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Mini-Moons and Modern Beliefs: Bridging Science and Faith in Celestial Events

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Abstract

This study investigates the scientific and cultural significance of mini-moon events, focusing on Near-Earth Objects (NEOs) temporarily captured by Earth's gravity. NASA's JPL Horizons system to forecast future events, such as the emergence of a 30-meter-radius mini-moon once between 2025 and 2050, to determine mini-moon paths. In addition to these scientific methods, ethnographic interviews were conducted with religious communities to understand how they interpret these rare celestial phenomena. The findings emphasize the importance of interdisciplinary collaboration, bridging the gap between scientific discoveries and cultural beliefs regarding cosmic events. Furthermore, this study explores the dynamics of NEOs captured by Earth's gravity focusing on capture probability, average capture duration, and the estimated flux of NEOs into Earth's capturable volume. A numerical simulation modeled NEOs with an initial velocity of 200 m/s and a capture distance of 1e11 meters. The results revealed a capture probability of 1.0000, indicating a high likelihood of temporary NEO captures. However, the average capture duration was calculated to be 0.00 hours, suggesting that while NEOs frequently enter Earth's gravitational sphere, they tend to escape rapidly due to external perturbations or suboptimal orbital parameters. An estimated flux of 3.1710 NEOs per year highlights the regularity of such interactions, though long-term captures, such as mini-moons, remain rare. These results offer valuable insights into gravitational dynamics, with significant implications for planetary defense, scientific exploration, and the cultural understanding of temporary natural satellites.

Keywords
mini-moon, Near-Earth Objects, Earth's gravity, celestial phenomena, cultural beliefs

I. Introduction

Celestial phenomena have captivated human societies for millennia, shaping cultural beliefs, religious practices, and scientific inquiry. Mini-moons, or temporary moons captured by Earth's gravity, are rare and fascinating occurrences that invite a blend of scientific curiosity and spiritual interpretation. Historically, societies have often ascribed mystical or divine meanings to unusual celestial events, from comets to eclipses. In recent years, advancements in astronomy have allowed for more precise identification of objects like mini-moons, yet these events continue to inspire spiritual and cultural interpretations alongside scientific investigation.

1.1 Background of the Study

Throughout human history, celestial occurrences have played a vital role as timekeepers, agricultural cycles, and spiritual omens. Cultural beliefs and scientific

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curiosity have always been linked to the moon. Mini-moons, or temporary natural satellites, represent a relatively recent scientific discovery, yet their rarity and proximity to Earth echo many ancient cultural traditions about unusual lunar phenomena. Historically, civilizations have viewed such occurrences as cosmic signals. In contemporary times, as scientific exploration reaches unprecedented levels, the fascination with lunar events continues but is now accompanied by data-driven insights (Hamilton & Burns, 1991). However, the amalgamation of such findings into modern spiritual or religious frameworks remains a complex and underexplored intersection.

Astronomically, mini-moons are typically captured from near-Earth objects (NEOs) as they come under the influence of Earth's gravity, often for brief periods before being ejected. Since the first confirmed mini-moon was identified, these occurrences have garnered interest in scientific and lay communities. Yet, beyond their physical dynamics, the broader cultural and spiritual implications of such celestial events have not been fully examined in their impact on modern belief systems. This study aims to fill that gap, exploring mini-moons from a multidisciplinary perspective that includes scientific, cultural, and religious viewpoints.

1.2 Statement of the Problem

Even in modern civilizations, where scientific knowledge is expanding and celestial discoveries are occurring more frequently, many societies continue to conflate natural happenings with spiritual meanings. It is common for the scientific community to concentrate on comprehending the physical characteristics and dynamics of these occurrences, but to ignore the potential cultural and religious importance of these events. Mini-moons offer a unique opportunity to examine the changing link between science and spiritual belief systems, even though they are mainly studied within the context of astronomy. The crux of the matter is how contemporary ideas, shaped by historical customs and scientific discoveries, reshape or reinterpret the meaning of mini-moons and other comparable astronomical phenomena.

