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News & Views

Communicating Discoveries in the Search for Life in the Universe Workshop Report

Jordan Bimm,[1] Mary Voytek,[2] Caleb Scharf,[2] Linda Billings,[3] Brianne Suldovsky,[4] Felisa Wolfe-Simon,[5] Morgan L. Cable,[6] Sara K. Yeo,[7] Michael A. Xenos,[8] Antigona Segura,[9] Anamaria Berea,[10] Ariel D. Anbar,[11] Marc Kaufman,[12] Vikki Meadows,[13] Heather Graham,[14] Kimberly Cartier,[15] Sofia Z. Sheikh,[16] Julie N. Nováková,[17] Ingrid Ockert,[18] and Jörg M. Determann[19]

Abstract

The potential discovery of life beyond Earth presents unique communication challenges for astrobiology. These include ambiguous data, public misconceptions, and the dynamics of social media platforms. Building on National Aeronautics and Space Administration's 2021 Standards of Evidence (SoE) workshop, a diverse group of experts—scientists, science journalists, content creators, and scholars—were convened during February and March of 2024 for the Communicating Discoveries in the Search for Life in the Universe workshop. This report summarizes structured discussions focused on how to responsibly share findings with different public audiences. Key themes that emerged from the workshop included the following: communicating uncertainty, reaching consensus, and building trust between the scientific community and the public. Such efforts will involve navigating the rapidly evolving landscapes of social media and academic (peer-reviewed) journal publishing. Workshop participants emphasized the need for proactive communication, early-career training in science communication, and interdisciplinary partnerships, all of which can foster sound public understandings of astrobiology research and its myriad of practices, mitigate misinformation, and sustain ongoing support for the search for life. In brief, this report includes the workshop rationale and structure, insights gleaned from past case studies and hypothetical future scenarios, common themes that emerged from the breakout groups, a discussion of the relationship of workshop outcomes to SoE, and guidance for individuals, agencies, and institutions. Key Words: Astrobiology—Science communication—Biosignature detection. Astrobiology 25, 743–758.

1. Introduction

Astrobiology is driven by the ongoing search for evidence of life beyond Earth. Such a discovery could have profound implications for science and society and would attract significant public interest. In recent years, the astrobiological community has increasingly recognized the critical importance of effective communication surrounding potential discoveries, especially those involving biosignatures: the detectable structures or chemical imprints indicative of living systems within an environment. This challenge is significantly magnified by the inherent ambiguity of early measurements and the

[1]Parrhesia Program for Public Discourse, University of Chicago, Chicago, Illinois, USA.
[2]NASA Ames Research Center, Moffett Field, California, USA.
[3]National Institute of Aerospace, Hampton, Virginia, USA.
[4]Department of Communication, Portland State University, Portland, Oregon, USA.
[5]Bay Area Environmental Research Institute, Moffett Field, California, USA.
[6]NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA.
[7]Department of Communication, University of Utah, Salt Lake City, Utah, USA.
[8]Department of Life Sciences Communication, University of Wisconsin–Madison, Madison, Wisconsin, USA.
[9]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, Ciudad de Mexico, México.
[10]Department of Computational & Data Sciences, George Mason University, Fairfax, Virginia, USA.
[11]School of Earth and Space Exploration and School of Molecular Sciences, Arizona State University, Tempe, Arizona, USA.
[12]Independent Scholar, Baltimore, Maryland, USA.
[13]Department of Astronomy, University of Washington, Seattle, Washington, USA.
[14]Goddard Spaceflight Center, Greenbelt, Maryland, USA.
[15]Eos, American Geophysical Union, Washington, District of Columbia, USA.
[16]SETI Institute, Mountain View, California, USA.
[17]Charles University, European Astrobiology Institute, Prague, Czech Republic.
[18]Independent Scholar, Berkeley, California, USA.
[19]Department of Liberal Arts & Sciences, Virginia Commonwealth University in Qatar, Doha, Qatar.

interpretation of data, which requires considerable time, analysis, and scientific debate to confirm or refute any claim of life detection.

There is a growing awareness in the astrobiology community that the way in which future discovery claims are communicated will profoundly influence how different public audiences understand and react to them. The stakes include the perceived credibility of astrobiologists, public confidence in science, and sustained support for the search for life. A crucial strategy that will enhance the communication of a potential extraterrestrial life (ETL) discovery effectively to the public involves cultivating relationships with professional science journalists and science communicators. These relationships increase the likelihood that public narratives about astrobiology accurately portray the reality of research, including the incremental, often ambiguous, nature of discovery, and how a potential detection might unfold. Laying this groundwork well in advance is crucial to managing public expectations, mitigating the risks of disappointment, confusion, misconceptions, or mistrust, all of which could potentially erode long-term public engagement and support for astrobiology.

The 2024 Communicating Discoveries in the Search for Life in the Universe (CDSLU) workshop was conceived as a direct result of the need to address critical communication challenges. It built upon the foundational work established by National Aeronautics and Space Administration (NASA)'s 2021 Standards of Evidence (SoE) workshop and its subsequent 2022 review by the National Academies of Science, Engineering, and Medicine (NASEM) Committee on Astrobiology and Planetary Sciences (CAPS). While the SoE workshop focused on developing scientific guidelines for evaluating biosignature claims, the CDSLU workshop deliberately shifted its emphasis to the question of how discoveries might be communicated effectively and responsibly beyond expert communities. For the first time, the workshop brought together a diverse, multidisciplinary group of experts, ranging from scientists and journalists to content creators and scholars, given the lack of a shared, dedicated forum for such discussions. Participants engaged in structured conversations designed to explore the unique complexities inherent in communicating information about a possible future discovery of ETL within the specific context of astrobiology.

Rather than aiming to produce a prescriptive white paper with formal communication recommendations and protocols, the CDSLU workshop's primary goal was to initiate conversations and surface a wide array of ideas, experiences, and challenges from across these different disciplines. The overarching objective was to foster a mutual awareness among all participants of the diverse communication hurdles specific to astrobiology, especially those surrounding how the communication of life detection is shaped not only by scientific data itself but also by inherent uncertainties, institutional and professional pressures, the dynamics of media platforms, and the historically and culturally shaped nuances of different public audiences. Participants discussed how to navigate ambiguous or contested results, confront existing public misconceptions, and avoid sensationalist media framings. This report summarizes the substance of these rich conversations and, by design, it reflects the exploratory goals of the workshop rather than prescribing specific recommendations or offering a unified consensus.

The urgency of these communication challenges is rooted in past experiences, present needs, and future probabilities. Scenarios such as the identification of fossil-like structures in martian rock samples or the detection of chemical signatures in the atmospheres of other planets and moons may seem futuristic, although such scenarios and their inherent communication challenges have already surfaced, as discussed in this report. Historical controversies also vividly illustrate risks. The intense public debate surrounding the martian meteorite ALH 84001 in 1996 and the more recent 2020 announcement of a possible detection of the chemical phosphine in Venus's atmosphere serve as potent reminders of the potential for misinterpretation, sensationalism, and the consequent erosion of public trust and interest. The CDSLU workshop provided a venue for structured discussions that explored historical case studies and plausible future scenarios of biosignature detection claims. A guiding principle of these discussions was the imperative to communicate responsibly about the search for life before any detection claim is made. Establishing a foundational understanding in advance of discoveries was considered essential for cultivating a sound public grasp of future developments. Proactive expectation management is considered a critical safeguard against disappointment, confusion, misconceptions, or mistrust, any of which could severely undermine public confidence and diminish long-term support for the search for life.

Astrobiology, unlike many other scientific disciplines, often benefits from an intense level of public interest, which has significant risks. The idea of ETL is deeply embedded in different cultural imaginaries, especially science fiction. Such popular representations and understandings often differ drastically from the realities of astrobiology research and possible discovery outcomes. This type of pervasive nonexpert interest presents a unique set of communication challenges, which manifest as distinct needs across different professional contexts between science, journalism, communication, and academia. While planning the structure and content of the workshop, the CDSLU organizing committee (OC) had conversations and meetings with representatives from these various communities to identify, in particular, the perceived needs and challenges of these various communities in advance. Insights about how to achieve these objectives, a selection of which are presented here, significantly informed the workshop's overall design.

