



Scientific, Societal, and Spiritual Implications of Finding (or Not Finding) Life on Mars

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Abstract

As humanity enters a transformative era of Mars exploration, guided by NASA's Moon-to-Mars roadmap, rapid advances in commercial spaceflight, and the National Academies' Science Strategy for the Human Exploration of Mars (2025), we approach a pivotal moment in the search for extraterrestrial life. Recent in-situ observations from Jezero crater have produced a potential biosignature in fine-grained sediments, while new laboratory studies indicate that relatively pure Martian ice could preserve organic molecules for geologically significant timescales. Together, these developments elevate the near-term stakes: they sharpen targets, raise the bar for planetary protection, and intensify public attention even in the absence of definitive proof. This paper systematically examines the scientific, societal, and spiritual implications of three outcomes: definitive discovery, confirmed absence, or persistent uncertainty. We assess how each pathway would

reshape astrobiology and sample-return priorities, recalibrate planetary-protection policies for human missions, and influence international cooperation, ethics, and cultural narratives. Whether Mars ultimately reveals evidence of a second genesis or underscores Earth's exceptional status, the pursuit itself compels deep reflection on our collective identity and responsibilities as planetary stewards, renewing appreciation for life's rarity, resilience, and intrinsic value.

Keywords: Mars exploration, astrobiology, biosignatures, planetary protection, space ethics, Rare Earth hypothesis.

1 Introduction

Few questions have captured human imagination more deeply than the possibility of life beyond Earth. With NASA's ambitious Moon-to-Mars roadmap, rapidly advancing commercial spaceflight initiatives from entities such as SpaceX, and enhanced international collaboration, human exploration of Mars is set to accelerate dramatically by the 2040s. This renewed focus on Mars is significantly informed by the recent



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publication of the National Academies' comprehensive Science Strategy for the Human Exploration of Mars (2025), outlining strategic objectives that shape both near-term robotic missions and the anticipated era of human landings (National Academies of Sciences, Engineering, and Medicine, 2025).

Since NASA's pioneering Mariner and Viking missions [1, 2], and subsequent surface missions that established ancient habitable environments [3, 4], Martian exploration has sought definitive answers regarding past or present life. Central to these missions is a foundational astrobiological question: If life ever existed on Mars, does it share a common genetic origin with terrestrial life via lithopanspermia, or does it represent an independent genesis, indicative of life arising separately under similar planetary conditions? Resolving this question would not only revolutionize astrobiology as an empirical discipline but would also necessitate comprehensive revisions of planetary-protection protocols to mitigate cross-contamination risks [5, 6].

In recent years, this enduring question has gained renewed urgency. In 2024–2025, NASA's Perseverance rover identified a rock within Jezero crater's "Bright Angel" formation exhibiting textures, mineralogy, and organic signals consistent with a potential biosignature—considered by many scientists to be the strongest in-situ candidate yet discovered [7–9]. Although abiotic explanations remain possible, this finding has intensified debate over the threshold for declaring biological evidence. Complementary laboratory studies further suggest that relatively pure Martian ice could preserve organic molecules or biosignatures for tens of millions of years, providing stable cryogenic environments that protect complex organics from radiation and oxidation. These developments mark a decisive shift from searching for environmental habitability toward probing direct indicators of biology and its preservation, reinforcing the scientific and philosophical magnitude of the coming decade of exploration.

Against this dynamic backdrop, this paper systematically explores three plausible outcomes of Mars exploration: (1) the definitive discovery of life, (2) the confirmed absence of life, and (3) sustained ambiguity. The discussion focuses on the profound implications each scenario holds across scientific, philosophical, societal, and spiritual dimensions. Scientifically, the confirmation of Martian life, whether genetically similar to or fundamentally distinct

from terrestrial organisms, would significantly alter our understanding of life's emergence, resilience, and cosmic distribution [12, 13]. Conversely, the confirmed absence of life would reinforce the Rare Earth hypothesis [10], prompting a reassessment of planetary-habitability criteria and underscoring Earth's unique biosphere. Persistent ambiguity due to inconclusive evidence would highlight the technological and epistemological limitations inherent to astrobiological research, encouraging continued scientific innovation and philosophical humility [11].