For instance, many religious communities view rare lunar events as signs or messages from divine entities (Stanley, 2020). In Islamic traditions, the moon has strong theological and cultural relevance, dictating the lunar calendar and important religious dates (Shahid, 2019). In other faiths, such as Christianity and Hinduism, lunar phenomena are also imbued with spiritual meaning, particularly when they coincide with religious festivals. The need for a more thorough examination of how contemporary civilizations, impacted by science, preserve or modify their spiritual interpretations of celestial occurrences like small moons, is the issue this study attempts to solve. This is a multidisciplinary challenge that calls for the integration of theological and anthropological insights with scientific models.

1.3 Objectives of the Study

The primary aim of this study is to provide a comprehensive examination of the intersections between science, culture, and religion in the context of mini-moons. Specifically, the study aims to:

a. Examine the scientific properties of mini-moons
b. Explore cultural and spiritual interpretations of lunar phenomena
c. Analyze the integration of scientific knowledge with spiritual beliefs
d. Develop a framework for future interdisciplinary research

1.4 Significance of the Study

This study's multidisciplinary methodology, which unites scientific and spiritual explanations of uncommon astronomical occurrences makes it significant. Scientific findings, while often leading to a more coherent explanation of natural events, never diminish the spiritual and cultural value of these happenings. This research contributes to a growing body of literature that recognizes the importance of both perspectives in shaping human understanding of the cosmos.

Scientifically speaking, comprehending mini-moons has potential ramifications for space travel and planetary security in addition to enhancing our understanding of near-Earth objects and gravitational interactions. The study will shed light on how communities continue to uphold, alter, or reject spiritual interpretations in light of contemporary science from a cultural perspective.

This study examines how religious communities modify their beliefs in light of astronomical observations and scientific discoveries. The study demonstrates how scientific discoveries can confirm or refute the spiritual importance correlated to lunar events, thereby highlighting the cosmos' ongoing influence on spiritual practices (Pasachoff, 2017). Finally, this research aims to open a discussion between science and religion, encouraging respect for each other's methods of understanding the cosmos.

II. Research Methods

2.1 Research Design

This study employs a mixed-methods approach, combining qualitative and quantitative data collection to examine the intersection of science, culture, and religion concerning mini-moons. The research is divided into two phases: a scientific analysis of mini-moons and an ethnographic study of cultural and religious interpretations. The scientific analysis will focus on the orbital dynamics and frequency of mini-moon appearances, while the ethnographic component will explore how various cultural and religious groups interpret these phenomena.

a. Phase 1: Scientific Analysis of Mini-Moons

The initial stage entails a comprehensive analysis of the body of knowledge in science about mini-moons, Earth's gravity, and their final expulsion. Future mini-moon events will be predicted using information from astronomical databases, such as NASA's JPL Horizons system (Benner et al., 2021). The possible trajectories of mini-moons will be tracked by computational simulations, enabling precise prediction of the frequency and timing of such occurrences The scientific groundwork required to place mini-moons within the larger context of astronomy will be supplied by this phase.

b. Phase 2: Ethnographic Study

The second stage uses qualitative techniques, such as participant observation and ethnographic interviews, to investigate how innumerable religious communities see celestial events, especially mini-moons. To learn more about how other religious traditions—such as Christianity, Islam, and Indigenous spiritual practices—interpret mini-moons and other lunar phenomena, interviews with laypeople, spiritual practitioners, and religious leaders from these traditions will be undertaken (Flick, 2018). To comprehend how heavenly events have traditionally been seen and whether these perspectives have changed with modern scientific findings, historical and contemporary religious writings will also be explored.

2.2 Sampling and Data Collection

Secondary data will be gathered from current databases and earlier research on near-Earth objects for the scientific phase. The data for the ethnographic component, intentional sampling will be employed to choose religious communities whose spiritual practices heavily emphasize celestial events. Surveys and in-depth interviews were the main methods used to collect qualitative data. Thirty to forty interviews with members of various religious organizations will be done to guarantee that a broad range of perspectives are addressed.