For scientists in astrobiology and related fields, a primary need is the accurate and effective dissemination of their research findings. This is crucial for ensuring continued funding, securing institutional support, and ultimately facilitating career advancement within a highly competitive landscape. However, engaging in public communication efforts, particularly when dealing with ambiguous or preliminary results, carries inherent risks of misrepresentation and sensationalism. Researchers must maintain scientific integrity and transparency while employing careful messaging to avoid fueling public misconceptions, such as linking legitimate research findings to stereotypical "alien" imagery from popular culture. The potential to oversimplify or sensationalize findings by anyone relaying or trying to understand the importance of a scientific discovery poses a constant challenge for all involved.

Science journalists operate with another distinct set of professional norms. Their profession requires adherence to rigorous journalistic standards that, in addition to ensuring accuracy, require they maintain independence from the scientific subjects they cover. Journalists are often constrained by tight deadlines that can, in certain cases, limit their capacity for in-depth investigation. Depending upon their background training and the area of reporting focus, they may also lack a deep familiarity with the norms, methodologies, and language of astrobiology. These realities can lead to friction with regard to their ability to accurately report on discovery claims, especially those characterized by uncertainty. Furthermore, there is an inherent risk for journalists in appearing too closely aligned with a particular scientist and/or scientific institution, which can raise legitimate concerns about their objectivity or potential conflicts of interest, thereby eroding public trust in their reporting.

For science communicators and content creators, particularly those active on social media platforms, their professional realities are shaped by powerful incentives to maximize audience engagement, visibility, and personal branding. On platforms such as YouTube, X, and TikTok, where attention can directly translate into income, these pressures can inadvertently encourage simplified or exaggerated messaging, especially when the scientific content is ambiguous, speculative, or nuanced. A significant challenge for these communicators is that there is often a lack of direct access to knowledgeable experts and their informed opinions or guidance on a particular topic, which can become a barrier to framing discoveries responsibly and accurately.

Recognizing the different professional realities and the unique challenges of these various groups of participants in the CDSLU workshop led to the collective emphasis on several shared needs essential for effective collaboration between disciplines and the public. Foremost among these is the imperative for each community to gain deeper insight into the operational realities of the others, including their respective workflows, overarching goals, inherent constraints, and underlying incentives. This mutual understanding is critical for fostering more productive interactions before, and especially during, a discovery claim event. Furthermore, there is a shared need to develop common expectations with regard to the use of language, communication timelines, and individual and institutional responsibilities. Establishing these shared understandings proactively was considered vital for reducing friction during moments of heightened public interest, where rapid, yet accurate, information dissemination must be prioritized. Finally, the workshop highlighted the importance of forming professional relationships well in advance of any major discovery. Building trust and establishing clear communication channels during periods when the stakes are low ensure that such relationships will be in place when they are urgently needed.

As with earlier initiatives, the CDSLU workshop represented a strategic continuation of the astrobiology community's commitment to improve science communication. Preceding the CDSLU workshop, community-wide guidelines for biosignature detections were generated by the SoE workshop (Meadows et al., 2022), released in July 2021. These guidelines were subsequently reviewed by the NASEM CAPS in July 2022 (National Academies of Sciences, Engineering, and Medicine, 2022). The goal of these preceding efforts was to strengthen scientific confidence in future life detection claims by formalizing criteria for evidence. Both the SoE workshop and the CAPS review critically underscored the need to foster a better understanding of the relationship between scientific results and the effective communication of these results to different public audiences. The CDSLU workshop was specifically designed to address this gap.

CDSLU's focus on communicating discoveries in astrobiology drew upon decades of scholarly discourse and ongoing debate surrounding postdetection protocols within the search for extraterrestrial intelligence (SETI) community, which originated during the early 1960s. Both astrobiology and SETI share the overarching objective of searching for, and comprehending the potential for, life beyond Earth. However, these distinct fields diverge in crucial ways with regard to their scientific methodologies, specific detection goals, range of possible outcomes, and, significantly, their unique communication challenges inherent in finding evidence of extraterrestrial technology versus extraterrestrial biology. A core rationale for the CDSLU workshop was to apply similar critical questions about how to effectively communicate a major discovery, but to do so within the unique context of astrobiology and the need to interpret potential biosignatures, rather than solely within the framework of SETI and its interpretation of possible technosignatures. This distinction allows for tailored approaches that acknowledge the different evidentiary requirements and public perceptions associated with biological versus technological indicators of life.

The rationale for organizing the CDSLU workshop was in direct response to the recognized need for improved communication of astrobiology research and biosignature detection claims across both traditional and online media landscapes. In designing the workshop, the OC recognized that this need was twofold: it is anticipatory, in that it must acknowledge the likelihood of future discovery claims, and also applies to the present, in that it must address ongoing communication challenges faced by the astrobiology community. Astrobiologists are increasingly optimistic that missions and instruments currently under development will possess the capability to detect possible biosignatures both within our own solar system and in the atmospheres of distant exoplanets. These include robotic missions launched by several spacefaring nations to the ocean-world moons of Jupiter and Saturn, such as Europa and Titan (e.g., Europa Clipper, JUICE, Dragonfly), as well as Mars Sample Return missions and continuing rover-based explorations on Mars. Further out in time and space, NASA's Habitable Worlds Observatory (HWO), currently slated for launch in the late 2030s or early 2040s, is designed to detect possible biosignatures in the atmospheres of distant exoplanets. Consequently, a significant motivation of the workshop was to proactively lay the groundwork for communicating findings from all of these, and other, upcoming missions, and to increase community-wide readiness for future high-impact announcements.

Even though some of these instruments and missions are years, if not a decade or more, in the future, astrobiologists have already faced key challenges when communicating discoveries related to the search for life in the Universe. A recent example is the controversy in 2020 generated by a peer-reviewed article that claimed the detection of phosphine in the atmosphere of Venus. This highly publicized event underscored the critical need to prepare for the communication of potential discoveries well in advance of their actual occurrence. Another example occurred during the summer of 2024, when NASA announced that scientists working with the Perseverance rover on Mars had discovered tiny rocks with what were characterized as possible biogenic markings. This incident, which transpired after the CDSLU workshop, confirmed that it was not merely a long-range anticipatory exercise, but it addressed an urgent, present need. Improvements in communication strategies and practices between the public, scientists, journalists, and social media communicators are required now: the possibility that an imminent future discovery of life beyond Earth will be misunderstood, disbelieved, politicized, or not properly recognized as a groundbreaking achievement for science and humanity could jeopardize ongoing support by the general public for the search for life.

2. Workshop Demographics and Structure

The CDSLU OC assembled a diverse group of experts to ensure broad intellectual breadth and depth (Fig. 1). The workshop structure included two tiers of participants: Tier 1 participants took part in all discussions and writing exercises. Tier 2 participants did not participate in discussions, but had access to all the prematerials, recorded elements, and could interact via dedicated Slack channels. The primary disciplinary identity and career stages for Tier 1 and Tier 2 participants are shown in Tables 1 and 2. Note that many participants mentioned fitting into more than one primary disciplinary category; for example, some astrobiologists also work as science communicators.

The workshop spanned 4 days of virtual meetings (Tier 1 participants only), with prematerials provided to both tiers. Day 1 was an introductory webinar and introductory breakout groups, day 2 focused on historical case studies, day 3 on future scenarios, and day 4 on synthesis discussions to capture key insights from the workshop.

3. Materials Used: Prematerials, Background Reading

To facilitate informed discussions, the OC prepared a concise set of precirculated materials. These included three background readings from subject matter experts: "History of Astrobiology and Lessons Learned Executive Summary" by Steven J. Dick, "Some Insights from Science Communication Research" by Linda Billings, and "Social Sciences and Astrobiology: Some Orientation and Future Directions" by Kathryn Denning. These readings provided a foundational understanding of relevant history, communication theory, and social studies of science.