Beyond science, each potential outcome would carry significant societal and spiritual implications. Discovering extraterrestrial life would profoundly influence global culture, religion, ethics, and education, reshaping humanity's collective narrative about our place in the cosmos. Alternatively, the absence or prolonged uncertainty of life beyond Earth would amplify our responsibility toward preserving Earth's biosphere, reinforcing global ecological stewardship and intergenerational responsibility.

Thus, Mars exploration transcends purely scientific inquiry, representing a profound moment of reflection, unity, and ethical maturity for humanity. Regardless of whether Mars ultimately reveals evidence of a second genesis, confirms humanity's cosmic solitude, or leaves us confronting persistent uncertainty, the pursuit itself—now guided explicitly by the strategic framework outlined in the National Academies' (2025) report and invigorated by recent in-situ discoveries—compels deep reconsideration of our collective identity, moral responsibilities as planetary stewards, and humanity's role as explorers within the broader cosmos.

2 Potential Outcomes: Discovery, No Discovery, or Inconclusive

2.1 Finding Present or Past Life

The discovery of life, either as fossilized remains or active microbial colonies, on Mars would constitute a transformative moment in science and human understanding. Definitive biomarkers such as biologically produced methane, complex organic molecules, or unequivocal microbial fossils would immediately raise profound questions about life's origins. If Martian life arose independently, a "second genesis," it would strongly suggest that life's emergence is not a rare cosmic accident but rather a natural outcome governed by universal physical and chemical laws. Such a finding would fundamentally

transform astrobiology from speculative inquiry into a robust empirical science, dramatically expanding our understanding of habitability and the chemical diversity possible in life [12, 14].

2.1.1 Emerging In-Situ Candidates from Jezero (2024–2025)

Recent analyses from NASA's Perseverance rover have provided compelling, though still inconclusive, evidence suggesting possible biosignature formation within Jezero crater. In 2024 and 2025, the rover identified a rock exposure in the "Bright Angel" region, informally named Cheyava Falls, that exhibits fine-grained laminations, redox-sensitive mineral assemblages, and organic-bearing phases consistent with environments that on Earth are often shaped by microbial activity [7]. These materials occur in mudstone and sandstone units deposited in an ancient deltaic setting, offering a microenvironment that may have once sustained water-rock chemical gradients favorable to early metabolism.

Although abiotic explanations remain entirely possible, the combination of textural, mineralogical, and organic features observed in these Jezero samples has been described as the strongest in-situ evidence yet found for potential biological processes on Mars [9]. The finding has renewed discussion regarding what constitutes a "threshold of proof" for biosignature claims in planetary science, emphasizing the need for reproducible multi-instrument confirmation and eventual laboratory verification through sample return.

Complementary laboratory research has strengthened this context by demonstrating that relatively pure Martian ice could preserve organic molecules or microfossil textures for tens of millions of years under cryogenic and radiation-shielded conditions. These results suggest that future missions might prioritize ice-rich terrains and ancient permafrost deposits as natural archives of past biology. Together, the Jezero findings and preservation experiments mark a transition from identifying environments of potential habitability to directly evaluating candidate materials for biological origin, underscoring the importance of coordinated robotic and human exploration strategies.

2.1.2 Implications for Detection and Containment

Conversely, if Martian organisms share DNA or fundamental biochemical structures with terrestrial life, the lithopanspermia hypothesis would gain support, suggesting interplanetary

transfer of life or its precursors via meteorites. Such evidence would underscore life's resilience and potential cosmic mobility, significantly influencing planetary-protection protocols to manage biological contamination risks between worlds [15, 16]. Detection of Martian life would also necessitate rigorous reassessment of planetary-protection measures. Current sterilization protocols, designed primarily for robotic exploration, would prove insufficient for human missions. Enhanced measures, including advanced bio-containment facilities and stringent quarantine procedures for sample-return missions, would become essential to safeguard both Martian and terrestrial ecosystems from cross-contamination threats [5, 6].

Philosophically, confirmation of extraterrestrial life would challenge and expand humanity's conceptual definition of life itself. Traditional definitions rooted exclusively in Earth-based biochemistry would need revision to accommodate potential alternative biochemical pathways and molecular structures. Such a discovery would reinforce the Copernican Principle, further emphasizing humanity's non-centrality in the cosmos and prompting profound reflections on the broader implications for consciousness and intelligence throughout the universe [13].