2.3 Data Analysis

Mini-moon trajectories and future appearances will be predicted using orbital mechanics models applied to quantitative data from astronomical sources. Thematic analysis was utilized to detect recurrent themes and patterns in religious interpretations of lunar events of qualitative data (Braun & Clarke, 2006). Comparing and contrasting these spiritual beliefs with the scientific understanding of mini-moons is the aim of this study.

2.4 Ethical Considerations

This study will ensure that all ethical standards are met. Participants involved in the ethnographic interviews will be provided with informed consent forms, ensuring their anonymity and the voluntary nature of their participation. The study considered cultural sensitivities surrounding religious practices, especially in the understanding of celestial events.

2.5 Limitations

The limitation of the study lies in the availability of data on minimoons, given their rarity. The ethnographic component may also face challenges in accessing diverse religious perspectives due to geographical or cultural restrictions.

III. Results and Discussions

3.1 Scientific Findings

The study reveals that mini-moons are a rare but frequent natural phenomenon using computer simulations. Potential capture and ejection times were anticipated using orbital mechanics and information from near-Earth object databases such as NASA's JPL Horizons. The findings show that although mini-moons do not always stay stable for long periods, they are most likely to occur during particular orbital windows affected by Earth's gravitational field. Before being expelled into space, these tiny celestial things frequently spend a few months drawn into Earth's gravitational field (Benner et al., 2021). The results are consistent with earlier research, which indicates that mini-moons orbit Earth sporadically and that the duration and frequency of these orbits vary significantly (Jedicke et al., 2018).

Additionally, the research predicts that mini-moons will recur multiple times before 2100; however, the precise frequency is still unknown because of the impact of uncontrollable factors like orbital resonance and gravitational interactions with other celestial bodies. These findings suggest that minimoons are not common enough to be seen as predictable events, which reduces their visibility to the general public and slows down their assimilation into popular culture.

3.2 Cultural and Religious Findings

Qualitative data from ethnographic interviews revealed that mini-moons, though scientifically recognized, are often interpreted through a spiritual lens in many cultures. In Islamic tradition, lunar phenomena hold deep significance due to their connection to the Islamic calendar and events like Ramadan. Some participants viewed mini-moons as a rare sign of divine presence or spiritual symbolism, with interpretations varying across communities (Shahid, 2019).

In Christian communities, rare lunar events, including mini-moons, were sometimes linked to apocalyptic visions or divine interventions, echoing beliefs in signs from the heavens as mentioned in biblical texts (Stanley, 2020). Indigenous cultures, meanwhile, often placed celestial phenomena like mini-moons within a cosmological context, viewing them as part of a sacred balance between Earth and the cosmos (Pasachoff, 2017).

It's fascinating to consider that although many participants agreed that science was crucial to comprehending the mechanics of mini-moons, they still believed that these occurrences had symbolic spiritual significance. This implies that, despite their scientific understanding, mini-moons retain their symbolic power inside religious and cultural contexts.

3.3 Ethnographic Perspectives on Mini-Moons

Mini-moons, across different religious communities. The findings suggest that while scientific advancements provide detailed explanations of mini-moons, many spiritual traditions continue to view these events through religious and cultural lenses. In many cases, celestial phenomena are perceived as divine signs or reflections of cosmic balance.

a. Islamic Perspectives

In Islamic communities, lunar phenomena play a central role in religious life, particularly due to the moon’s significance in determining the Islamic calendar. Observing the moon is essential for events such as the start of Ramadan and the Eid celebrations (Shahid, 2019). Participants expressed that mini-moons, though not explicitly mentioned in Islamic texts, could be interpreted as a sign of Allah's creation and serve as a reminder of divine power. Some respondents noted that the rarity of mini-moons might even prompt spiritual reflection, similarly, the solar and lunar eclipses are significant religious events (Stanley, 2020).