In addition, Aneka Kazlyna compiled five historical case studies to be discussed: Mars meteorite ALH84001 (1996), climate change (2001), the arsenic-based life study (2010), Laser Interferometer Gravitational-Wave Observatory (LIGO)'s detection of gravitational waves (2015), and the COVID-19 pandemic (2020). A summary of each case study included discussion questions that probed themes of uncertainty, consensus, and trust. Caleb Scharf also developed a document that outlined three plausible future discovery scenarios: "Another Earth" (exoplanet atmospheric biosignatures), "Icy Moon Oceans" (complex organic molecules on Enceladus), and "Mars Sample Return" (fossil-like structures and polyelectrolyte molecules). These scenarios were designed to stimulate discussion on communicating uncertain data, partial results, and issues such as biocontamination.

The following sections provide a condensed overview of findings from the CDSLU workshop report. The full report can be found on arXiv and as Supplementary Material (SM1).

4. Insights from the Past and Case Studies

To understand the complexities of communicating potentially impactful discoveries, workshop participants examined five historical case studies: Mars meteorite ALH 84001, climate change, arsenic life, LIGO's detection of gravitational waves, and the COVID-19 pandemic. Discussions of these cases revealed several recurring themes, including uncertainty, scientific consensus, competing interests, audience

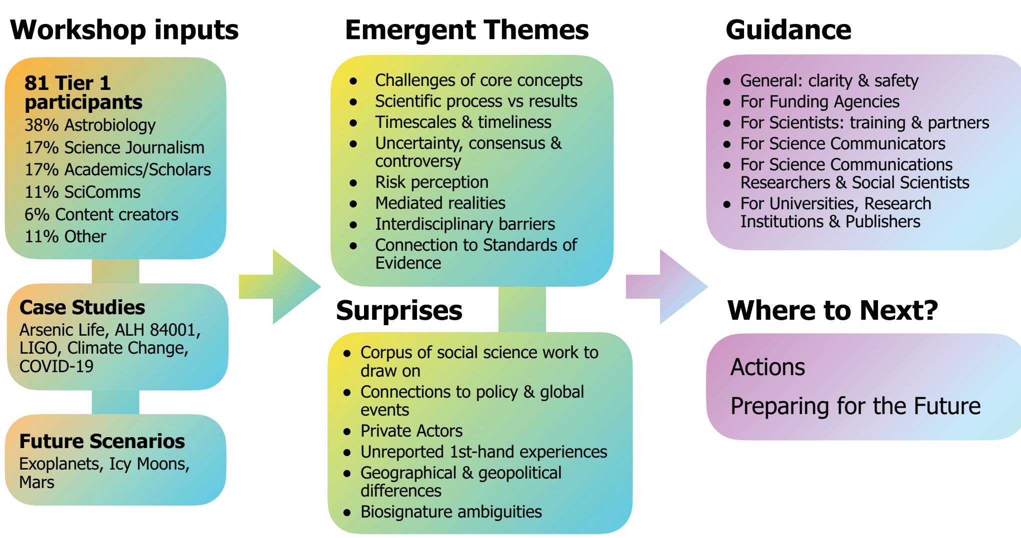

FIG. 1. Summary of the CDSLU workshop inputs, emergent themes, and guidance for communicating discoveries in astrobiology.

Table 1. Disciplinary Identity by Tier

Disciplinary identity	*Tier 1* (n = *81*)	%	*Tier 2* (n = *273*)	%
Astrobiologist	31	38	111	41
Science journalist	14	17	6	2
Academic/Scholar	14	17	73	27
Science communication researcher	9	11	42	15
Science content creator	5	6	16	6
Other	8	11	25	9
Total	81	100	273	100

characteristics, trust and mistrust, embargo and peer review, and communication strategies.

4.1. Case studies

4.1.1. Mars meteorite ALH 84001. The August 1996 announcement that possible microscopic fossils of ancient martian life had been detected in a meteorite that originated on Mars generated immense enthusiasm and speculation and a new level of public visibility for astrobiology and life detection claims. This case involved a prepublication leak of the findings, although it occurred before the widespread use of the internet, suggesting its unfolding might differ significantly today. Notably, the lead author, a midcareer NASA scientist and civil servant, faced minimal career challenges as a result of the media attention. Other scientists could test the claims and eventually reached different conclusions about whether the structures were produced by life.

4.1.2. Climate change. The climate change case study revealed the significant disconnect that can exist between overwhelming scientific evidence and public perception, often exacerbated by the politicization of science. Workshop discussions focused on the intentional spread of misinformation by organizations, which creates a false impression of scientific dissent and exploits public reliance on opinion leaders. This dynamic became especially pronounced following the 2001 release of the IPCC's Third Assessment Report, which clearly attributed recent global warming to human activity. Scientists often face pressure to avoid public disagreement and healthy scientific debate, fearing exploitation by those with an agenda. The public's reduced tolerance for scientific uncertainty when stakes are high, as seen in climate change, adds another layer of complexity to communicating about astrobiology discoveries.

Table 2. Career Stage by Tier

Career stage	*Tier 1* (n = *81*)	%	*Tier 2* (n = *273*)	%
Midcareer academic	21	26	24	9
Senior professional/ Academic	15	18	44	16
Early-career professional/ Academic	9	11	34	12
Graduate student	7	9	83	30
Postdoctoral researcher	5	6	15	6
Other/Blank	24	30	73	27
Total	81	100	273	100

4.1.3. Arsenic life. The arsenic life case, which made headlines in December 2010, highlighted several critical issues, including the safety of early-career scientists, dynamics of peer review, the influence of the internet and social media on science communication, and various biases (e.g., racism, sexism, ageism). Discussions emphasized the responsibility of senior scientists to protect early-career researchers from online harassment, as exemplified by a highly publicized instance in which an early-career female scientist faced attacks that impeded her career. Another significant point was the divergent, and often conflicting, motivations of various actors in the overall science communication process, including scientists, institutions, journalists, and influencers.

4.1.4. LIGO and gravitational waves. The LIGO discovery in 2015, which confirmed gravitational waves predicted by Einstein, stood out as a successful example of a major scientific announcement. This success was attributed to a well-coordinated communication strategy involving a prepared media and carefully managed embargo. The nature of the discovery, a confirmation of established theory rather than an initial, ambiguous finding, also contributed to its smoother reception by the public. Despite the positive outcome, this case also underscored the challenges of communicating complex physics to a broad audience and the challenges that emerge as a result of the media's tendency to oversimplify or sensationalize. The incident highlighted the fact that not all scientific breakthroughs are equally amenable to simple narratives, and that preparing well in advance and managing expectations are key.

4.1.5. COVID-19. Beginning in early 2020, the COVID-19 pandemic presented a unique communication challenge characterized by rapid data dissemination, an evolving media landscape, and very high stakes for the public. The urgent need for public health information often meant data were released before full peer review, highlighting that the peer review process, while essential, does not guarantee correctness, nor does a lack of peer review equate to incorrectness. This scenario emphasized the complexity of communicating rapidly evolving scientific understandings, where transparent communication of uncertainty, which ideally should have built trust between the public, regulatory agencies, and the corporate world, can also be misconstrued or weaponized. The pandemic also highlighted how rapidly changing scientific guidance, although part of the scientific process, can erode public trust if not managed carefully.

4.2. Cross-cutting themes from case studies

4.2.1. Uncertainty. Uncertainty was acknowledged as a fundamental aspect of scientific inquiry, yet it also emerged as a significant source of public confusion and skepticism. Participants explored methods for communicating the limits of current knowledge without eroding scientific credibility. Crucially, some viewed transparent communication of uncertainty not as a weakness but as a foundation for building trust. This requires moving beyond simplistic "yes/no" answers and explaining the nuances of scientific confidence. The challenge is amplified by media trends that often favor concise, exciting narratives over detailed explanations of ambiguity. Public perception of uncertainty and its role in science is inherently complex. Even if an announcement is carefully worded, as in the arsenic life and ALH84001 cases, it may still convey more certainty than exists within the scientific community. Similarly, evocative imagery, such as that of ALH84001, can create an impression of a "slam-dunk" discovery when the science is more complicated. Interestingly, participants reported that when stakes are high and fear is elevated, scientific uncertainty becomes less tolerable for the public, as exemplified by the controversies over climate change and COVID-19. Although public audiences may react poorly to scientific uncertainty, particularly with COVID-19, it should ideally signal honesty and build trust when clearly communicated. Communicating the complexity and uncertainty of science effectively involves emphasizing what is known, what remains unknown, and the ongoing efforts to address those unknowns. This approach contextualizes the scientific process, demonstrating that an initial discovery is not a definitive endpoint, and helps to establish appropriate timelines for future developments.

