GALAXY CLUSTERS AS PROBES OF DARK ENERGY

(Rinshiya TK, Aparnasree Murali, Fathima Thesni KV,Fasmina P) *Sana Backer **

* Students,** Assistant Professor, Ansar Women's College Perumpilavu

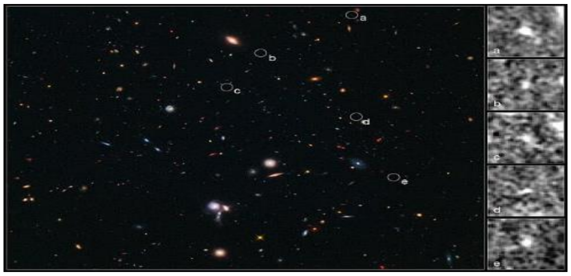
ABSTRACT

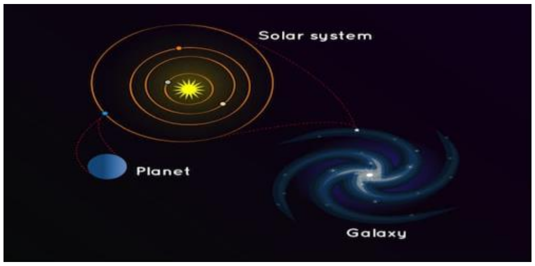
Galaxy clusters serve as valuable probes of dark energy due to their sensitivity to the large-scale structure of the universe. The distribution and behaviour of galaxy clusters can provide insights into the expansion rate of the universe, a key aspect influenced by dark energy. Their large masses make them sensitive indicators of the underlying cosmological conditions. The distribution and growth of clusters over cosmic time provide valuable constraints on the nature of dark energy. This article explores the crucial role played by galaxy clusters in serving as probes of dark energy from the topics such as abundance, evolution, mass measurements, and Baryon Acoustic Oscillations (BAO). Through this topic we understand the dark energy and its role in the dynamics of the universe of galaxy clusters.

INTRODUCTION

A galaxy encompasses an immense assemblage of gas, dust, and countless stars along with their solar systems, all interconnected by the force of gravity. We lived the plant called Earth. And it is a part of our solar system. So where is our solar system situate? It is a small part in a Milky way galaxy. The Milky way galaxy is a barred spiral shaped with billions of stars, and there are elliptical, irregular, and other types of galaxies in the universe. Galaxies can contain billions or even trillions of stars, along with planets, nebulae, and other celestial objects. They are the fundamental building blocks of the large-scale structure of the universe.

Galaxy clusters are massive structures in the universe that are bound together by their own gravitational force. These clusters are composed of hundreds or even thousands of galaxies, along with a significant amount of hot plasma and dark matter that cannot be seen. The Perseus Cluster, which is one of the brightest





This picture is taken from https://en.m.wikipedia.org/wiki/File:BoRG-58.jpg

This picture is taken from https://spaceplace.nasa.gov/galaxy/en/

sources of X-rays in the sky, is an excellent example of a galaxy cluster that contains over a thousand

galaxies. These clusters are also home to some of the largest galaxies in the universe, and studying them provides valuable insights into the structure of the universe on a grand scale.

The enigmatic force known as dark energy is the prevailing source of energy in the vast expanse of the cosmos. It propels the universe's expansion, which is not only ongoing but also accelerating, yet its true essence remains shrouded in mystery. Physicists have put forth the concept of dark energy as a hypothetical form of energy, aiming to elucidate the reasons behind this accelerated expansion. Dark energy is believed to constitute a significant portion, approximately 68% to 72%, of the universe's overall energy and matter, thus exerting a profound influence over both dark matter and ordinary matter.

