of galaxy clusters, it is black hole activity that predominantly influences galaxy evolution. Another model, correspondingly, relies on Tsallis entropy and includes another interpretation, by which the acceleration at late times and the rotation curves of galaxies at flatness may be explained within the gravitational and thermodynamic modifications unrelated strongly with the dark matter. Moreover, the Tsallis entropy model allowed for a reasonable alternative to the standard cosmological theories by suggesting that the variations of gravitational law could explain cosmic expansion and the large-scale structure of the universe. These results, in which gravitational modifications and thermodynamics could take a much larger place in the future models of cosmic evolution, are suggesting the same.

5. Observational Techniques and Evidence

5.1 Observational techniques and methods

The major dependence in the study of cosmic expansion and the behavior of galaxies is mainly observational; two big methods regarding the rate concern the distance-redshift relation and the Hubble constant. The acceleration of the expansion of the universe is directly evidenced by Type Ia supernovae and CMB data. Early dark energy was not strong enough to drive the acceleration we see today, but it would have caused the plasma formed after the Big Bang to cool off sooner. Such more rapid cooling changes the way that we interpret CMB data, which becomes relevant when trying to calculate the age of the universe and the different components of its expansion rate. The latter depends on the length of time sound waves moved through the plasma before it became transparent to form gas. Observatories like Planck analyze the leftovers of that transition visible in the sky—a window to the universe at an early stage, which is essential for understanding how cosmic expansion evolved [5].

5.2 Observational evidence

It is not a major player in the process of early galaxy formation, though being a significant candidate, it greatly suppresses star formation at the late stage of a galaxy's life cycle. Another investigation was carried out by Sheykhi in the year 2020 [6]. He adopted Tsallis entropy for describing accelerated expansion of the universe without incorporating dark energy. This model essentially enacts the changes in Newton's law of gravitation and also in the Friedmann equations to describe late-time acceleration [7]. Observational evidence for the accelerated expansion of the universe largely comes from distance-redshift measurements of Type Ia supernovae serving as "standard candles." These supernovae offer a reliable method of charting the expansion history of the universe. Observations of Type Ia supernovae are critical to establishing the accelerated expansion of the universe. These findings are further reinforced by the accurate cosmological parameters being supplied by the observational data obtained by the Planck collaboration. Hydrodynamical simulation studies, such as those from the EAGLE project, offer insights into how dark energy may enter into the process of galaxy formation and cosmic structure evolution. Dark energy would be quite unimportant at early times during galaxy formation but later on play a significant role in suppressing star formation. Sheykhi tried another way in 2020, in which Tsallis generalized entropy is an alternative approach to explaining the accelerating expansion of the universe without including the dark energy. This model hence modifies both Newton's law of gravitation and the Friedmann equations to explain late-time acceleration. Observational evidence for the accelerated expansion of the universe comes largely from distance-redshift measurements of Type Ia supernovae, which act as "standard candles"[8]. These supernovae thereby provide a reliable

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means to map the expansion history of the universe.

6. Summary

In particular, the paper presents the dynamics of dark energy and its influence on galaxy dynamics and cosmic expansion. The research uses hydrodynamical simulations to illustrate how dark energy normally accounts for a negligible factor in the process of galaxy formation. Instead, what really actively inhibits star formation in large galaxies is the active galactic nucleus feedback created by black holes. The study also considers an alternative model, resting on Tsallis entropy, and provides another interpretation of the late-time cosmic acceleration and flat galactic rotation curves without invoking dark matter. A review of some observational data on Type Ia supernovae and CMB confirms that the expansion of the Universe is accelerating, but at the same time offers some evidence that early dark energy might have implications on plasma cooling after the Big Bang. Accordingly, the paper concludes that new cosmic evolution models need to focus on gravitational law modifications and thermodynamics adjustment toward giving proper considerations to the huge size of cosmic structures.

Acknowledgements
All the authors contributed equally, and their names were listed in alphabetical order.

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