4.2.2. Defining and communicating consensus. Defining and communicating scientific consensus proved to be a persistent tension. While in fields such as physics, consensus often relates to repeatable, quantifiable results, its definition in astrobiology remains less clear. For example, in the search for life, there is a struggle in defining what constitutes "life." Participants debated the merits of announcing preliminary results early and risking error, versus waiting for broader agreement and risking perceptions of secrecy or slowness. Some scientists worried that emphasizing consensus could lead to groupthink or be seen as censorship, potentially stifling dissent. Conversely, others noted that the lack of a unified view about a reported scientific discovery could undermine acceptance of other solid findings. The media's tendency to seek opposing viewpoints, even from fringe positions, further complicates the communication of consensus.

4.2.3. Trust and mistrust. Trust, or its absence, was identified as central to how audiences interpret scientific claims, particularly in the wake of the COVID-19 pandemic. Workshop discussions highlighted that trust is not solely about informational accuracy but also encompasses the perceived credibility and motivations of the communicator, and their relationship with the audience. Mistrust can stem from past institutional failures, perceived elitism, or geopolitical dynamics, all of which influence the reception of life detection claims across different contexts. Trusted sources vary across audiences and scientific subjects, and those who are trustworthy are not always trusted. Communicator characteristics, including affect, gender, race, and age, can influence trust or mistrust due to prior experiences and prejudices. Whether communicators are perceived as acting in the public interest also impacts audience trust. Disentangling credible information can be challenging for audiences, leading them to rely on mental shortcuts, or heuristics and social cues, which may increase polarization.

4.2.4. Embargo and peer review. While critical for scientific integrity, traditional embargo and peer review practices were recognized as potentially unreliable in the era of leaks, preprints, and social media. Strategies successfully used in fields such as physics, similar to that by the LIGO collaboration, may not directly translate to life detection, where the subject matter often elicits greater public interest, anxieties, and varied interpretations. Scientific journals, as information gatekeepers via peer review, can present a tension between the scope of their gatekeeping and the interpretation of new findings by other educated community members, including academics, science writers, and the public. The arsenic life case demonstrated the need to reevaluate how to navigate this tension publicly and privately, given the evolving communication landscape. Peer review is fundamental for career advancement and funding, yet its process can be circumvented, sometimes for public good, other times for different purposes. The increasing popularity of preprint servers, lacking external quality assessment, and the rapid release of COVID-19 data for public good illustrate that peer review does not guarantee correctness, nor does its absence imply incorrectness. Participants wondered how to convey to persons not trained in the scientific method that disproved results are part of the scientific process rather than a flaw. Historically distinct scholarly and public communication lines may now be blurring, suggesting a continuum of engagement across audiences.

4.2.5. Competing needs and interests. The workshop also identified that different stakeholders often have competing interests and power dynamics. These include scientists, institutions, journalists, content creators, and policymakers. Conflicting goals or timelines among these groups can lead to confusion or conflict. To mitigate these risks, participants stressed the importance of developing communication plans proactively and adapting them to different public audiences as the search for life progresses.

5. Insights from Hypothetical Future Scenarios

To anticipate and address challenges in communicating a potential discovery of life, workshop participants explored three hypothetical future scenarios, each representing different levels of data abstraction and perceived public risk. These included the following: distant observations of exoplanets, *in situ* analysis on our solar system's ocean worlds, and measurements from samples returned from Mars. Discussions for each scenario covered potential stakeholder considerations, audience responses, scientific community preparedness, and unique communication challenges, acknowledging that future social contexts and communication landscapes (e.g., artificial intelligence [AI]'s impact on media) will certainly evolve beyond current assumptions.

5.1. Hypothetical scenarios

5.1.1. Another Earth. This scenario envisions the HWO in the 2040s detecting spectroscopic data on a rocky exoplanet suggestive of a large, active biosphere with metabolically generated gases in a temperate environment. While conclusions rely heavily on modeling, primary investigators would consider this the strongest evidence yet of a "living planet," despite the abstract nature of remote observational data for the public.

5.1.2. Icy moon oceans. In our solar system, NASA's proposed flagship Enceladus Orbilander mission (2030s–2050s) finds unequivocal evidence of an active hydrothermal system and chemical processing potentially attributable to living systems. The detection of a unique complex biomolecule, despite the absence of other expected molecular species, would be considered a putative life detection with many unanswered questions.

5.1.3. Mars sample return. This scenario involves the successful return and analysis of martian samples to Earth by 2031. Scientists discover fragments of unexpected polyelectrolyte molecules and microscopic structures consistent with fossilized organisms. This represents strongly consistent, although not yet independently examined, evidence of ETL. A major concern here is public uproar regarding the potential biocontamination of Earth.

5.2. Themes

Discussions across these scenarios highlighted several key themes. Participants emphasized the necessity of taking ownership over uncertainty, recognizing that no life detection will be completely unambiguous. Any biosignature discovery should clearly communicate inherent uncertainties, focusing on the novel yet robust aspects of observations. Preparations should include acknowledging diverse scientific opinions and providing contextual scaffolding, such as confidence scales, and frameworks, such as the ladder of life detection (Neveu et al., 2018). The abstract nature of model-dependent discoveries from remote observations can be difficult for the public to grasp, requiring advanced planning for the interpretation of visualizations, the ability to convey to the public the findings via multimodal communications (including American Sign Language), open-source data access for validation, and press releases tailored for diverse audiences. The current media landscape, driven by rapid news cycles and viral content, poses challenges for journalists to capture nuanced perspectives, necessitating stronger relationships between discovery agents such as the NASA and the media.

Ethical considerations were prominent, particularly concerning the roles of private companies in space exploration and the enforceability of international law regarding sample collection or territorial claims. The issues of planetary protection and contamination control will become more critical once there is a human presence on Mars, raising questions about whether detected life is indigenous or a result of exploration.

The ambiguity of remote observational data was a recurring challenge, as definitive life detection from telescopic or robotic observations of exoplanets is difficult, if not impossible. Communicators need to prepare the public to see "traces from faraway places before they see faces," addressing the risk of over-hyped or misrepresented findings, particularly given realistic artist renderings and the growing impact of generative AI. Public excitement may also be tempered by the lack of direct images or *in situ* exploration for exoplanet discoveries.

Clarity in language is paramount. Precise scientific jargon should be accompanied by plain language explanations, especially for terms such as "potential biosignature" or "Earth-like," to prevent misinterpretation or loss of public interest.

The potential impact on communities of faith was also considered. While some religious groups might view ETL as a challenge to the uniqueness of Earth life or human creation, historical resilience to other scientific discoveries suggests diverse responses. A deeper understanding of various religious perspectives is necessary.

Discussions also emphasized the need for distinguishing *confirmed* from *assumed* knowledge (e.g., the presence of hydrothermal vents on Enceladus); engaging the imagination through storytelling to foster awe and potentially increase funding; and connecting discoveries to the human experience by highlighting relatable scientific issues (e.g., protecting extraterrestrial microbial habitats) or emphasizing spin-off technologies.

Building public trust is a foundational element of communicating scientific discovery. Lessons from the COVID-19 pandemic highlight existing low public confidence in science. Specific concerns arose regarding public reaction to housing extraterrestrial samples in facilities similar to those for deadly pathogens. Strategies for improving public confidence in the scientific method, addressing trust in announcements from nongovernmental or foreign entities, and acknowledging political factors were discussed. This included the development of a global public education platform with internationally sourced discoveries and fostering international science–media collaborations.

Concerns related to national security might arise if a discovery comes from a less transparent commercial entity or is perceived as a threat, potentially leading to different handling protocols depending on the discovering agency. Power dynamics within large scientific collaborations, where a few individuals often become the "face" of a discovery, were also noted as requiring mitigation strategies.