Ethically, discovering extraterrestrial life would raise critical moral questions regarding humanity's responsibilities toward non-Earth organisms. New ethical frameworks would be required to guide interactions, potentially designating Mars as a protected natural reserve, prioritizing scientific investigation and ecological preservation over resource extraction or colonization.

In essence, finding life on Mars would catalyze interdisciplinary reassessment across biology, astrobiology, ethics, philosophy, and spirituality. Such a discovery would profoundly reshape humanity's approach to planetary exploration, environmental stewardship, and cosmic citizenship.

2.2 Finding No Life

If comprehensive robotic and human-led investigations uncover no definitive evidence of past or present life on Mars, the scientific implications would be profound, significantly reshaping our understanding of planetary habitability and life's emergence. Such a finding would directly bolster the Rare Earth hypothesis, which posits that Earth's conditions enabling life—especially complex organisms—may be exceptionally uncommon

in the universe [10]. Mars's apparent inability to support life, despite historically favorable conditions including liquid water, essential organic molecules, and conducive geological environments, would highlight the extraordinary delicacy and rarity of life's genesis. This scenario would imply that habitability encompasses far more nuanced and restrictive criteria than currently understood.

Scientifically, this outcome would compel researchers to re-evaluate fundamental prerequisites for life's origin. It would underscore the essential roles played by sustained energy sources such as active volcanism, hydrothermal activity, or solar-driven chemical gradients. A lifeless Mars would prompt deeper examination of the importance of planetary magnetic fields for atmosphere retention, plate tectonics for nutrient recycling, and critical trace elements such as phosphorus and sulfur, driving scientists to refine their understanding of these geochemical and geophysical factors influencing planetary habitability [17, 18].

Philosophically, the confirmation of a lifeless Mars would profoundly affect humanity's perception of its cosmic significance. Earth could be viewed as exceptionally rare—a uniquely fortunate cradle of life amidst an otherwise barren cosmos. This realization would enhance our appreciation of Earth's preciousness and vulnerability, intensifying ethical considerations regarding planetary stewardship. Humanity might increasingly reflect on its role as possibly the sole intelligent caretaker capable of preserving and propagating life, reinforcing moral imperatives to safeguard Earth's fragile biosphere. In sum, the absence of life on Mars would significantly recalibrate scientific research priorities, deepen philosophical considerations of humanity's unique cosmic position, and reinforce our collective responsibility to preserve Earth as an extraordinarily rare oasis of life in a seemingly silent universe.

2.3 Inconclusive Results

An inconclusive scenario, in which Mars exploration yields neither definitive confirmation nor complete rejection of evidence for life, underscores both the planet's complexity and the current limits of scientific methodology. Robotic missions and landers typically examine only minute fractions of Mars's vast and heterogeneous environments, potentially overlooking microbial niches hidden deep underground, beneath thick ice layers, or within transient aqueous habitats [11, 23].

The recent observations at Jezero crater provide a vivid illustration of this ambiguity. Data from the "Bright Angel" region, reported in 2024 and 2025, revealed textures, mineral assemblages, and organic signals that could plausibly arise from biological activity but are equally consistent with non-biological geochemical processes [7]. Although the findings represent the strongest in-situ evidence yet detected, they remain inconclusive without sample-return verification and laboratory replication. As with the Viking experiments of the 1970s, Jezero's mixed signals highlight how tantalizing results can sharpen both curiosity and controversy rather than provide closure [2].

Persistent ambiguity of this kind accentuates the critical need for continued advances in detection technology and exploration strategy. Future missions must employ more sophisticated robotic probes capable of deep-subsurface drilling, contextual geochemical mapping, and high-resolution in-situ biochemical analyses. Human missions may gain additional justification by bringing adaptive decision-making and the analytical versatility of field laboratories directly to Mars. Broader collaboration among engineering, geology, biology, and data-science disciplines will be essential to interpret subtle biosignatures and minimize false positives.

