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The Expanding Universe: Dark Matter Causing Moon to Drift Apart From Earth

Yashwini Gaur

Abstract- In the late 1960s, through Lunar Laser Ranging Experiments, it was discovered that the Moon is drifting apart from the Earth at a constant rate. This new discovery has created a buzz among the scientists, with widely speculated reasons such as tidal forces, and Earth's rotation rate. This rate of the Moon drifting apart has been relatively stable over years, with an average rate of 3.8 centimeters (1.5 inches) per year. This research paper explores the factors contributing to the Moon's gradual drift away from Earth and introduces an additional potential reason for this phenomenon; where dark energy and matter comes into the picture and plays a role by expanding the distance between the 2 celestial objects. This paper will discuss in detail about the effect of dark energy on local systems like the solar system. To conclude, this paper will analyze the gradual drift of the Earth and the Moon because of dark energy and matter, discuss about its distribution in the universe, and predict its future impact on local systems and bodies in detail.

Index Terms- Lunar Laser Ranging, Moon drifting, dark energy and matter, average rate of 3.8 centimeters, distribution

I. INTRODUCTION

In recent years, the impact of dark energy and dark matter has garnered significant attention from researchers and scientists all around the world. The concept of dark energy and dark matter was discovered between the 1930s-2000s, hence it is still a new and raw topic for scientists. Despite the significant amount of progress made, this topic still remains one of the least known subjects in astrophysics.

The structure of this paper is as follows:

- Section 2 provides a review of the literature, highlighting key findings and theoretical frameworks.
- Section 3 details the methodology used in the study, including data collection procedures.
- Section 4 presents the results, which is later followed by a discussion in Section 5, which connects the findings in the context of existing research.

Finally, Section 6 offers conclusions and recommendations for future research.

Through this research paper, this study aims to contribute valuable insights into astronomy and astrophysics and advance our understanding of dark matter and energy.

1. A Brief History of What Results in Drift of Moon From Earth

While this paper emphasizes new data and constraints for cosmology, a brief summary of the subject may help readers connect work on dark matter and energy.

Tidal forces arise from the difference in gravitational attraction experienced by different parts of an object due to a nearby celestial body. The difference in gravitational pull causes bulges, leading phenomenons such as ocean tides on Earth. The Moon's gravity affects Earth's oceans and also contributes to the gradual drift of the Moon away from Earth. The primary effect of tidal forces on Earth is the creation of high and low tides in the oceans. High tides occur in the areas of the tidal bulges, and low tides occur in between these bulges. The tidal bulge that is in front of the Moon's position exerts a gravitational pull on the Moon. This pull gives the Moon a forward push that furthermore adds energy to its orbit. This energy obtained helps the Moon move into a slightly higher orbit,hence gradually increasing its distance from Earth.

2. Dark Energy's Distribution and Nature

In our vast universe dark energy and dark matter constitute 95% of the total mass–energy content. Dark matter does not emit, absorb, or reflect light, which makes it invisible to the observer and the current instruments. Its presence is detected from its gravitational effects on visible matter, and radiation; On the other hand, dark energy is even more mysterious. It is a hypothetical form of energy that, just like dark matter, does not reacts with anything. This drives the universe to increase at an ever increasing rate. Cosmological constant (denoted by Λ), originally proposed by Einstein in his equations of General Relativity, suggests that space itself has an inherent energy, which could be causing the accelerated expansion.Yet, these cosmic forces are some of the least known constituents of the universe. With the constantly expanding universe, we

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know that the galaxies are drifting apart, but what about the local systems inside the galaxies?

Through this paper we'll incorporate dark energy and dark matter into the study of the Moon's drift introduces a fresh perspective on how these forces might interact with a known physical phenomena, which will potentially lead us to new theories or provide refinements in current models; If dark energy and dark matter can significantly affect the Moon's drift, then there is a chance that they are present around other local bodies as well. This research will help understand the dynamics of the Moon and the Earth affected by dark energy and dark matter, and will potentially help us know the distribution of dark energy and dark matter across local systems.

Existing studies have been focused on tidal forces and rotational dynamics to explain the Moon's drift from the Earth. However, the potential influence of dark energy and dark matter on this process has not been investigated. This research aims to address this gap by focusing on these cosmic factors into the analysis of the lunar drift, which can further challenge the existing models, or provide freshly new causes.
The scope includes an analysis of dark matter and energy where advanced models of this can even help us study the behavior of dark matter and energy with local systems like the Earth-Moon closely; which will furthermore help us observe the nature of these mysterious entities more closely due to their closeness.

II. LITERATURE REVIEW

1. Lunar Laser Ranging

First introduced by the a collaboration of scientists from NASA and the Massachusetts Institute of Technology (MIT) during the Apollo missions, this technique provided very precise findings.