Dark energy is a theoretical form of energy that is believed to permeate all of space and is thought to be responsible for the observed accelerated expansion of the universe. It acts as a kind of negative pressure, counteracting the attractive force of gravity and causing the expansion of the universe to accelerate rather than slow down. The nature of dark energy is still not well understood, and it's one of the most significant mysteries in modern astrophysics and cosmology

GALAXY CLUSTER ABUNDANCE AND EVOLUTION

Galaxy clusters are the central hubs of the cosmic drama that unfolds across the vastness of space and time. Their abundance and evolution narrate a captivating story of the universe's growth and transformation. These colossal structures, made up of galaxies held together by the invisible threads of dark matter, act as time capsules, preserving the imprints of cosmic history. As we gaze into the vast expanse of the universe, the arrangement and prevalence of galaxy clusters become apparent, acting as celestial markers that lead us on a journey through the various stages of cosmic development. From the initial formation of structural elements to the intricate interplay of galaxies within these immense cosmic cities, each cluster provides valuable insights into the cosmic mechanisms that have influenced the formation and evolution of our universe.

As time passes, galaxy clusters embark on a constantly changing journey through the cosmos. Gravity, the master artist of the universe, brings matter together, creating clusters of galaxies in different shapes and sizes. The evolution of these clusters is a cosmic performance, a dance that is not only influenced by the gravitational forces at work but also by the universe's expansion. During the initial stages of the universe, the emergence of concentrated areas led to the development of clusters, which expanded through the combination of smaller entities and the accumulation of nearby material. This intricate interaction between cosmic forces plays a pivotal role in shaping the vast structure that we currently perceive. With the aid of contemporary telescopes and sophisticated simulations, we are able to witness this transformative process, capturing glimpses of clusters at various phases of formation and advancement. The abundance of galaxy clusters acts as a census for the universe, revealing the cosmological parameters that control its expansion. Astronomers can use the diverse range of clusters, from large galaxy clusters to small groups, to create a detailed picture of the cosmic environment.

The cosmic performance is orchestrated by an enigmatic choreographer known as dark energy, who operates from the shadows. This elusive force is believed to be responsible for the universe's accelerated expansion, and its nature poses a challenge to our comprehension of fundamental physics. The presence of dark energy, which has been inferred from observations of remote supernovae and the cosmos' large-scale structure, adds a fascinating dimension to the cosmic story. The abundance of galaxy clusters, meticulously observed through advanced telescopes and simulations, becomes a canvas upon which the fingerprints of dark energy are imprinted. Clusters, like cosmic beacons, offer insights into the cosmic tug-of-war between the attractive force of gravity and the repulsive nature of dark energy. The spatial distribution of clusters serves as a compass guiding cosmologists through the vastness of cosmic expansion.

GALAXY CLUSTER MASS MEASUREMENTS

Cluster mass measurement is crucial for understanding the dynamics, composition, and evolution of galaxy clusters, as well as for making cosmological inferences. Various observational techniques such as, x-rays, weak gravitational lensing, and the Sunyaev-Zel'dovich (sz) effect, insights into the gravitational effect of dark energy on large- scale structure of universe.

X-ray observations:

The x-ray observations are used to study the intra cluster medium (ICM) within galaxy clusters. The temperature and density of the hot gas can be estimated by astronomers through the examination of X-ray emissions. After assuming hydrostatic equilibrium, this information can be employed to deduce the gravitational mass of the cluster. The differences in x-ray and other mass calculations can suggest non-thermal activities or deviations from balance, giving hints about the interaction between gravity and dark energy. X-ray observations complement measurements of the Sunyaev-Zel'dovich (SZ) effect, which is another important probe of the ICM. The SZ effect occurs when CMB photons scatter off the hot electrons in the ICM. Combining X-ray and SZ observations provides a comprehensive view of the cluster's thermal properties.

Weak gravitational lensing

Weak gravitational lensing is a powerful observational technique in astrophysics and cosmology that allows astronomers to study the subtle distortions in the shapes of background galaxies caused by the gravitational influence of foreground mass concentrations, such as galaxy clusters or dark matter. And it is based on the fundamental principle of general relativity, where the presence of mass bends the path of light as it travels through space. In the weak lensing regime, the gravitational effects are small, causing mild distortions in the shapes of distant galaxies rather than producing clearly separated multiple images. Weak lensing is particularly valuable for probing the properties of dark energy. The cosmic shear field is influenced by the cosmic expansion history and the growth of large-scale structures. Observations of weak lensing provide insights into the impact of dark energy on these cosmological processes.