Points of tension and friction were identified in communication strategies. The debate between peer review versus releasing preliminary discoveries suggests a need for defining a "threshold" for life detection announcements, and for nurturing strong journalist–scientist relationships. Balancing excitement with factual accuracy requires communication training, institutional support, and potentially a multistaged evidence approach rather than a single "Eureka moment." Deciding what to say, and how to say it, involves providing press packets while respecting scientists' comfort with a narrative. Finally, the nondetection case was considered, noting that a definitive lack of life elsewhere might be more surprising than microbial discovery, potentially revitalizing studies on the emergence of life on Earth.

6. Common Themes Across All Discussions

Workshop participants reviewed notes from earlier sessions on case studies and future scenarios to identify consistent themes. This synthesis aimed to pinpoint recurrent topics and connections, while acknowledging individual differences. Nearly all discussions converged around three overarching themes: (I) "classical" problems of science communication, (II) challenges posed by "mediated realities" (Scheufele, 2014) and a "post-truth" landscape (Iyengar and Massey, 2019), and (III) the crucial role of interdisciplinarity.

6.1. Classical problems of science communication

This theme centered on the fundamental difficulties of effectively transmitting scientific information about potential astrobiological discoveries so that the public accurately understands them. Participants expressed concern about the public's tendency to either under- or overinterpret findings, often due to misunderstandings of the nature of science itself, particularly regarding concepts such as certainty, uncertainty, and scientific consensus.

A core challenge is defining and communicating "life" itself, as scientific and popular understandings may not align. There is a recognized need for a clearer, differentiated terminology to precisely describe what might be detected. Compounding this, historical data indicate that a significant portion of the global population already believes that ETL exists or has been discovered (Crowe, 1999; Determann, 2021; Dick, 1982; Malik and Determann, 2024). Furthermore, precise terminology such as "consistent with" can be misinterpreted by the public as conclusive evidence.

Communicating the scientific process versus only its results is vital to distinguishing raw evidence from its interpretation, as exemplified in the Mars meteorite ALH84001 case (McKay et al., 1996; Shen et al., 2023). The disparity between scientific timescales (slow, peer-reviewed) and news media cycles (fast, short attention spans) poses a significant challenge. While preprints can accelerate dissemination, they do lack the important feedback of peer review. Public announcements require complex coordination among scientific teams, PR offices, and journals. Releasing information too quickly risks misleading claims, while delays can foster perceptions of secrecy or conspiracy. Embargoes are often ineffective in a competitive journalistic landscape (Kiernan, 2000).

The inherent uncertainty and evolving nature of scientific findings, contrasted with the public's desire for definitive answers, make communication difficult, especially when information is reduced to headlines. Scientific consensus is a complex concept, varying in definition and mechanisms in different situations (Fuller, 1986). Its relevance is particularly evident in policy-related fields such as climate change (Wesselink et al., 2015) or in public health crises such as COVID-19 (Gerotziafas et al., 2021), where rapid consensus is critical. While consensus exists for cases such as the martian meteorite not containing *bona fide* fossils, dissensus can hinder communication (Jasanoff, 2019). Traditional journalistic norms, which often seek opposing viewpoints, can further complicate the communication of consensus. A long-term communication strategy is needed to integrate discussions of uncertainty, future research, and consensus, highlighting progress even when full certainty or agreement is yet to be achieved.

The perceived risk of finding life elsewhere also impacts communication effectiveness. Despite widespread belief in the existence of ETL (Lampert and Papadongonas, 2017), surveys suggest low public support for increased funding for the search, especially for intelligent ETL (Kennedy and Tyson, 2023; Schwartz, 2020), with a significant fraction of US citizens believing that aliens could be hostile (YouGov, 2010, 2015; 2022). Public perception regarding planetary protection (e.g., concerns about biocontamination from returned samples) remains poorly quantified, and existing international laws such as the Outer Space Treaty (United Nations Office for Outer Space Affairs [UNOOSA], 1966) are not easily enforceable. Utilizing risk communication expertise and assessing public perceptions are crucial.

6.2. Mediated realities and a post-truth media landscape

Significant shifts in the media environment present new communication challenges, in what some describe as a "post-truth society" (Iyengar and Massey, 2019), where scientific information is increasingly mediated by social and political divisions (Scheufele, 2014). Key changes in recent periods include media fragmentation, increased openness to new actors (including "fringe" voices), and rising political polarizations.

The digital public sphere, dominated by social media and algorithmic design, facilitates cognitive biases and "armchair science," where individuals may prioritize, or be fed, interpretations that align with their preexisting worldviews or prejudices. The question arises: "How can people distinguish a voice of reason from statements that lack support by evidence?" This highlights a clear need for curation of online information.

The supply-side of information reflects a highly competitive attention economy, where various interests vie for engagement. Scientists have incentives to attract attention or protect themselves, and tools such as preprints offer new avenues for these interests to influence public discourse. Journalists and communicators, driven by economic or institutional incentives, often prioritize engagement over strict objectivity. Furthermore, other actors, motivated by profit, ideology, or politics, opportunistically use discoveries to advance their goals, including propagating conspiracy theories. This can foster public skepticism even toward genuine scientific communication.

A critical distinction was identified between misinformation (unintentional communication failures leading to misinterpretations) and disinformation (explicit, intentional efforts to deceive or promote agendas, sometimes fueled by prejudice or jealousy). While both lead to negative outcomes for science communication, their different etiologies may require distinct countermeasures. In addition, distinguishing between misinformation and disinformation can often be challenging.

6.3. Interdisciplinarity and communicating about the search for life in the Universe

Participants frequently stressed the importance of transcending traditional disciplinary boundaries in both astrobiology research and communication efforts. Existing divisions between natural sciences, social sciences, and humanities create barriers to productive discovery and discourse, impacting research programs, publication, and who can effectively communicate findings to public audiences.

There was a strong call for greater recognition of the contributions from social scientists and humanities scholars. For instance, the Royal Society's difficulties with genetically modified crops were cited as an example where scientific expertise alone was insufficient without understanding public reaction, necessitating social science input. Fields such as science communication, risk communication, science and technology studies, anthropology, psychology, and philosophy offer crucial insights into understanding diverse public responses and tailoring effective communications.

In practical terms, recommendations included directly integrating social scientists and humanities scholars into research teams and providing communication training for natural scientists. Such training would equip scientists with strategies to adapt to different audiences and effectively convey complex concepts. In addition, involving communications and media scholars in fostering discussions about astrobiology ahead of discoveries could help inoculate against misperceptions. Developing curricular modules for primary and secondary schools on science and society topics, emphasizing the complex nature of scientific discoveries, was also suggested.

7. Surprises, Disconnects, Misunderstandings

The workshop discussions revealed several "surprises" for participants, categorized primarily into insights for natural scientists and those for social scientists and science communicators. Natural scientists were surprised by the extensive and deep scholarly expertise available within the social sciences. Conversely, social scientists were surprised by the inherent ambiguity in scientific findings, noting that clear, definitive results are rare, and by the limited number of social science studies on public reactions and consequences of past controversial scientific revelations, such as the ALH84001 meteorite and arsenic-based life discoveries.

7.1. Several broad categories emerged from the discussions

7.1.1. Communication science, information science, and social science. A key distinction was made between science communication as a practice and the academic fields of social science, communication science, and information science. Participants noted that social sciences, including computational social sciences, offer decades of research on information and communication effects in society, applicable to science communication. Examples include studies on the economic effects of major events, social unrest from big announcements, social media's impact on misinformation and polarization, and social network analysis for identifying influential actors. The inevitability of belief polarization regarding potential astrobiology findings was acknowledged, underlining the need for preparing for communication with grace and understanding. Despite extensive general research on the impact of significant public announcements, there is a notable lack of robust, evidence-based research on the specific impact of ETL discovery on economic, political, social, religious, or value systems globally, underscoring a critical need for dedicated research in this area. Communicating such a discovery would necessitate the involvement of key governmental partners, especially given the potential for multiple countries or geopolitical actors to compete for or claim discoveries.

7.1.2. Private actors. The increasing role of private funding and initiatives in astrobiology (e.g., Breakthrough Listen, Bigelow Aerospace, the Star Shot project, Blue Origin, SpaceX) introduces a significant "wild card" in the communication landscape The rise of such efforts impacts not only scientific priorities but also the social science and communication of discoveries, particularly regarding adherence to peer review and traditional scientific discourse. For example, private space exploration could potentially surpass government initiatives in life detection, with major implications for communication and subsequent policy.