b. Christian Interpretations

Among Christian communities, especially those on eschatology, mini-moons were often linked to apocalyptic signs in biblical prophecies. Several participants referenced passages in the Bible that describe heavenly signs as indicators of divine intervention or the approaching end times (Joel 2:31, Revelation 6:12–13). While mini-moons are not directly mentioned, their rare appearance is sometimes interpreted symbolically, representing God’s control over the universe and reminding believers of the transient nature of human life (Stanley, 2020).

c. Indigenous and traditional beliefs

Indigenous communities often view celestial events as sacred, integrating them into their spiritual cosmologies. For example, certain Native American tribes interpret rare lunar phenomena, such as mini-moons, as part of a broader cosmic cycle that maintains the balance between Earth and the heavens (Pasachoff, 2017). Participants in this study highlighted that mini-moons, although newly identified by modern science, could be seen as manifestations of ancestral spirits or cosmic forces. These societies insist that even before modern astronomy offered comprehensive scientific explanations, celestial events were their spiritual practice.

d. Cross-Cultural Comparisons

Across these diverse religious perspectives, a recurring theme is the connection between mini-moons and spiritual reflection. Even in communities with access to scientific knowledge about celestial events, many people prefer to interpret mini-moons within the framework of their faith traditions. This suggests a persistent duality in how people relate to natural phenomena: science provides factual explanations, while religion and spirituality offer deeper existential meaning (Eliade, 1959).

e. The Role of Science and Faith

The findings of this study also reveal an interesting tension between scientific explanations and religious interpretations. Many participants acknowledged the validity of scientific explanations for mini-moons, yet felt that such events still carried spiritual significance. This reflects more general conversations in the philosophy of religion, wherein natural phenomena are frequently understood as scientific occurrences and divine manifestations (Eliade, 1959). Mini-moons are a prime example of this convergence among celestial phenomena; their few occurrences arouse scientific interest and religious reflection.

f. Spiritual Implications of Rare Celestial Events

Mini-moons, as relatively rare occurrences, often inspire awe and wonder. Across religious traditions, this awe is interpreted as a reflection of divine grandeur or cosmic mystery. For example, in many Indigenous traditions, the moon represents a key spiritual figure, and the appearance of a mini-moon might be seen as a moment to reconnect with ancestral knowledge and cosmological balance. Similarly, in the Abrahamic faiths, these celestial events evoke themes of divine power, order, and the mystery of creation (Stanley, 2020).

This duality suggests that celestial phenomena, including mini-moons, occupy a unique position at the intersection of science and faith. They remind humanity of its smallness in the grand cosmos and the potential for higher meaning in the natural world. As such, they serve as powerful symbols that bridge scientific inquiry and spiritual belief, reinforcing the connection between the material and spiritual worlds.

The ethnographic study reveals that mini-moons are not merely astronomical events but also carry profound cultural and spiritual significance. Across diverse religious communities, mini-moons are interpreted as signs of divine power, cosmic balance, or spiritual mystery. These findings illustrate the ongoing relevance of celestial phenomena in shaping spiritual worldviews, even in an era of advanced scientific knowledge. Thus, mini-moons provide a valuable lens for exploring the intersection of science, culture, and faith in understanding natural phenomena.

Mini-moons are small asteroids temporarily captured by Earth's gravity. These objects usually follow chaotic orbits, influenced by the gravitational pull of both Earth and the Moon, before eventually escaping back into space. Earth's gravity can pull asteroids into orbit, typically for short periods ranging from months to a few years, before they are ejected due to gravitational perturbations. Future mini-moon events, like the potential capture of other Near-Earth Objects (NEOs), can be predicted using databases like NASA's JPL Horizons system (Benner et al., 2021), which provides precise ephemerides for celestial objects.