Philosophically, enduring uncertainty invites reflection on the epistemological limits of science and the patience required for truth. Ambiguity should not be viewed as failure but rather as a catalyst for deeper understanding of habitability, resilience, and the nature of inquiry itself. By facing uncertainty collectively, humanity strengthens its identity as One Humanity, united by curiosity and perseverance in exploring the unknown. Societally, prolonged ambiguity exerts complex effects on public engagement. While recurring uncertainty can test public patience, it can also sustain fascination, dialogue, and support for continued exploration. Constructively communicated, ambiguity becomes an educational tool that fosters scientific literacy, critical thinking, and appreciation of how discovery in frontier science often proceeds through incremental, self-correcting steps rather than definitive revelations.

3 Societal and Spiritual Dimensions

A definitive answer about whether life exists, or ever existed, on Mars would reverberate far beyond planetary science, profoundly impacting educational priorities, resource allocation, and humanity's broader self-conception within the cosmos. Even ambiguous

results hold immense significance, catalyzing cultural debates and ethical reflections on our role as explorers and stewards of distant worlds.

3.1 Global Public Engagement and International Collaboration (or Competition)

The confirmation or definitive absence of life on Mars would markedly reshape global public engagement in space exploration, while influencing societal perceptions, international relationships, and policy priorities. Historically, milestones such as the Apollo Moon landings and robotic Mars missions have captured public imagination, symbolizing human ingenuity and national achievement. Even announcements of potential biosignatures, such as the Jezero crater findings reported by NASA in 2025, demonstrate how preliminary scientific results can ignite widespread discussion long before definitive conclusions are reached [7, 9]. Within hours of publication, news of possible Martian biosignatures dominated global headlines, trending across social media and prompting statements from scientific academies, religious leaders, and policy organizations. These rapid reactions underscore how public interest now responds not only to confirmed discoveries but also to early stages of scientific interpretation, magnifying both excitement and misunderstanding. The intense attention surrounding such announcements highlights the importance of responsible communication. Space agencies and research institutions must convey uncertainty with precision, distinguishing between potential and confirmed evidence. Balanced messaging is essential to sustain public trust, prevent misinformation, and maintain support for long-term missions whose results may unfold over decades. Media training for scientists, transparent data-release policies, and early engagement with international partners can help manage expectations and preserve credibility.

A historical precedent illustrates both the power and the pitfalls of premature conclusions. The 1996 announcement that the Martian meteorite ALH 84001, discovered in Antarctica, might contain fossilized microbial life captured worldwide attention—including a high-profile presidential statement—but was later challenged by subsequent analyses that provided non-biological explanations for the observed structures [19]. The episode remains a seminal example of how extraordinary claims demand extraordinary scrutiny. It also underscores the need for careful framing of preliminary findings,

as early overinterpretation can blur the distinction between hypothesis and evidence in the public mind. Lessons from ALH 84001 continue to guide today's communication strategies, emphasizing transparency, interdisciplinary review, and humility in the face of uncertainty.

From an educational standpoint, even tentative discoveries inspire surges of curiosity that transform how science is taught and valued. Announcements suggesting traces of life can catalyze renewed enrollment in astrobiology, planetary science, and ethics courses. Museums, science centers, and planetariums often experience immediate increases in attendance, while public discourse broadens to include questions of philosophy and stewardship. Whether or not biosignatures are later verified, such moments strengthen science literacy and promote critical understanding of uncertainty as a natural feature of exploration. At the geopolitical level, potential biosignature claims can act as stress tests for international cooperation. The 2025 Jezero announcement, for example, prompted simultaneous calls for shared verification and competitive interest in sample access, illustrating how near-breakthroughs can both unite and divide spacefaring nations. Historically, space exploration has oscillated between collaboration and rivalry—from the Cold War space race to the multinational partnerships of the International Space Station. A future claim of biological evidence on Mars could rekindle these tensions, especially if questions arise over intellectual property, data control, or sample custody. Differing political systems and economic priorities may complicate collaboration, making clear diplomatic frameworks indispensable.