7.1.3. Prior controversial discoveries. Participants who are scientists and were involved in past controversial discoveries shared firsthand accounts, revealing an amount of surprise among other scientists that such experiences had not been systematically examined, or that practices had not been developed in response, within the field of astrobiology. The need for sociological studies focusing on controversial discoveries, including competition, biases, and nonscientific incentives among scientists, was emphasized.

7.1.4. Biosignature misunderstandings. Social scientists expressed surprise at the complexity of exoplanetary science and spectrometry, particularly the nuanced reality that biosignature detection is a long, complex process likely to involve doubt and to require follow-on research, contrary to an expectation of clear detection. Even within the scientific community, the definition of the term "biosignature" itself is highly debated.

7.1.5. Geographical and geopolitical differences. Discussions revealed differences in goals, funding, and focus between scientists from Western countries and those from nations such as China, Russia, Iran, and some African countries. While commonalities exist among scientists and communicators globally, the prevailing communication approach was seen as a top-down, the Western perspective, with limited consideration of how the public in various regions might or should care about the topic.

7.1.6. Scientific reporting in the media. The workshop revealed the extent of difficulties that science reporters are experiencing in their field. Moreover, in many ways, these difficulties stem from funding constraints for both scientists and science communicators and the pressure to produce work that generates additional revenue.

8. Relationship of Workshop Outcomes to SoE

The inherently challenging nature of detecting ETL necessitates multiple, interdisciplinary measurements to establish a convincing claim. As life detection is unlikely to be instantaneous or unambiguous, requiring extensive community input for interpretation, effectively managing public perception is critical. This involves making the public aware of the potentially lengthy, multistep confirmation process, a goal that the Community Biosignature Assessment Framework (BAF) from the 2021 SoE Workshop is well-suited to facilitate.

In 2021, the NASA Network for Life Detection and the Nexus for Exoplanet System Science communities developed this generalized scientific framework to assess biosignature discoveries (Green et al., 2021). The framework comprises five questions that address biosignature detection and authenticity, biological versus nonbiological origins, and future steps for strengthening or disproving life hypotheses. Answering these questions systematically boosts confidence in life detection claims by validating signals, ruling out false positives, and assessing plausibility. It also contextualizes the scientific community's progress, from initial tentative signals to independent verification and detailed testing.

8.1. Uses of the BAF for communication of the life detection process

The BAF is a valuable tool for communicating the nuanced, complex, and uncertain scientific process of life detection to the public. It helps convey what has been discovered and what still needs to be done, guarding against "slam-dunk" claims and informing journalists and the public about the evolving confidence level as independent evaluations and new data emerge.

Effective, trustworthy communication of biosignatures requires wide community adoption of communication guidelines from both journalists and astrobiologists, based on reported evidence. For example, communicating an exoplanet biosignature detection accurately requires emphasis on the chain of interpretations; from signal identification and confirmation of indigenous origin, to attributing specific chemical compounds to biotic processes, and finally, modeling to suggest a low likelihood of abiotic presence. This multilayered inference contrasts sharply with public perceptions of "detection" as direct observation of aliens through a telescope. Given the high costs of life search efforts, maintaining public support hinges on clear communication of any project's rationale and on fostering confidence in scientific results and processes.

8.2. Considerations for the use of the community BAF

By conveying the BAF's process of validation and exploration, including how to grapple with incomplete or ambiguous information, we can build public trust in advance of discoveries and provide guardrails against overstating findings by scientists or journalists. It is also crucial to address conspiracy theories and preconceived notions, and to counter misinformation when reporting discoveries. Communicating "the unknowns"—both identified and unforeseen—provides essential context for understanding confidence in life detection claims, drawing inspiration from other fields facing similar challenges.

8.3. Supporting the use of the community BAF

While the workshop was not tasked with producing communication best practices, it identified this as a high priority for future work, requiring additional community input. Journalists specifically requested guidance on how scientists could best interact with them to establish trust, highlighting the value of noninterview interactions fostered by the workshop. Future activities should delve deeper into lessons from past cases (Section 4), current best practices, and transformations in the communication landscape, such as the growing role of AI (Sections 9 and 10).

The BAF could also drive the development of best practices, particularly for conveying uncertainty and confidence. Newer scientific fields, such as exoplanet science, are adopting a "team of teams" paradigm for analyzing high-impact data, where multiple independent sub-teams increase confidence and quantify uncertainty. For life detection claims, such an effort could also involve a team of communication and social scientists.

The group also discussed developing "standards for life detection communication" to parallel the scientific efforts. These could include briefing packets for journalists on past tentative life evidence reports (Section 4) and recommendations for scientists on visual design and wording. Infographics, hyperlinks to the BAF, and background materials could help journalists focus on compelling stories. Communication design should prime the public for a continuous, iterative understanding of confidence and uncertainty, rather than a linear scale, drawing inspiration from other fields that have tackled the conveyance of "unknowns." Pathways for scientists to collaborate with designers and social scientists on communication questions were also deemed necessary.

8.4. Other topics discussed

Discussions also touched on the pros and cons of the standard practice for soliciting rapid comments on embargoed articles. While important for preparing the astrobiology community to address hyperbolic claims, some scientists expressed discomfort with being asked to comment on complex articles they had only just received, especially when contrasted with the years of work by discovery teams. This tension highlights a perceived unsatisfactory form of "balance" in rapid commentary, although others noted issues with public information offices hindering quick responses.

9. Guidance for Individuals, Agencies, and Institutions on Communicating Life Beyond Earth

While the aim of this report was not to convey consensus recommendations, this section presents notional suggestions and guidance raised by workshop participants for key stakeholders, including individuals, agencies, and institutions. These are initial outputs, acknowledging that the communication landscape will evolve and require ongoing investment, resources, and expert attention. The intent here is to indicate some ways to proactively prepare stakeholders, and cultivate resources and infrastructure for accurate, engaging, coordinated, and safe announcements. While some guidance may be US-centric due to the workshop's organization, most are broadly applicable.

9.1. General guidance

Announcements should be direct and clear. Press offices should issue concise preannouncement notices with involved scientists' names and a brief summary (e.g., "evidence consistent with life, more work needed") to help prevent misinformation, speculation, and public anticlimax from vague preannouncements. This enables journalists to conduct preinterviews and research for more informed reporting.

Clarity and honesty in communication are paramount. This involves ensuring that both communicators and their audiences can understand scientific terminology, especially complex jargon that can lead to disinterest or misinterpretation. Training for scientists and journalists should include lists of commonly misunderstood terms (e.g., "extraterrestrial life," "habitable," "detection") and guidance on using better descriptions or analogies (Blancke et al., 2017). Agencies and informal education centers can "prebunk" these terms through process stories or hands-on activities to reduce future miscommunication (Maertens et al., 2021). While rogue actors may disseminate misinformation, scientists and communicators should maintain their focus on issuing accurate information (Cho, 2016; Drake, 2016; Sample, 2020). Combating disinformation should be handled by institution-paid communicators trained in this expertise, rather than scientists.

Prioritizing safety for all participants is crucial. Scientists at the center of major announcements often lack adequate protection, leading to threats, denigration, and impacts on their research, funding, and personal safety (O'Callaghan, 2020; Wright, 2020). This is particularly acute for early-career or pretenure scientists and is exacerbated by the online environment where personal details can be widely shared, which may result in harassment. An ETL discovery requires a detailed communications strategy that prioritizes individual safety.

Integrating and funding ongoing research into scientific communication are essential, as an ETL discovery marks a beginning, not an end, to conversations about research, philosophy, policy, and more. Continuous research into policy, evolving public opinions, and effective communication strategies are necessary. Agencies and universities should actively maintain institutional memory to build on successes and avoid past mistakes, prioritizing long-term reputation over short-term fame. Previous work should be shared effectively to allow new and historically excluded individuals to contribute.