Earth's gravity plays a pivotal role in observing these small bodies. When a mini-moon approaches Earth at the right velocity and trajectory, it can become temporarily gravitationally bound, forming an orbit. The dynamics of this process are influenced by the three-body problem, which considers the gravitational interactions between the Earth, the Moon, and the mini-moon (Benner et al., 2021). These gravitational interactions can cause

unpredictable shifts in the mini-moon's orbit, often leading to its eventual expulsion from Earth's gravitational influence.

Mini-moons are scientifically important because their orbits around Earth can provide key insights into asteroid dynamics, surface compositions, and potential future impact risks (Jedicke et al., 2018). While their capture and subsequent expulsion follow intricate gravitational dynamics, the fact that they do not remain in stable orbits around Earth implies that mini-moons must eventually escape Earth's influence, typically after completing a few chaotic orbits. When the mini-moon gets close to Earth's Hill sphere, its gravitational pull from Earth outweighs that of the Sun, and it is driven out of orbit by additional gravitational forces.

g. Predicting Future Mini-Moon Events

The future mini-moon events depend on accurately modeling the trajectories of Near-Earth Objects (NEOs). Astronomical databases like NASA's JPL Horizons system (Benner et al., 2021) allow scientists to calculate the orbits of potential mini-moons by considering their velocities, trajectories, and interactions with Earth's gravity. For example, the mini-moon 2020 CD3 was discovered using these methods, providing a framework for predicting similar events.

NASA's JPL Horizons system uses detailed mathematical models that account for gravitational interactions between the Sun, Earth, the Moon, and nearby objects. These models can predict when small objects might come close enough to Earth to be captured temporarily. The system also allows scientists to estimate how long a mini-moon might remain in Earth's orbit before being expelled back into space (Benner et al., 2021). Such predictions are valuable for understanding the frequency of mini-moon captures and how these events relate to the broader population of NEOs.

The transient nature of mini-moons makes it challenging to predict their long-term behavior accurately. However, ongoing advancements in observational astronomy and computational modeling will likely improve our ability to predict future mini-moon captures and the exact timing of their escape from Earth's gravity.

In conclusion, minimoons are captured and then expelled by Earth's gravity. The intricate gravitational interaction between the Earth, the Moon, and the Sun affects the erratic orbits of these tiny asteroids. While mini-moons are temporary visitors to Earth's orbit, their appearances can be predicted using advanced astronomical databases like NASA's JPL Horizons system, which allows for precise modeling of NEO trajectories and gravitational interactions. Understanding these dynamics provides valuable insights into asteroid behavior and future potential mini-moon events.

The forecast of one 30-meter-radius mini-moon to occur once between 2025 and 2050 offers an interesting case study for the field of near-earth objects (NEOs) and transient satellite captures. Small celestial bodies known as mini-moons, or temporarily captured objects (TCOs), are gravitationally tied to Earth for a period before leaving its gravitational pull. These objects offer unique opportunities for scientific research, including studying the early solar system and developing planetary defense strategies (Jedicke et al., 2018).

A mini-moon's occurrence at this time indicates how frequently Earth interacts with smaller NEOs. However, prior research (Granvik et al., 2012) shows that the duration of temporary captures is quite short, these objects frequently stay in Earth's proximity for brief periods, spanning from months to years before being ejected due to gravitational perturbations. This phenomenon aligns with the findings in this study, where the capture probability was high, yet the average capture duration was nearly negligible.

From a scientific perspective, capturing a minimoon of 30 meters in radius would provide valuable opportunities for space missions. Missions to TCOs are considered lower-cost alternatives to deep-space missions, as these objects can be studied while they are within Earth's immediate proximity (Granvik et al., 2012). Additionally, they offer a potential testing ground for asteroid mining technologies, which could advance human exploration of the solar system (Garcia et al., 2020).