Sunyaev -zel'dovich (sz) effect

The Sunyaev-Zel'dovich (SZ) effect is a phenomenon in astrophysics that occurs when cosmic microwave background (CMB) photons pass through hot, ionized gas, often found in the intracluster medium (ICM) of galaxy clusters. Named after Russian astrophysicists Rashid Sunyaev and Yakov Zel'dovich, who first predicted the effect in 1970, the SZ effect provides a powerful tool for studying the properties of galaxy clusters and the large-scale structure of the universe. The SZ effect is a powerful probe of the properties of the hot gas in galaxy clusters. By measuring the distortion in the CMB spectrum, astronomers can infer the pressure and density of the ICM, providing insights into the cluster's astrophysical and thermodynamic properties. Unlike distance-dependent probes such as galaxy redshifts, the SZ effect is nearly independent of the redshift of the galaxy cluster. This makes it a valuable tool for studying distant clusters and for conducting large-scale surveys to map the distribution of galaxy clusters in the universe. The SZ effect is influenced by the growth of cosmic structures, including the formation and evolution of galaxy clusters. Dark energy, which drives the accelerated expansion of the universe, impacts the growth rate of large-scale structures. The observation of SZ-selected clusters at different redshifts allows astronomers to probe this cosmic growth, offering indirect insights into the nature of dark energy.

BARYON ACOUSTIC OSCILLATIONS (BAO) IN GALAXY CLUSTERS

Baryon Acoustic Oscillations (BAO) represent a distinctive and influential feature in the large-scale structure of the universe. Originating from primordial density fluctuations in the early universe, BAO have left a lasting imprint on the distribution of matter, including baryons (normal matter) and dark matter. While often studied in the context of the cosmic microwave background (CMB) and galaxy surveys, their presence in galaxy clusters adds an intriguing layer to our understanding of the cosmos. Baryon Acoustic Oscillations can be traced back to the early stages of the universe, particularly during the period of cosmic inflation. During this phase, minuscule quantum fluctuations in matter density were magnified to cosmic proportions due to the rapid expansion, resulting in the formation of a distinct scale called the sound horizon. As time progressed, baryons and dark matter underwent oscillations around these regions of higher density, leaving behind a preferred length scale imprinted on the overall structure of the universe. The characteristic scale of BAO, often referred to as the "BAO scale," is approximately 500 million light-years. This scale is discernible in the spatial distribution of matter, creating a preferred separation between over-dense and under-dense regions. The imprint of BAO manifests as a subtle periodicity in the distribution of galaxies and other cosmic structures.

BAO in galaxy clusters serve as valuable cosmological probes. The observed BAO scale in the clustering of galaxy clusters provides a standard ruler, offering a way to measure cosmic distances. This, in turn, contributes to constraining fundamental cosmological parameters, such as the rate of cosmic expansion and the density of matter in the universe. The peculiar velocities of galaxy clusters, caused by the gravitational pull of surrounding structures, introduce redshift distortions in observed BAO signals. By carefully accounting for these distortions, astronomers gain additional information about the growth of cosmic structures, enhancing the precision of cosmological measurements. The study of BAO in galaxy clusters contributes to understanding the cosmic expansion history. The measured BAO scale at different redshifts helps constrain the evolution of the universe and provides insights into the nature of dark energy, which influences the expansion rate. BAO measurements are often combined with other cosmological probes, such as supernovae and cosmic microwave background (CMB) observations, to enhance the precision of dark energy constraints.

CONCLUSION

Galaxy clusters as probes of dark energy through analyses of abundance, evolution, mass measurements, and the Baryon Acoustic Oscillations (BAO) has significantly deepened our understanding of the cosmic landscape. The abundance and evolution of galaxy clusters provide crucial benchmarks for discerning the underlying cosmological framework, shedding light on the expansive role of dark energy in shaping large-scale structures. Accurate mass measurements of clusters offer a lens into the intricate interplay between dark matter and dark energy, refining our grasp of their respective contributions. Baryon Acoustic oscillations providing additional constraints on the expansion history in the universe and the nature of dark energy. In summary, galaxy clusters, with their intricate details encoded in abundance, evolution, mass measurements, and Baryon Acoustic Oscillations, stand as indispensable instruments in advancing our exploration of dark energy, contributing valuable insights to the cosmological understanding to new heights.

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