9.2. Guidance for funding agencies

Effective communication requires dedicated funding sources. Current efforts by scientists are often *ad hoc*, unpaid passion projects, or they are ancillary to funded research. These efforts must be intentional, prioritized, and sustained long term. Expecting researchers to develop communication skills and resources *pro bono* is unrealistic and unsustainable. Funding agencies, such as stakeholders, should use strategic foresight to anticipate communication challenges and prepare in advance. There is precedent for agencies such as the NASA and National Science Foundation (NSF) to disseminate information, and funding communication efforts promotes this mandate (NASA, 2024; United States Congress, 1958).

Specifically, agencies and institutions should support scientists' communication and verification endeavors by providing investigator-level grants for communication activities and incentivizing engagement (e.g., awards, tenure consideration). Scientists should also support peers who engage in public communication, countering the "stay in your lane" mentality, as public support directly translates to funding. Agency-funded scientists must be allowed to speak freely and immediately with the media to provide timely context, as slow approval processes can hinder accurate reporting in fast-paced news cycles. Grant applications could explicitly include media training as a budget item. Funding agencies should also consider "triggered funding"—a discrete grant program for independent verification of potential life discoveries (Meadows et al., 2022). This would provide a more rigorous, specialized avenue for high-impact claims, focusing on ruling out nonbiological explanations, often requiring different expertise from the original discovery team (Vickers et al., 2023).

Agencies and institutions should support the development and maintenance of educational, public-facing content. This includes paying communicators and scientists to create "prebunking" articles and maintaining a robust data infrastructure for reliable, vetted information. These resources should be high-quality, engaging, multimodal, accessible, appeal to diverse audiences, address public misconceptions, and be cocreated by communicators, artists, and journalists who are compensated for their work. Such repositories serve as critical resources for journalists during high-profile news cycles, and they must be resilient to cybersecurity attacks.

Funding social science research is vital, as science communication issues often link to broader societal concerns. While precedents for federal funding exist (e.g., National Institutes of Health, Department of Energy, NASA, NSF), there is a critical need for more recent, astrobiology-related social science and science communication research. Funding agencies should target identified research areas, facilitate collaboration between social scientists and astrobiologists, and implement grant opportunities that support interdisciplinary internships.

Agencies must also develop institutional safety structures. Past astrobiology announcements have led to media frenzies that have threatened scientists' safety, a problem exacerbated in today's online environment, particularly for scientists with marginalized identities (Sheikh et al., 2021; Smith et al., 2021; Wolfe-Simon et al., 2011). Funding agencies, research institutions, and publishers should provide resources or develop structures for safety, including dedicated paid personnel to combat misinformation and correct myths online. Emergency institutional support must be readily available when threats arise, and it should strike a balance between transparency and protecting researchers. Secure information sources capable of handling heavy traffic and resisting cyberattacks are also a critical aspect of safety.

Finally, agencies should develop strategies that consider national and international political implications. Recognizing that ETL discoveries might originate from non-US institutions or the private sector, potentially from countries with strained diplomatic relations, US funding agencies must develop specific communication guidance for these scenarios. They should clearly communicate expectations to astrobiologists, maintain good relations with the government, and utilize social science to understand public reactions to discoveries from diverse sources.

9.3. Guidance for scientists

These recommendations apply to all researchers intersecting with ETL, taking into consideration varying levels of funding and organizational priorities.

To improve their communication skills and better understand how different sectors of society may receive a scientific announcement, scientists should rely on the publicly available tools, statistics, and methodologies created by the social sciences (Jamieson et al., 2017). Scientists may also consider taking media training courses to better understand science journalism, interview best practices, and obscured media processes. While challenging due to real or perceived lack of time or relevance, media training improves communication quality and is particularly crucial for astrobiology (Bardi and Meyers, 2015). Scientists should see value in practicing the communication of caveats and clarifications without appearing evasive or dampening excitement, even if life is not detected (e.g., the Viking mission's "active surface material" becoming unexpected soil chemistry) (Klein, 1999; Reinecke and Bimm, 2022). Recent examples, such as the Cheyava Falls rock discovery by the Perseverance rover in the summer of 2024, demonstrate the successful, clear, communication of possibilities without overstating findings. Scientists should also remain authentic, appreciating that misinterpretations can occur.

Scientists can and should consider proactively building relationships with media professionals. Instead of being reactive, scientists interested in life detection discussions can identify trustworthy journalists and informal science communicators and reach out to offer expertise. Leveraging institutional communication offices to create background materials and prepare announcements years in advance is also crucial, acknowledging potential differences in agendas between institutions and scientists.

Finally, scientists should be encouraged to actively seek opportunities to communicate with and understand different public audiences. This involves self-education of science communication research, incorporating audience interests into articles and press releases, and building partnerships with primary/secondary schools or museums to design educational materials on life detection and the scientific process. Pursuing pedagogical training, engaging with broader outreach initiatives, and consulting a wide, diverse set of experts (including indigenous and non-EuroWestern perspectives) are essential for a holistic view of potential global impacts.

9.4. Guidance for science communicators

These recommendations are for freelance and staff journalists, media professionals, editors, museum exhibit designers, press officers, public information officers, and social media content creators. Many of the recommendations are already journalistic best practices and serve as reminders for covering a high-stakes discovery such as ETL.

Science communicators could provide or participate in media training courses for scientists. If media professionals desire trained and confident scientific sources, they could facilitate training across all career levels and media formats (e.g., panels, workshops, webinars). Conversely, independent journalists could critically assess the source of scientists' media training, as institutional training may carry biases aimed at promoting the institution; seeking independent sources is crucial for an unbiased context.

Communicators would benefit from staying up-to-date with ETL research and researchers by engaging with relevant workshops or conferences (e.g., AbSciCon, American Geophysical Union, American Astronomical Society) and cultivating relationships with scientists years in advance. This ensures accurate, updated information and a curated list of reliable sources for unexpected announcements (Wu, 2023).

To inoculate against misinformation, science communicators and media outlets could proactively provide factual, contextualized content ("prebunking" or "scaffolding") on websites to build public knowledge before an ETL discovery. Stories explaining the astrobiological process can prime audiences for complex discoveries, potentially finding homes in museums or informal educational networks. Communicators should not rely solely on peer review, especially in a multidisciplinary field that includes predatory journals, but consult experts across relevant disciplines (astronomy, biology, social science) for a more comprehensive understanding of a scientific discovery. Vigilance against AI-generated misinformation (images, video, audio, text) will be critical. Communicators should educate themselves on identifying it and include "prebunking" on this topic in their communications (Lewandowsky et al., 2020).

Finally, communicators may consider training in new and nontraditional reporting media. As a growing percentage of people consume news from online sources and social media, familiarization with and training in formats such as short-form videos, infographics, and interactive data visualization are essential for reaching broad audiences with an ETL discovery (Kelly, 2023; Pew Research Center, 2024).

9.5. Guidance for science communication researchers and social scientists

This guidance is for anyone studying science communication within scientific fields, including communications scientists, sociologists, psychologists, historians, and political scientists.

These researchers could expand astrobiology-relevant research to address context-specific factors that influence information acceptance. Key areas include communicating uncertainty and caveats, managing controversies while maintaining evidence-based balance, understanding preexisting public worldviews, addressing terminology concerns, handling misinformation and rogue actors, and evaluating public knowledge about the search for life beyond Earth. This research is vital as the public is not a "blank slate" regarding astrobiology due to popular culture depictions.

Direct collaboration with astrobiologists is encouraged to connect them to the latest science communication research literature. This would offer novel avenues for targeted research projects such as collaborative literature reviews that apply state-of-the-art science communication research to astrobiology.

9.6. Guidance for universities, research institutions, and publishers

Universities and research institutions could provide funding, full-time equivalent (FTE) time, and media training for academics and researchers. This training, whether in-house or externally funded, would cover working with media, media operations, and preparing for interviews. Providing dedicated funding and FTE time is critical, as scientists are typically not compensated for media interactions, and such support fosters skill development and enhances institutional reputation.

Press offices could consider nonstandard press office strategies for an ETL discovery, which will far outlive a typical news cycle. To allow for more well-informed and prepared media, they could issue full written press releases or summaries under strict embargo ahead of press conferences, knowing that the discovery's importance would ensure media attendance despite this nontraditional approach. This facilitates better-researched, more nuanced follow-on stories and deeper audience engagement.