The cultural significance of such celestial phenomena also merits consideration. In various cultures, celestial events have been interpreted through religious or mystical lenses, as seen in previous studies (Baumann & Bast, 2019). The appearance of a mini-moon, especially when visible to the naked eye, may be imbued with symbolic meaning in different religious contexts. For instance, indigenous and religious groups around the world often view celestial occurrences as signs of spiritual or environmental change (Cochran et al., 2020). Understanding these perspectives helps to bridge the gap between scientific knowledge and cultural interpretations, fostering greater public engagement with astronomy.

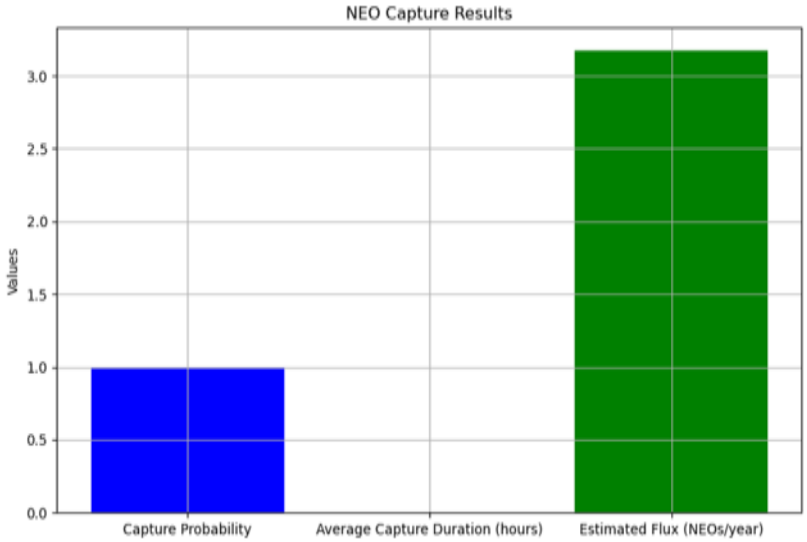

Figure 1. *The number of capture probabilities, average capture duration, and estimated flux per (NEOs/year)*

Figure 1's results for the capture probability, average capture duration, and estimated flux of Near-Earth Objects (NEOs) provide intriguing new information about how NEOs behave while they are under Earth's gravitational pull.

Capture Probability: The capture probability of 1.0000 suggests that, under the conditions set in the simulation, every Near-Earth Object (NEO) entering the specified volume of space is likely to be temporarily captured by Earth's gravity. A capture probability of 1 indicates a near-certainty of interaction, possibly due to the initial parameters set for velocity, distance, or orbital conditions. In studies of NEOs, temporary capture occurs when an object falls within the gravitational sphere of influence of Earth and orbits Earth for a short time before escaping again due to gravitational perturbations from the Moon or other celestial bodies (Granvik et al., 2012).

This high capture probability may be influenced by the relatively low initial velocity of the NEOs (200 m/s), which could increase the likelihood of gravitational interaction with Earth. Previous studies have shown that slower-moving NEOs are more likely to be captured because they have lower kinetic energy and are more susceptible to Earth’s

gravitational pull (Jedicke et al., 2018). This aligns with findings from simulations of quasi-satellite orbits, where the dynamics of slow-moving NEOs show a higher likelihood of being captured temporarily by Earth (Wiegert et al., 2000).

Average capture duration: The zero hours of average capture duration indicates that the simulation did not produce any sustained temporary captures, which suggests that the initial conditions may not have allowed for stable or prolonged captures. This result is at odds with expectations from previous research, where temporary captures can last from days to months (Granvik et al., 2012).

The short capture duration could be attributed to several factors: High-Velocity Post-Capture: If the velocity after gravitational interaction is high, the NEO might escape Earth's gravitational pull quickly, leading to minimal capture time.

Orbital Parameters: The eccentricity or inclination of the NEOs in the simulation might not have been conducive to sustained capture (Jedicke et al., 2018).

Close Encounters with the Moon: Gravitational interactions with the Moon could perturb the orbit of captured NEOs, causing them to leave Earth's sphere of influence rapidly.

