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# Exploring the Nature of Dark Matter and Dark Energy

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**A B S T R A C T**

Only 5% percent of the universe is made of atoms. Still, dark matter and dark energy are invisible 95 percent of the universe is made up of dark matter, and dark energy dark energy has a property of expansion. the existence of these elements is largely unknown. The rotation of galaxies is due to dark energy. Various types of cosmological phenomena are stated which reflect the presence of dark matter and dark energy. Dark matter is not baryonic particles i.e. it is not made up of neutrons or protons. The presence of dark matter can be seen in the presence of microwave background radiation. The experiments of hadron colliders are stated which help us find dark matter presence on earth.

Keywords: Dark Matter, Dark Energy, Cosmology, Astronomy, Physics, Star, Galaxy.

## Introduction

It is evident through recent experiments that only 5% of the universe is made up of atoms and molecules that we are familiar with. Which is the smallest indivisible particle. Both dark matter and dark energy are invisible substances making up 95% of the universe. Dark matter holds the galaxies together by 25%. Dark energy on the other hand has a property of expansion of space and is known for its antigravity nature. There is little evidence about the existence of these substances but their true nature is largely unknown. The evidence about both dark matter and dark energy is that galaxies keep rotating and it does with velocities such as there is more mass than what we can observe which suggests the presence of dark matter. The light that we receive from distant galaxies is bent known as a lensing effect which refers to mass that cannot be seen and leads us to dark matter. There is cosmic microwave background radiation temperature with constant fluctuation leads us to the influence of dark matter on the early universe. the gravitational effect of a cluster of galaxies on their member galaxies exceeds the pull expected from visible matter alone. This indicates the presence of dark matter. (Cottrell 2019)

## Research Methodology


## Literature Review

***Observational Evidence***

Dark matter is the strongest gravitation force in the universe yet its composition is unknown. The constraints and evidence on dark matter's nature are derived from astronomical observations. With all the knowledge we have dark matter cannot be baryonic which means that it consists of protons and neutrons just like any other matter in its composition in the observational universe. Dark matter cannot possess any of these qualities. it does not interact with light and can not be observed through electromagnetic radiation. There is evidence from the study of existing cosmic microwave background and cosmic structure which would not be the same if dark matter was baryonic. Cosmic microwave radiation is the one aspect that supports the Big Bang theory and it also refers to heat left over from the Big Bang which is now observed as microwave radiation so it's very clear because of mapping of existential data cannot change. Just because we have the total amount of baryons we know how much portion of the data of the universe is missing. And the missing part is the amount of dark matter. Which is immensely huge. Dark matter constitutes 23% of the universe and is essential for the universe to sustain. Without it, we will not have the present. The search for Solar weakly interacting massive particle is similar to dark matter we can not see it or feel it since its interactivity with us and the visible universe is very low. but still, WIMP cannot be directly proven or completely related to dark matter. Even after all the experiments with colliders. there is something called cold dark matter theory which states that dark matter was a very slow-moving particle at the time when galaxies were formed. The cold dark matter model is simulated and the results of it indicate that dark matter has cupsy density profiles which means steeply rising density of dark matter towards the centers of halos.

**Figure 1 The huge halo around giant elliptical galaxy Messier 87**

A halo is a particular region in space dominated by dark matter that binds together galaxies and clusters of galaxies together. These halos which consist of dark matter are ellipsoidal just like any individual galaxy and their planets orbits. The density of dark matter inside a halo increases as we move towards the center of the halo the region near the center is known to have a cuspy density profile. (Peter 2012) figure 1 shows the image of The huge halo around the giant elliptical galaxy Messier 87.

***Galactic rotation curves***

There is a presence of dark matter on an astronomical scale from galaxy structures to individual galaxies. Galaxy cluster masses are ten times higher than the expected luminosity alone. The mass within the galaxies increases linearly with radius suggesting massive dark halos around galaxies. Other proposed constituents of dark matter, such as black holes or low-mass stars have faced difficulties, reinforcing the dark matter hypothesis. The central black hole of a galaxy like the Milky Way's cannot account for the observed rotation curves, implying additional mass beyond the visible matter. virial theorem relates the average kinetic energy of particles in a system to the average potential energy under certain conditions. Used to estimate the masses of galaxy clusters by comparing observed velocity dispersion to gravitational binding energy. implies that visible matter alone cannot account for the observed dynamics suggesting the presence of dark matter. Dark matter is an unseen substance hypnotized for gravitational effects that cannot be explained by visible matter alone.it is proposed to explain the flat rotation curves of galaxies where the orbital velocity of stars does decrease with distance as expected by Keplerian dynamics matter is thought to form massive halos around galaxies contributing to a higher dynamical mass compared to luminous mass. The presence of dark matter is inferred from its gravitational influences, as it does not emit, absorb, or reflect light. (Sivaram n.d.)