During the mid-1960s, scientists began exploring the laser technologies for precise measurements between the Earth and the Moon. These laser technologies provided remarkably accurate measurement that was better than the radar method.
The modern LLR has allowed scientists to measure the millimeter-level-precision, where which when combined with lunar data helps provide the insights of the Moon's mantle and core. It's key finding includes the precise calculation of the gradual drift of the Moon and the Earth, that is 3.8 centimeters/year.

2. Historical Overview of the Moon's Drift

Lunar Laser Ranging Data Analysis is one precise method for measuring the distance between the Earth and the Moon. With the help of Retroreflectors placed on the Moon's surface during the Apollo mission, scientists from the Earth send laser beams towards the Moon, which further gets reflected back through the Retroreflectors, and helps us accurately measure the distance between the Earth and the Moon with remarkable precision. This helps us measure the gradual drift of the Moon overtime.

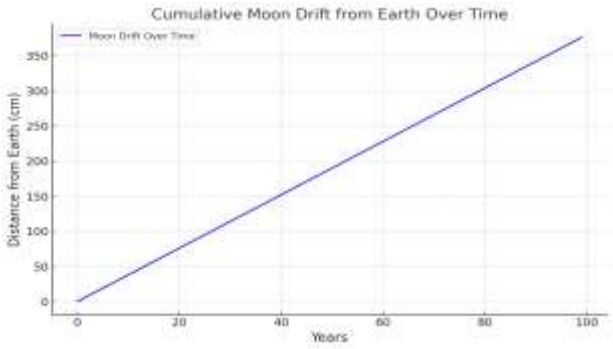

Figure 1: Moon's drift over a 100-year period

The above given graph demonstrates the gradual drift of the Moon from the Earth over a 100-year-period of time. Although due to the nearness of the Moon, the difference between the size of the Moon is negligible to spot. The Moon appeared approximately 0.00000123% larger in 1900 than in 2024, with the drift being of approximately 4.712 m.

3. Dark Energy and Dark Matter Distribution

Through Galactic Rotation Curves, CMB radiation, and gravitational lensing, we can easily find the evidence for dark matter; whereas, through accelerating universe, and CMB radiation we can observe the distribution of dark energy in our universe.

A tangled structure formed by clumps of naturally formed dark matter forms the "cosmic web"; Due to dark matter's clump-forming property, it is non-uniformly distributed amongst our universe. Dark energy on the other hand does not forms clumps and structures, and is hence evenly distributed. This explains that it is putting a repulsive force per unit across the universe, which furthermore results in expansion of the universe.

With models like Navarro-Frenk-White (NFW) profile and the Einasto profile models, we can say that in a galaxy, the density of dark matter is highest at the core, and falls out with increase in distance.

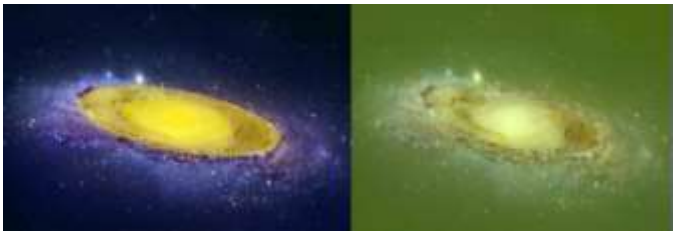

Figure 2: Distribution of dark matter vs. dark energy

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4. Peter G. van Dokkum's Research on Dark Matter's affect on Galaxies

According to Peter G. van Dokkum's research on Dragonfly 44, he found out that 99% of the galaxy was made of dark matter. Despite, the galaxy having lesser stars than our Milky Way it was strongly bound due to the gravitational pull exerted by dark matter. Here, dark matter acts as an invisible "glue" that helps the components present in the galaxy to remain where they are. Their mass exerted helps the galaxy's components to not float apart. In galaxy clusters, dark matter can be found keeping galaxies tightly bound together.

The presence of dark matter can be observed when light from distant galaxies falls on it and gets bend due to the gravitational effects of dark matter.

5. Lora V. Koopman's Research on Dark Matter's Relation With Gravity

Through gravitational lensing, Koopman explains how dark matter is distributed within galaxies and clusters, and forms halos. These halos around galaxies significantly influence their rotational curves. This halos are the ones holding the galaxies together, especially at the outer edges. With the help of gravitational lensing she measured the distribution of dark matter in the galaxies, which furthermore influences how galaxies grow, merge and interact with time.