10. Where to Next?

Historically, there have been numerous instances where humanity believed it discovered life, or even intelligent life, beyond Earth—from martian canal builders to microscopic fossils in meteorites, radio signals from distant civilizations, and alleged megastructures around stars. While scientists generally exercise caution with incomplete evidence, many purported discoveries of alien life have been widely reported over the past 150 years. The current communication landscape is rapidly evolving with social media and generative AI, necessitating a "map" to navigate it safely. This workshop marks an important step in fostering greater understanding between researchers and science communicators with regard to the complexities of ETL detection and its communication. The primary objective of this section is to outline proposed action items, their benefits, drawbacks, target audiences, responsible parties, and existing related activities.

10.1. Action items

A recurring theme is the urgent need for action. The following suggestions, derived from workshop discussions, build a foundation for future science communication:

Locating necessary funds to compensate journalists and communication professionals for their contributions was a frequent suggestion. Many communicators, especially journalists, early-career scientists, and those in nonprofits, struggle financially and often volunteer their time for such projects, leading to overwork and limiting participation from diverse backgrounds. Future engagement should be compensated to build a robust and inclusive communications workforce. Suggestions include direct fellowships for journalists embedded in research institutions (e.g., Europe's FRONTIERS Media project), combined research and outreach positions, and part-time longer term residency programs, all while ensuring journalistic independence.

Utilizing existing resources for dissemination and creating an index of potential partnerships was another suggestion. Organizations such as SciLine, AstroACCEL, the Planetary Society, and NASA's Solar System Ambassadors Program offer valuable expertise. Leveraging established media such as television and radio remains important, particularly for reaching older generations, and collaborating with legacy producers such as NOVA and Science Friday is beneficial. Furthermore, outreach efforts should not be solely NASA-centric, as future discoveries might come from citizen scientists, private companies, or noncooperating states. Identifying and fostering communication networks in less represented regions globally would be essential for truly inclusive outreach.

Developing a long-term communications strategy with a focused message and a shared vocabulary could be a critical step for the community. Such a strategy would promote nuanced messages about astrobiological research, integrating discussions of uncertainty and future research, and addressing controversies while maintaining an evidence-based approach rather than false balance. Drawing lessons from historical public outreach campaigns (e.g., Apollo missions, nuclear energy, Space Race) can inform planning that may span a decade or more. It is vital to identify and understand diverse audiences (scientific, political, educational, inclusive communities, special interest groups) who can also act as cocreators of content. Narratives could productively shift away from an overemphasis on the "scientific method" to highlighting the process of scientific consensus-building. Consulting social sciences, computational social sciences, and the historiography of science communication can provide insights into effective messaging and the societal implications of information. The inclusion of a public-facing ethicist on communication teams could guide conversations and preempt concerns about an institution's consideration of broader implications. Developing a shared vocabulary, similar to the Department of Energy's Office of Science glossary, would help standardize terms such as "biosignature" and foster shared understanding between practitioners and the public. Discussions regarding uncertainty frameworks (e.g., SoE, Ladder of Life Detection, IPCC framework) and how they might complement each other for assessing confidence in life detection claims would also be beneficial.

Creating guidelines for press releases and other communications assets would be important once a long-term strategy is in place. An ETL discovery is a long-term news story, requiring a myriad of assets with consistent branding. Guidelines for both visual and written communications, including templates for press releases, could be shared externally to assist freelance journalists and other agencies. Institutions could also work to anticipate the impact on scientists who become public points-of-contact, providing robust support and protection against harassment. Communicators could anticipate challenges posed by the media's tendency to reduce complex scientific information to headlines and the limitations of word limits, particularly concerning the discussion of uncertainty. New developments in social media and generative AI will present further challenges for information dissemination and potential misinformation.

Developing and supporting opportunities for the integration of science and arts are a promising avenue for public engagement. While not ideal for granular details, art (comics, books, games, music, performance art) effectively spreads awareness and interest, as seen with NASA's Exoplanet Travel Bureau posters. Existing sci-art fellowships and residencies (e.g., SETI Artists in Residence, S + T+ARTS, Arts at CERN) demonstrate a long tradition of bringing science closer to people and inspiring interest. Supporting astrobiology-focused public programs can help anticipate the public's reactions to challenging scenarios, such as undecipherable extraterrestrial transmissions, and engage audiences on an emotional level. More accurate depictions of science in fiction, through expert consultation (e.g., Science & Entertainment Exchange), could also be encouraged. Art can also increase accessibility (e.g., 3D-printed planetary models for the visually impaired) and foster interest in science through active participation in sci-art programs and contests. However, further data-backed research would be needed to fully understand the impact of such art-focused endeavors on public perception.

Developing communications training programs was seen by many participants to be essential for long-term planning. These types of programs can swiftly bring cohorts of scientists and communication partners to speed up on project communication needs, build relationships, and disseminate communication styles and best practices across geographic areas. Many participants perceived an urgent need to train communicators in new and nontraditional media to reach diverse audiences. NASA could help organize such training, potentially leveraging existing programs (e.g., Solar Systems Ambassadors, Alan Alda Center, Story Collider, STEM Ambassador Program) to create new programming or supplementary training. A comprehensive index of existing programs would benefit the broader community and prevent duplication of efforts. In addition, implementing public science literacy courses, possibly integrated with citizen science programs and school districts, could prepare the public for future high-impact discoveries in astrobiology and counter disinformation.

Creating an institute or program to proactively address societal issues by studying them was a key piece of guidance mentioned by participants. While interest in the societal impacts of astrobiology has periodically been heightened, it often wanes due to lack of sustained funding. Establishing a virtual institute focused on the sociology and communication of astrobiology discoveries, an idea first proposed over half a century ago in the Brookings Report (1960), could pool resources, avoid "reinventing the wheel," and provide better research opportunities for social scientists. Existing entities such as the Planetary Habitability Laboratory, Astrosociology Research Institute, European Astrobiology Institute/Network, and the SETI Post-Detection Hub could potentially take on this role to form an "ecosystem."

Participants noted that successful communication will likely be based on the key understanding that space exploration and the search for life are driven by diverse motivations. While a roadmap is being drafted, "known unknowns" persist: the role of private companies, new laws for protecting potential ETL, evolving public trust in science, AI's impact on misinformation (e.g., false images, deepfakes) and the scientific discovery process itself. "Unknown knowns" (what we think we understand but don't) and "unknown unknowns" (unforeseen technological, social, or global shifts) also loom. Enhancing "future literacy" and drawing insights from well-informed fiction could also be beneficial. Ultimately, it is hoped that discussions such as these can translate into concrete action: improving outreach, involving journalists, developing evidence-backed communication guidelines, studying social impacts, fostering inclusivity, and collaborating with artists, educators, and communicators. It is helpful to view astrobiology discoveries and communication as part of a broader landscape of public trust in science, education, and internal scientific challenges, emphasizing interdisciplinary collaboration, especially with experts in risk and uncertainty communication. The outcome of a future tentative discovery of life depends partly on these proactive efforts.

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Supplementary Material

Supplementary Data

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Address correspondence to:
Jordan Bimm
Parrhesia Program for Public Discourse
University of Chicago
5845 South Ellis Avenue
Chicago, IL 60637
USA

E-mail: jordanbimm@uchicago.edu

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Abbreviations Used

AbSciCon = Astrobiology Science Conference
AI = artificial intelligence
ALH = Allan Hills
BAF = Biosignature Assessment Framework
CAPS = Committee on Astrobiology and Planetary Sciences
CDSLU = Communicating Discoveries in the Search for Life in the Universe
CERN = European Organization for Nuclear Research
COVID-19 = coronavirus disease 2019
ETL = extraterrestrial life
FTE = full-time equivalent
HWO = Habitable Worlds Observatory
IPCC = Intergovernmental Panel on Climate Change
LIGO = Laser Interferometer Gravitational-Wave Observatory
NASA = National Aeronautics and Space Administration
NASEM = National Academies of Sciences, Engineering, and Medicine
NSF = National Science Foundation
OC = Organizing Committee
SETI = Search for Extraterrestrial Intelligence
SMI = Science, Media, and Information
SoE = Standards of Evidence
STEM = science, technology, engineering, and mathematics
UNOOSA = United Nations Office for Outer Space Affairs