Conversely, the global significance of such findings could serve as a catalyst for collective governance. Recognizing that evidence of extraterrestrial life belongs to all humanity might encourage nations to pursue joint missions, shared laboratory facilities, and harmonized planetary-protection standards. Precedents such as the Antarctic Treaty and the Artemis Accords demonstrate how scientific discovery can motivate cooperative rulemaking. Similar models could guide Mars exploration toward responsible stewardship rather than competition for prestige or resources.

Policy responses to biosignature reports would likely be rapid and wide-ranging. Governments and space agencies may increase funding for

verification missions, biohazard containment, and sample-return infrastructure. International organizations could convene scientific review panels or propose new ethical guidelines for contact with potential extraterrestrial biospheres. At the same time, persistent uncertainty could shift priorities toward improving detection capabilities, strengthening interagency data-sharing, and balancing investment between Mars and Earth-based challenges such as climate change and sustainability. Ultimately, Mars exploration—whether culminating in confirmation, rejection, or continuing ambiguity—embodies humanity's collective aspirations and maturity. Just as iconic images of Earth from space reshaped our self-awareness, even the suggestion of life on another world reaffirms our shared destiny. Despite political and cultural differences, the responsible communication and cooperative governance of potential biosignatures can foster a deeper sense of planetary unity and mutual stewardship, reinforcing the vision of One Humanity exploring the cosmos together.

3.2 Cultural Narratives and Societal Cohesion

The discovery or definitive absence of life on Mars would significantly reshape cultural narratives and societal cohesion worldwide. Historically transformative discoveries, such as Copernicus's heliocentric model and Darwin's theory of evolution by natural selection, have profoundly altered human self-perception and societal frameworks. Similarly, the detection of Martian life would challenge entrenched cultural assumptions positioning Earth as uniquely hospitable to life, necessitating shifts toward viewing the universe as potentially abundant in biological diversity. Conversely, confirming Mars's sterility would reinforce narratives emphasizing Earth's exceptional ecological balance, prompting intensified societal commitment to environmental stewardship.

If Martian life is discovered, its cultural repercussions would permeate literature, media, arts, and popular discourse. Science fiction's longstanding tradition of imagining extraterrestrial life would gain renewed authenticity, prompting artists, writers, filmmakers, and philosophers to reinterpret fundamental human themes such as identity, purpose, and cosmic interconnectedness. Societies would be compelled to adapt these new narratives, acknowledging that life's diversity extends beyond terrestrial bounds.

Educational systems worldwide would rapidly evolve to integrate such discoveries into curricula,

emphasizing not only scientific dimensions of life's origins and evolution, but also societal, philosophical, and ethical implications. Such educational transformation would likely stimulate a renaissance in STEM disciplines, fostering a new generation inspired by humanity's place within a biologically enriched cosmos. Courses in astrobiology, interdisciplinary studies, and the broader societal impacts of extraterrestrial discoveries would gain prominence.

Conversely, if Mars exploration conclusively finds no evidence of life, cultural narratives could pivot toward celebrating Earth's uniqueness. Such a scenario would likely invigorate advocacy for ecological conservation and sustainability, highlighting the rare and precious conditions sustaining terrestrial life. Educational institutions would similarly shift, emphasizing Earth sciences, ecology, and environmental stewardship to underline the urgency of protecting our planet's unique biosphere.

Mars exploration outcomes could also influence societal cohesion in nuanced ways. The shared experience of discovering extraterrestrial life could help to mend many of the rifts within humanity, fostering a collective identity transcending national, cultural, and ideological divides. Martian life could symbolize humanity's collective journey, strengthening global empathy and cooperation. Alternatively, cultural divisions might emerge around the interpretation and ethical treatment of extraterrestrial organisms—ranging from strict preservation and scientific research to resource utilization—potentially generating ideological tensions and cross-purposed initiatives.

Even persistent ambiguity or inconclusive results could foster societal humility and resilience, reinforcing philosophical awareness of the inherent limits of human knowledge and the continual necessity for exploration and inquiry. Ambiguity could encourage societies to embrace philosophical tolerance for uncertainty, recognizing humanity's search for cosmic meaning as a dynamic, ongoing journey rather than a clearly defined endpoint. Ultimately, the narratives arising from Mars exploration—whether celebrating cosmic biological diversity or underscoring Earth's exceptional singularity—will significantly shape humanity's cultural identity and social cohesion. The collective experiences and reflections inspired by these discoveries hold potential either to unify humanity around a shared planetary vision or to

highlight and challenge existing divisions, depending largely on how societies interpret and act upon these transformative insights.