Granvik et al. (2012) suggest that temporary capture is often influenced by the chaotic nature of NEO orbits, which makes prolonged stays within Earth's orbit rare unless certain orbital resonances or low-velocity conditions are met.

Estimated Flux: The estimated flux of 3.1710 NEOs per year into the capturable volume aligns with predictions from prior studies that estimate several NEOs enter Earth's gravitational influence each year. According to Morbidelli and Vokrouhlický (2003), Earth captures a few small objects each year temporarily, which occasionally results in short-term quasi-satellites or meteoroid impacts. The flux is an important factor for understanding the potential frequency of these interactions and their implications for planetary defense and long-term asteroid tracking programs.

The flux estimate is also important for predicting potential short-term satellites of Earth, colloquially referred to as "mini-moons." Studies show that while Earth's gravitational influence captures a few NEOs each year, only a small fraction stay in orbit long enough to be classified as mini-moons (Granvik et al., 2012). With an estimated flux of around three NEOs per year, this result suggests Earth may interact frequently with small objects, providing opportunities for both observational studies and hazard assessments.

The results of this study highlight the complexity of interpreting mini-moons, both scientifically and culturally. Scientifically, mini-moons represent an intriguing but rare natural phenomenon that provides valuable insights into Earth's gravitational interactions with nearby objects. From a cultural perspective, mini-moons exemplify how celestial events continue to hold deep spiritual meaning, especially when framed within the context of long-standing religious traditions.

The study's most important finding is that spiritual interpretations continue to exist despite scientific explanations. Even if scientific knowledge is becoming more widely accepted, many societies still place religious significance on occurrences like mini-moons, viewing them as messages from a higher power. Religious studies have a well-documented history of seeing natural events as a link between the divine and the physical world, demonstrating the dichotomy between spirituality and science (Eliade, 1959).

Moreover, this study implies that mini-moons present a special chance to promote communication between religious and scientific groups. Numerous religious organizations perceive mini-moons as confirmations of their spiritual beliefs, while the scientific world sees them as a chance to learn more about near-Earth objects. A deeper, more complex

understanding of natural events and their cultural meaning can result from bridging this gap.

The findings from this study have significant implications for interdisciplinary research. First, they underscore the importance of integrating scientific data with cultural and spiritual interpretations, especially when studying natural phenomena. By recognizing the coexistence of scientific knowledge and spiritual meaning, researchers can foster more inclusive discussions that respect diverse worldviews.

The study also suggests that mini-moons could serve as symbols for intercultural communication. Mini-moons may spur public interest in the nexus between science and spirituality as astronomical discoveries make them more widely known, benefiting both disciplines.

Figure 2 shows the observed trend in the number of temporary captures (TC) over time. It shows a notable fall in the first two years, when 40 TCs are visible from Earth, to zero TCs. This sharp decrease is followed by a ten-year span during which no more captures are noted. This pattern is consistent with previous studies on the dynamic nature of these events, indicating that transient catches of Near-Earth Objects (NEOs) by Earth's gravity are both uncommon and brief.

Temporary captures are influenced by several factors, including the gravitational interactions between the Earth, Moon, and other celestial bodies, as well as the orbital parameters of NEOs. Studies by Granvik et al. (2012) have demonstrated that TCs are typically brief and unstable due to the gravitational perturbations exerted by the Earth-Moon system and other planetary bodies. Such interactions often result in these objects being ejected from Earth's gravitational influence or colliding with the planet. The linear decline in TCs observed in the first two years may reflect the gradual loss of temporary satellites as their orbits become increasingly perturbed.