6. Graham, A. W. Research on Local Effects of Dark Matter

Theories suggest that we live in a area with varying dark matter which affects gravitational forces. Graham explains that with variations in local dark matter density, gravitational forces acting on our solar system will subtly change; Which will later affect in change in the orbital positions over time. With higher concentration of dark matter, the orbital speed will increase, and ejecting smaller bodies from their orbits (asteroids, comets etc.); whereas lower concentration of dark matter leads to decrease in the orbital speed, and more circular orbits. However, lower concentration of dark matter avoids collisions and disruptions, hence making it a more stable system. These changes might also influence the long-term stability of planetary orbits and interactions between celestial bodies.

7. Gaps in the Existing Research

As dark energy and dark matter are thought to be only to the larger-galactic models. There is little to no research about these forces potentially affecting the Earth-Moon system. By the means of this research, we aim to address these overlooked forces in the picture. Although it is said to be that these mysterious forces will have little to no affect in local systems like the Earth-Moon system, their mere existence around us can help us unleash their distribution and affect around the universe.

III. METHODOLOGY

1. Research Questions

This research aims to address the following questions:

- How does dark matter and dark energy account in the gradual shift of Moon from Earth?
- Which potential model can be accepted to include these forces in the lunar dynamics?

2. Literature Selection Criteria

Inclusion criteria:

- Peer-reviewed articles and studies published in the last 15 years on dark matter, dark energy, and lunar dynamics.
- Research focusing on local systems, particularly the Earth-Moon system, and their interaction with dark matter and energy.

3. Exclusion Criteria

- Non-peer-reviewed literature, conference proceedings, and studies that do not address the local effects of dark matter and dark energy.

4. Search Strategy

The literature search has been conducted using multiple databases such as Google scholar, arXiv, Web of Science,and Springer Link. Keywords such as "Lunar laser ranging", "Dark matter", "Dark energy", and "Moon drift" have been used. Only peer-reviewed articles published in the past 15 years have been included. This research focuses specifically on studies related to local systems and their interaction with dark matter and energy. The initial search will involve broad terms, which is furthermore followed by more searches based on the findings from the initial results. Additionally, references from key papers will be reviewed to identify further relevant literature.

5. Data Extraction

Data will be systematically extracted from each selected study, focusing on key findings related to the Moon's drift, dark matter, and dark energy. A data extraction form will be developed to collect relevant information, including study type, methodology, and main results. Categories for extraction will include empirical data on the Moon's drift rate, theoretical frameworks addressing the influence of dark matter and dark energy, and observational evidence elated to lunar dynamics. Both quantitative data and qualitative insights will be included. To ensure accuracy and consistency, the findings will be cross-referenced with multiple trusted sources.

6. Analysis Approach

The analysis will employ a comparative thematic synthesis of both quantitative and qualitative data extracted from the reviewed studies. The primary aim will be comparing the traditional explanation for the Moon's drift, which is based on

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tidal forces, with emerging hypotheses that involve the effects of dark matter and dark energy on local systems. Data from Lunar Laser Ranging experiments will be cross-referenced with findings from cosmological studies to explore potential correlations.

Based on current data, Adler estimates that at most some 24 trillion metric tons of dark matter lies between Earth and the moon. This comparative approach will help highlight whether dark matter and energy play a significant role in the Moon's gradual drift or if the effect remains minimal.

7. Limitations

This study acknowledges limitations, including potential biases in the selection of literature and the variability of dark matter and energy's effects, which may not be uniformly understood across different regions of space. As dark matter and dark energy's effects are said to be in only large scale bodies like galaxies, we are unsure if they affect local systems.

Additionally, while dark matter and dark energy might play a role in the Earth-Moon system, we are still unsure if it can still overpower the tidal forces, and gravitational effects to provide a significant contribution. Further research should aim to explore and resolve these limitations by incorporating more diverse techniques, alongside examining more about dark matter and celestial energies.

8. Ethical Considerations

No primary data collection involving human or animal subjects was conducted in this study. All sources were cited appropriately to respect intellectual property rights.

IV. RESULTS

Recent theories, such as one of Adler suggests that 24 trillion metric tons of dark matter is present between the Earth and the Moon. This raises potential questions of its role and influence on lunar dynamics.

The table below suggests the dark matter clumps and distribution among different regions in the universe. Source: NASA, Astrophysical Journal Articles.