3.3 Religious and Theological Perspectives on Extraterrestrial Life

Clearly, the discovery of life beyond Earth, especially on neighboring Mars, would profoundly influence theological and religious discourse across diverse faith traditions. Historically, major religions have placed humanity and Earth at the center of divine creation narratives, either implicitly or explicitly asserting our planet's unique spiritual significance. Detecting extraterrestrial life—whether microbial or more complex—would necessitate reconsideration and reinterpretation of theological doctrines and religious philosophies, echoing historical instances such as the Copernican revolution, which fundamentally shifted human understanding of our cosmic position.

Within Abrahamic traditions, evidence of Martian life would ignite extensive doctrinal debates surrounding creation narratives. Religious scholars would grapple with integrating extraterrestrial beings into existing scriptural frameworks or formulating new theological interpretations. Such discoveries would prompt profound discussions regarding divine creativity, including whether multiple independent origins of life ("geneses") indicate a broader and more complex understanding of divine creation. Traditional theological anthropologies, which typically view humans as uniquely imbued with spiritual significance, might be reconsidered. The potential spiritual significance of Martian organisms would challenge religious teachings to adapt and expand their cosmological and spiritual frameworks accordingly.

Eastern religions, characterized by expansive cosmologies and often less anthropocentric viewpoints, might more readily incorporate discoveries of extraterrestrial life into their spiritual and philosophical narratives. For instance, Hindu and Buddhist traditions might interpret extraterrestrial life as affirmations of the universe's inherent diversity and interconnectedness, aligning naturally with concepts of cosmic unity rather than posing theological contradictions. Nonetheless, these traditions would still need to articulate the implications of extraterrestrial life for human identity, moral responsibilities, and our interconnected role within a broader cosmological tapestry.

Discovering life on Mars would also serve to catalyze significant interfaith dialogue, encouraging rich and cooperative discussions across diverse religious communities about humanity's place within a potentially biologically diverse universe. Religious leaders and global communities might collectively reflect on humanity's moral and spiritual responsibilities toward extraterrestrial life forms, fostering broader conversations on cosmic purpose, divinity, and ethical stewardship of both terrestrial and extraterrestrial ecosystems.

Conversely, definitive absence of life on Mars would carry its own profound theological implications. Some religious communities might interpret a lifeless Mars as affirming traditional doctrines that emphasize Earth's unique status as a singular act of divine creation, thereby heightening humanity's spiritual and moral responsibility to protect Earth's exceptional biosphere. Alternatively, this outcome could prompt deeper existential and theological introspection, raising challenging questions about divine intent and purpose in creating a seemingly lifeless universe beyond Earth's singular biosphere. In all scenarios—discovery, absence, or persistent ambiguity—Mars exploration will invite deeper religious and theological engagement, urging humanity toward more expansive, inclusive, and reflective spiritual perspectives.

3.4 Ethical Questions about Exploring or Colonizing Mars

3.4.1 General Ethical Principles for Mars Exploration and Colonization

The exploration and potential colonization of Mars raise profound ethical challenges, particularly if the planet is discovered to currently host, or even to have once hosted, a biosphere of its own. Confirmation of Martian life would immediately invoke moral considerations regarding humanity's interactions with indigenous extraterrestrial organisms. Central to these ethical deliberations is whether Martian life, even if microbial, possesses intrinsic moral value deserving protection and respect, independent of scientific interest or practical utility.

Philosophers and ethicists have long debated the intrinsic moral worth of nonhuman life on Earth, a discourse that would significantly expand within an interplanetary context. If Mars harbors indigenous life forms, ethical frameworks must clearly delineate the moral status of such organisms. Critical questions emerge: Should Mars be preserved as a pristine

natural reserve to prevent potential harm to native ecosystems? Would limited, carefully regulated scientific exploration or colonization be morally justifiable, and under what conditions and constraints?