***Gravitational Lensing***

Einsteins' general theory of relativity suggests gravity is not a force but a manifestation of a curved space-time continuum. Gravitational lensing occurs when light bends around a massive object creating phenomena like Einstein's rings. Massive objects like galaxy clusters wrap the fabric of space-time, bending the path of light passing nearby

This bending of light creates magnified or distorted images of background objects such as galaxies or stars. The lensed images can appear stretched into arcs or even form multiple images around the lensing mass. The surface brightness of the source remains constant, but the distortion increases the surface area, leading to an apparent brightening. Light bends around massive objects due to the curvature of space-time as predicted by Einstein's General Theory of Relativity The gravitational field of a mass such as a galaxy or black hole acts as a lens, distorting the path of light that passes close to it. The degree of bending depends on the mass of the lensing object and the proximity of the light path (Raghav 2019)

***Cosmic microwave background (CMB) anisotropies***

The Cosmic Microwave Background (CMB) was discovered by Arno Penzias and Robert Wilson in 1964 at Bell Laboratories in New Jersey Their discovery was initially an unexpected finding while using a well-calibrated horn antenna Penzias and Wilson were awarded the Nobel Prize for Physics in 1978 for this discovery.

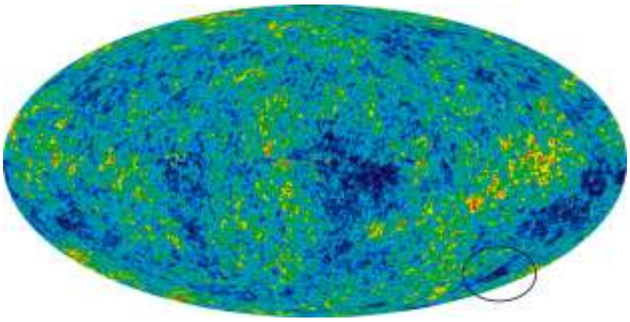

**Figure 2 Cosmic Microwave Background Radiation**

Penzias and Wilson were investigating sources of radio noise and potential systematic effects of noise in satellite communication systems and suddenly they discovered microwave background radiation. COBE's discovery of CMB fluctuations confirmed the predictions of inflationary models and marked the beginning of a new era in cosmology Subsequent experiments like MAXIMA confirmed the flatness of the Universe and supported inflation as the mechanism for structure formation Observations of CMB anisotropies have provided insights into the early Universe, primordial nucleosynthesis, neutrino masses, and the age of the oldest stars. (Smoot 2007)