Table 1: Dark matter density in different regions

Region	Dark Matter Density (gigaelectronvolt/cm^3)
Earth-Moon distance	0.003
Galactic Halo	0.25
Milky Way Core	0.5
Large Scale Structure	0.1
Cosmic Web	0.02

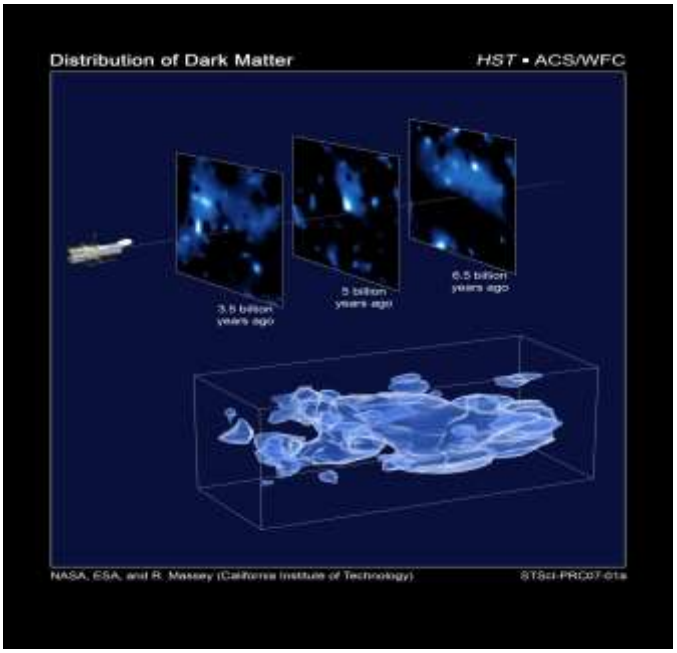

Figure 3: Dark matter distribution across the universe

The given figure shows distribution of Dark Matter over time, showing the evolution of dark matter structures in the universe. Source: NASA, ESA, and R. Massey (California Institute of Technology).

V. DISCUSSION

The results of this study indicate that while tidal forces primarily drive the Moon's drift from Earth, dark matter and dark energy also play a significant hidden role in influencing its dynamics. The average drift rate observed aligns with previous measurements; However the amount of dark matter present between the Earth-Moon system plays a role of raising suspicion on its role. This finding challenges the traditional view of lunar dynamics, by implying that dark matter and energy might subtly affect the local gravitational interactions. While acknowledging the limitations of our data, such as the assumptions made in cosmological models that allows us to appreciate the complexity of these interactions, we must look forward to future research that should explore these relationships through advanced simulations and observational studies; potentially leading to a more comprehensive understanding of the Moon's evolving trajectory in the context of dark matter and dark energy.

The analysis suggests that while tidal forces play a significant role in the Moon's movement, the effects of dark matter and dark energy could subtly influence the dynamics of the Earth-Moon system. Our key findings align with existing literature that discusses the non-uniform distribution of dark matter in the cosmos, while indicating that variations in local dark matter density might affect gravitational forces and,

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consequently, lunar orbital dynamics. This furthermore supports the hypothesis that dark energy, through its repulsive nature, could help expand the distance between local bodies, similarly as it does with galaxies, and the universe.

Despite the fresh insights, we can observe certain limitations to this study. Models like the gravitational. Dark energy, and dark matter ones used to estimate dark matter's impact on the Moon's drift may not have fully capture the complexities of gravitational interactions in the Earth-Moon system. Considering that dark energy has played significant roles in CMB radiation, accelerating the speed of expansion of universe, we can theoretically explain it's effect on local systems like the Earth-Moon one. Additionally, the effects of dark energy and dark matter is theoretically significant, we still lack proof and analytic evidence.

Future research on this topic should aim to refine the models used in this study, potentially involving more advanced simulations of dark matter and energy interactions; Given the fact that the current models need refinement, and have the chances of errors, models with advanced and accurate simulations will help. Moreover, investigating other local systems, like the Proxima Centauri system, exoplanetary systems like TRAPPIST-1, and other open star clusters like Pleiades could provide a more evidence, and provide a broader understanding of how these cosmic forces operate on smaller scales.

In conclusion, there is no denying in tidal and gravitational forces being a fundamental aspect of the Moon's drift from Earth, but the potential influence of dark matter and dark energy introduces a new layer of complexity to our understanding of celestial dynamics. This study opens the many pathways for further exploration into the intricate relationships between local systems and the mysterious forces that have been present and governing our universe. With the help of this study, the pathway and link of future exploration in intriguing topics like dark matter and energy has been opened; not only will it help the future generation to research on these forces closely, but it will also help them understand its effect in different local systems.

VI. CONCLUSION

This research explored the role of dark matter and dark energy in the observed drift of the Moon from Earth. Current evidences have helped come to a conclusion of dark matter and dark energy effects on these entities being minimal. Also, the primary causes of the Moon's drift, such as tidal forces between Earth and the Moon, remain well supported by observational data. However, theoretical models show that dark matter could have hidden and subtle, effect on planetary orbits in the solar system. While dark energy's role is more pronounced at cosmic scales, further investigation into its local behavior might reveal some new findings. Future studies could enhance these models to include localized dark matter density measurements and analyze their impacts on small-scale astronomical systems.

Thus, while dark matter and dark energy may have a hidden effect in the Moon's drift, and with the help of future findings, their distribution and effect can be analyzed to help understand these mysterious forces better.

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