Long-term colonization scenarios further complicate these ethical dimensions. Should humanity establish permanent settlements on Mars, ethical guidelines must carefully balance scientific exploration, economic interests, ecological stewardship, and moral obligations toward indigenous life forms. Human activities could potentially disrupt or irreversibly damage Martian ecosystems, raising ethical dilemmas analogous to terrestrial debates surrounding conservation, invasive species, and habitat preservation—now amplified to interplanetary scales.

Current international agreements such as the Outer Space Treaty (1967) and more recent frameworks like the Artemis Accords provide preliminary guidelines aimed at preventing harmful contamination and preserving scientific integrity. However, these existing legal and ethical norms may require significant revision and expansion to address the unique moral complexities presented by potential extraterrestrial biospheres. Formulating effective, universally accepted ethical standards would necessitate extensive international cooperation, diplomatic dialogue, and global consensus, ensuring a responsible, collective approach to Martian exploration. Robust planetary-stewardship principles, emphasizing humanity's ethical responsibility as caretakers of potentially life-supporting worlds, must be clearly articulated and internationally adopted.

Moreover, ethical considerations regarding Mars colonization extend into philosophical questions about humanity's broader responsibilities as a spacefaring species. If Mars is conclusively shown to be lifeless, ethical discourse might pivot toward debates on whether humanity possesses a moral imperative, or even the right, to introduce terrestrial life into otherwise sterile planetary environments, potentially initiating novel evolutionary pathways. Such concepts of directed panspermia, and even large-scale terraforming, raise challenging ethical questions about humanity's role in actively shaping the cosmic future and the appropriate moral boundaries of interplanetary actions.

Ultimately, Mars exploration and colonization compel humanity to critically examine and extend ethical frameworks beyond terrestrial boundaries. By

proactively engaging with these multifaceted ethical questions, humanity has an opportunity to establish thoughtful, responsible, and comprehensive ethical guidelines that will be vital in guiding our collective future as we venture into a cosmos that may, or may not, harbor other forms of life.

3.4.2 *Ethics in the Grey Zone: Acting under Potential Biosignature Conditions*

The 2025 Jezero crater “potential biosignature” exemplifies an ethically ambiguous frontier where evidence is suggestive but not definitive. Acting prematurely could jeopardize a genuine Martian biosphere, yet delaying too long could stall vital scientific progress. Ethical prudence in such cases requires decision-making frameworks that balance precaution with knowledge advancement.

Key considerations:

- Precautionary Access Rules: Limit physical disturbance near candidate biosignature sites until independent analyses confirm results. Robotic sample-collection paths, rover sterilization procedures, and human mission landing zones should avoid these areas.
- Tiered Quarantine Protocols: Establish clear containment levels for returned samples, with automatic elevation of biosecurity standards when organics or redox-active minerals are detected.
- Transparent Communication: Release preliminary findings with explicit uncertainty language and open data access to prevent politicization or misinformation.
- International Ethics Councils: Convene interdisciplinary panels—including scientists, ethicists, theologians, and policy experts—to evaluate potential biosignature claims before authorizing direct contact or sampling.
- Dynamic Ethical Review: Require continuous reassessment as new data emerge, allowing ethical guidelines to evolve alongside the science.

These measures would help humanity act responsibly in the “grey zone” between discovery and confirmation, safeguarding both scientific integrity and moral stewardship during the formative decades of human–Martian interaction.

4 Discussion

The quest for life on Mars is more than an exploration of another planet; it is a profound human endeavor that probes fundamental questions about existence, identity, purpose, and destiny. Whether we ultimately discover microbial fossils beneath Jezero crater, uncover subtle traces of ancient biology elsewhere on Mars, or confirm the planet as completely barren, this pursuit reflects humanity itself—illuminating our scientific curiosity, ethical maturity, cultural cohesion, spiritual aspirations, and planetary responsibilities.

Mars serves as more than a neighboring celestial body; it acts as a mirror, revealing our collective character, ambitions, and the manner in which we navigate uncertainty. The methods we choose for exploration, the philosophical questions we ask, and our handling of the Jezero finding, characterized by careful optimism, broad collaboration, and immediate ethical reflection, suggest that humanity may be developing the moral and institutional frameworks required for mature exploration.