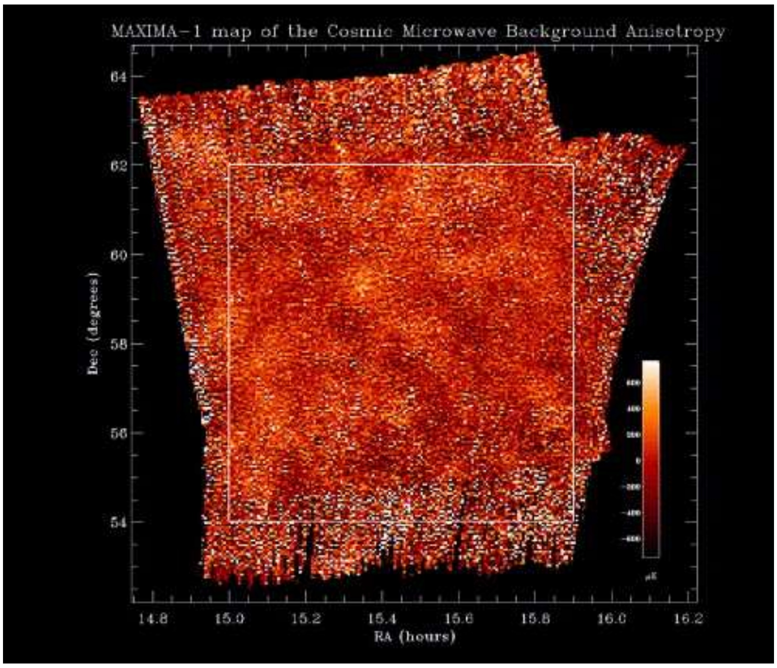


**Figure 3 MAXIMA**

***<u>Dark Matter</u>***

B. Particle Physics Candidates

The Standard Model of Particle Physics is a culmination of gauge theories, including quantum electrodynamics and the electroweak theory. Quantum chromodynamics, the theory of strong nuclear interactions, is also a fundamental part of the model. The discovery of the Higgs particle in 2012 at CERN is a significant milestone. The Standard Model is a robust framework that has been validated by numerous experiments over the past forty years. Quantum electrodynamics (QED) is a well-established theory within the Standard Model. (Kibble 2014)

***<u>Weakly Interacting Massive Particles (WIMPs)</u>***

Most of the universe is not detected by instruments, with only 10% of its mass being luminous Solar neutrinos can be detected through a change in resistance, hinting a processes within the sun.

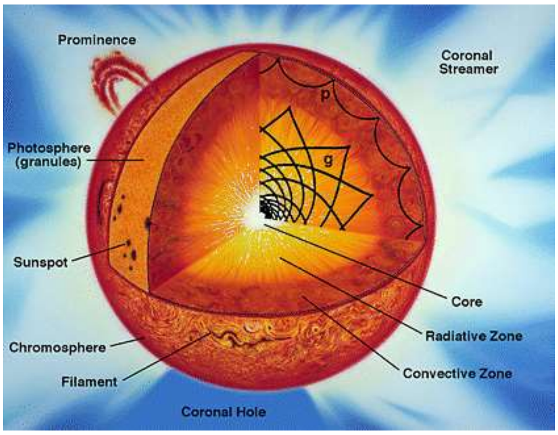


**Figure 4 Solar Neutrino**

The deficit of solar neutrinos might be explained by particles called cosmos affecting the sun's core. Solar neutrinos are detected through a specific reaction that changes when neutrinos interact with matter (Saleh Ahmad Qutaishat Anon n.d. Petra University)

***Axions***

Axions are theoretically motivated and could play a role in astrophysics and as a dark matter candidate. Experimental techniques are being developed to detect axions A statistical combination of results from different astrophysical observations favors the existence of axions(Irastorza 2022)

***Massive Compact Halo Objects (MACHOs)***

The paper discusses the search for massive compact halo objects (MACHOs) using a (semi) robotic telescope. Authors involved in the study include Craig Alcock, T. S. Axelrod, Kem H. Cook, and Hye-Sook Park. The publication date of the article is January 1992. The paper has been cited 13 times and has 95 reads, indicating its influence and reach in the research community.

***Large Hadron Collider (LHC) experiments***

The LHC project has been approved and the conceptual design has been refined. The experimental program includes ATLAS, CMS, ALICE, and LHC-B detectors.

**Figure 5 Large Hadron Collider**

Construction and testing of the CMS solenoid is underway. The injection of protons from the CERN SPS is planned The LHC is expected to reach useful luminosities of around 10^33 cm^2 s^-1. (Potter 1996)

***Dark matter detection experiments***

Two-phase emission detectors are the leading technology for cold dark matter experiments. Emission detectors can detect WIMPs with up to 10 tons of targets. Emission detectors can also detect rare events such as neutrino scattering and double-beta decay. Emission detectors have unique detection properties for background suppression and particle identification. Emission detectors can use massive isotopically enriched targets. (Bolozdynya 2015)

***Dark Energy***

***Observational Evidence***

Baryon acoustic oscillations

Baryon Acoustic Oscillations (BAO) are frozen relics from the pre-decoupling universe. BAO provides distance estimates rooted in well-understood, linear physics.