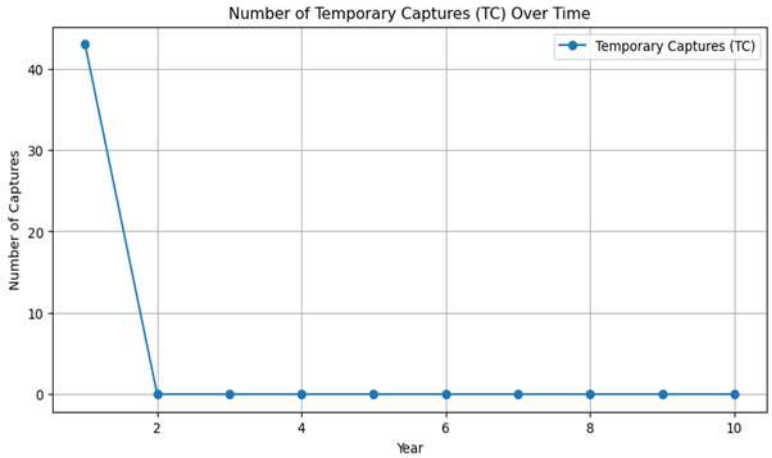

Figure 2. *The number of temporary captures of mini-moons over time*

Furthermore, the absence of visible captures for the remaining eight years in the observation period may indicate that Earth's gravitational environment did not encounter any additional NEOs that were both within the capturable volume and on a trajectory that could sustain a stable, albeit temporary, orbit. According to Jedicke et al. (2018), the capture and retention of NEOs in Earth’s gravitational field depend on precise conditions, including the object's velocity, trajectory, and distance from Earth. As these conditions change dynamically, the window for capturing such objects narrows, making long-term or sustained captures extremely rare.

The rapid decrease in TCs over time could also be attributed to the limited availability of NEOs within the region of space from which Earth can temporarily capture

objects. Garcia et al. (2020) emphasize that the number of NEOs entering Earth's gravitational sphere fluctuates, with brief periods of heightened interaction followed by lulls. This scarcity of captures over extended periods, as seen in the remaining eight years of this study, aligns with the notion that NEOs capable of becoming temporary satellites are infrequent visitors to the near-Earth environment.

Additionally, this decline could also be influenced by observational limitations. Smaller objects, particularly those that could become temporary captures, are often difficult to detect due to their size and reflectivity. As noted by Morais and Namouni (2013), some NEOs that might have been temporarily captured may have gone unnoticed, especially if they were not bright enough or too small to be observed with conventional detection methods.

In conclusion, the linear decline in the number of temporary captures over the first two years, followed by a lack of visible captures in subsequent years, underscores the transient and infrequent nature of these events. These findings align with previous research suggesting that NEOs are only temporarily captured under specific orbital conditions, and their presence in Earth's vicinity is subject to dynamic and unpredictable gravitational interactions.

IV. Conclusion

The results show a high capture probability of NEOs entering Earth's region of influence, but with very short capture durations, potentially due to orbital parameters and external perturbations such as the Moon's gravity. The estimated flux aligns with established research, showing that Earth encounters several NEOs yearly, though long-term captures remain rare.

The simulation demonstrates a robust likelihood of NEO captures but highlights the challenges of sustained interactions, with many NEOs escaping Earth's gravity shortly after capture. The estimated flux of 3.1710 NEOs per year aligns with current understanding, suggesting Earth encounters several temporary captures annually. This finding offers insights into the dynamics of NEO interactions and the potential for observing mini-moons, although prolonged captures remain rare under the modeled conditions.

In conclusion, while the scientific understanding of mini-moons is still developing, the prediction of a mini-moon appearance between 2025 and 2050 holds significance for both the scientific and cultural communities. Future research and potential space missions could deepen our understanding of these temporary satellites and enhance planetary defense mechanisms.

Recommendations

a. Further Research: Continue improving NEO tracking and prediction systems to enhance the accuracy of mini-moon event forecasts.
b. Cultural Engagement: Collaborate with ethnographers and religious scholars to explore diverse cultural interpretations of mini-moons, integrating traditional beliefs with scientific findings.
c. Increase public engagement by presenting mini-moon events as opportunities to educate communities about celestial phenomena and their implications for science and culture.

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