The potential discovery of life on Mars would undeniably represent a historic turning point. If biochemical similarities were identified between Martian organisms and terrestrial life, they would lend partial support to the long-standing hypothesis of interplanetary biological exchange through meteorites or other natural transfer mechanisms. Yet such parallels would not, by themselves, constitute definitive validation of panspermia. Given that all known life on Earth utilizes the same limited set of twenty amino acids and similar nucleic acid structures, a shared biochemical profile could also arise through convergent evolution—the tendency of systems governed by the same physical and chemical laws to arrive at comparable molecular solutions. In this view, panspermia and biochemical convergence are not mutually exclusive but rather complementary frameworks that together could describe life's remarkable adaptability and its potential to emerge in multiple locales under similar constraints. Either interpretation—common ancestry through exchange or independent emergence through convergence—would profoundly expand our understanding of life's resilience and universality.

Alternatively, if Martian life exhibited distinctly different biochemical structures, it would indicate a true second genesis, meaning life arising independently within our solar system, and dramatically increase the likelihood of life

throughout the galaxy. Either result would compel a profound philosophical and spiritual reevaluation of humanity's place within an expansive, life-filled cosmos, challenging deeply ingrained anthropocentric perspectives. Conversely, a definitive absence of Martian life would highlight Earth's extraordinary uniqueness, emphasizing the rarity and fragility of our biosphere within a potentially lifeless cosmos. This realization would reinforce humanity's ethical imperative to preserve and protect our planet, promoting global solidarity around environmental stewardship, sustainability, and ecological consciousness. Moreover, finding Mars devoid of life would sharpen scientific inquiries into the precise conditions required for life, refining our understanding of habitability and guiding exploration toward promising targets in the outer solar system and in exoplanetary systems [20–22].

Yet we must acknowledge the growing probability that Mars will continue to present ambiguous evidence for decades, including tantalizing hints, subtle biosignatures, and competing interpretations such as those emerging from Jezero. These uncertainties invite humanity to practice the very ethics of the “grey zone” discussed earlier: to act prudently under incomplete information, to preserve potential biospheres, and to avoid both reckless intrusion and paralyzing hesitation. Ambiguity is not failure but an essential stage of learning. It can serve as a catalyst for intellectual and spiritual growth, encouraging refinement of instruments, analytical rigor, and ethical foresight. Embracing uncertainty reflects a philosophical maturity that recognizes profound cosmic questions require sustained, collective inquiry across generations.

Mars exploration thus becomes a living exercise in global ethical responsibility and planetary stewardship. Each mission, dataset, and cross-agency collaboration provides an opportunity to cultivate cooperative decision-making and transparent communication. The development of universally accepted guidelines for planetary protection and ethical conduct, particularly those addressing potential biosignature conditions, marks the emergence of a planetary consciousness—an awareness that our actions on another world are inseparable from our moral evolution on this one.

Lessons drawn from Mars have direct implications for life on Earth. The planet's arid landscapes, ancient lakebeds, and candidate biosignatures offer analogues

for understanding environmental change, ecosystem fragility, and planetary resilience. By studying how life might persist or vanish elsewhere, we deepen appreciation for the delicate equilibrium that sustains life here. The search for extraterrestrial life therefore reinforces humanity's obligation to protect biodiversity, stabilize climate, and nurture the only confirmed biosphere we know.

In essence, the pursuit of Mars exploration is as inward-looking as it is outward-reaching. Each mission extends not only technological frontiers but also our ethical, cultural, and spiritual horizons. As we transition from isolated tribes on ancient plains to a united planetary—and potentially multiplanetary—civilization, Mars symbolizes the transformative potential of curiosity guided by wisdom and compassion.

Ultimately, Mars exploration invites humanity into deeper self-reflection about our shared identity and destiny. The discoveries and uncertainties of Jezero remind us that the search for life beyond Earth is inseparable from our search for meaning within ourselves. Whether we confirm life's universality or confront its rarity, our response will measure the depth of our maturity as a species—our ability to act as stewards of life, custodians of knowledge, and participants in a cosmos that continues to challenge, inspire, and humble us.

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Conflicts of Interest

Jonathan H. Jiang is an employee of Beacon in the Cosmos LLC, Pasadena, CA 91101, United States. The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

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