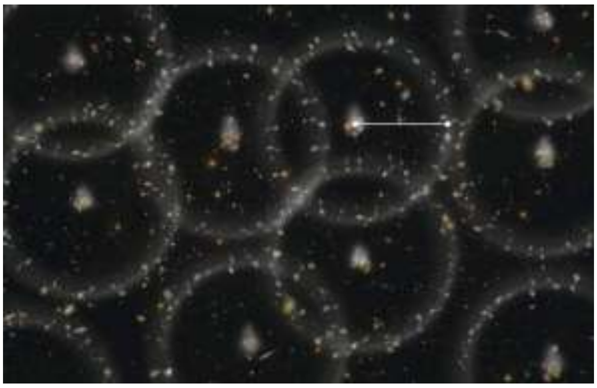

**Figure 6 Baryon Acoustic Oscillations**

The review covers theoretical, statistical, and observational aspects of BAO cosmology. It includes a map of future BAO surveys, both spectroscopic and photometric.(Bassett and Hlozek 2009)

***Cosmic Microwave Background (CMB) studies***

The discovery and analysis of Cosmic Microwave Background (CMB) confirms the Big Bang model. CMB contains information about the early stages of the Universe, possibly inflation. CMB fluctuations come from quantum fluctuations during rapid expansion. CMB observations support the growth of initial fluctuations into large-scale structures.(Smoot 2007)

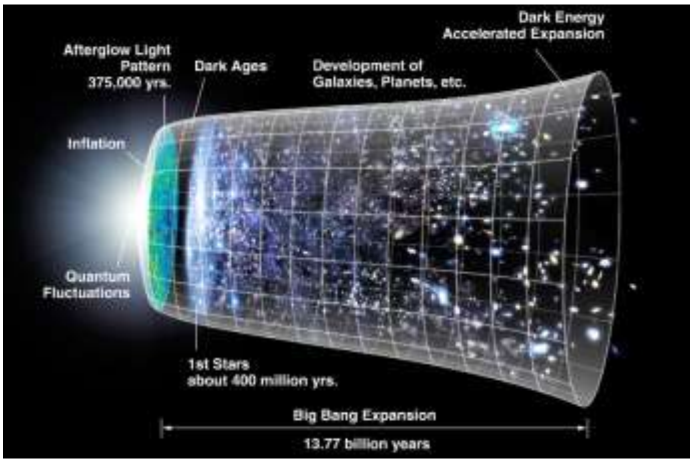


**Figure 7 Cosmological Constant**

All constant as a function of the system frame of the universe, Implementation of a frame transform to resolve the measure concerning the internal measurement frame of the universe. Resolving the "biggest blunder" in fundamental physics. Derived value of the cosmological constant using the 2018 results for the Hubble constant and dark energy. The difference between the derived value and the value using the CMB as a source measure falls within the bounds of measurement uncertainty. (Geiger 2023).

***Quintessence***

Dark energy may be provided by a light field called quintessence. The underlying particle theory responsible for quintessence is unknown. The theory may have connections to supersymmetry, supergravity, or string theory. Quintessence can be embedded in theories with scalar fields (moduli). The interaction of moduli fields with

***Modified gravity theories***

The paper discusses the dependence of components on coordinates. The lowest mass scale is determined by generic real functions. The junction conditions only contain second derivatives concerning x.(Sbisà 2014)

***Current Experimental and Observational Efforts***

***Dark Energy Survey (DES)***

First public data release of the Dark Energy Survey (DES DR1). Data includes reduced single-epoch images, co-added images, and catalogs. Covers ~5000 deg2 of the southern Galactic cap in five photometric bands. Photometric precision of <1% in all bands. Astrometric precision of 151 mas Nearly 400 million distinct astronomical objects detected. Largest photometric data set to date at achieved depth and precision (Abbott et al. 2018)

***The Dark Energy Spectroscopic Instrument (DESI)***

DESI measures the expansion history of the Universe using Baryon Acoustic Oscillation. It will measure spectra of 35 million galaxies and quasars.

**Figure 8 The Dark Energy Spectroscopic Instrument (DESI)**

A new prime focus corrector for the KPNO Mayall telescope will be used. 5000 fiber optic positioners will deliver light to the instrument. Spectrographs split light into three channels with distinct spectral resolutions.(Jelinsky et al. 2018)

## Conclusions

In this paper, we went through several natural astronomical phenomena that point us toward the presence of dark matter and dark energy. We are getting closer to finding the true nature of dark matter and dark energy. This research paper will help reinforce the theoretical background of dark matter and dark energy. The limitation of this paper is we have not spoken about the mathematical calculations behind the theory and experiments. but still, we have compiled most of the evidence of the presence of dark matter. Further research can be done to reinforce the theoretical background of dark matter and dark energy.

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