

John I Davies & Gill Norman report on recent developments in interstellar studies

IRMA: New Era for Interstellar Travel?

In *IRMA: New Era for Interstellar Travel* (<https://arc.aiaa.org/doi/epdf/10.2514/6.2025-97839>), Christina Decker, Felix May and Javid Bayandor, researchers from University at Buffalo - The State University of New York and the University of Sheffield (UK) present a conceptual mission consisting of two identical spacecraft to interstellar space beyond the Kuiper Belt. They call this the Interstellar Radioisotope and Modular Architecture (IRMA) mission. Data collection and comparative analysis between two IRMA spacecraft would investigate the unexplained origin and formation of the Kuiper Belt and the interactions between the Solar System and the interstellar medium at the edge of the heliosphere/heliopause. They believe this would help to answer, and possibly confirm, many theories of anomaly while also anticipating the discovery of the origins of life in the Solar System and the universe. By safe navigation approaching interstellar space they would advance scientific knowledge preparing for future deep-space missions capable of reaching destinations far beyond the Solar System. They would also incorporate means to protect against the hostile environment using varying radiation and dust-debris impact shields.

To see ourselves as others see us

In 1786 Robert Burns yearned -

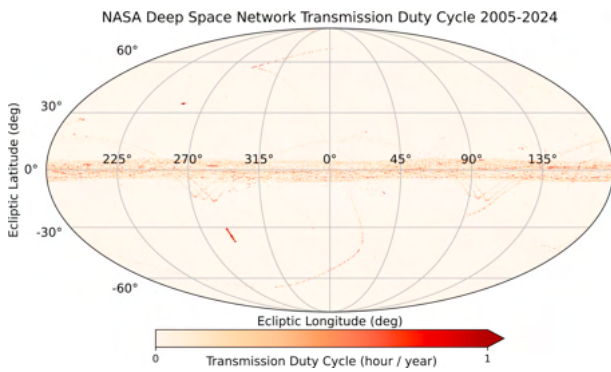
O wad some Pow'r the giftie gie us
To see oursels as ithers see us!
It wad frae mony a blunder free us,
An' foolish notion:

-in *To A Louse, On Seeing One on a Lady's Bonnet at Church*. And SETI researchers have sometimes wondered how we would appear to ETI's conducting SETI research of their own.

In *Detecting Extraterrestrial Civilizations that Employ an Earth-level Deep Space Network* (see <https://arxiv.org/pdf/2508.15425>), Pinchen Fan, Jason T Wright, and T Joseph W Lazio of The Pennsylvania State University have turned their attention to the possible ETI perception of the NASA Deep Space Network, three communications stations set 120 degrees apart to enable communication with deep space probes throughout the Solar System and its immediate neighbourhood [1]. Unsurprisingly their transmissions are primarily in the ecliptic plane where the major planets orbit the Sun. They examine transmission logs over the last 20 years (though the three station system originated in 1961, 64 years ago). Directions such as the Lagrange 2 point, for the James Webb telescope and others, and Mars with the largest population of NASA deep space probes are the vectors where the most fortunate curious ETIs might successfully spot its transmissions. The net effect is one area of the universe being "most favoured".

[1] <https://www.nasa.gov/directorates/somd/space-communications-navigation-program/what-is-the-deep-space-network/>

For example -



Map of DSN duty cycles using transmissions from 2005 to 2024. Around a Sun-angle ecliptic longitude of 0°: the box-shaped area represents transmissions to the Advanced Composition Explorer (ACE) and the Deep Space Climate Observatory; the edge of the oval-shaped area represents transmissions to the Solar and Heliospheric Observatory (SOHO); the inside of that oval-shaped area represents transmissions to Wind. Around a Sun-angle ecliptic longitude of 180°, the circle represents transmissions to the James Webb Space Telescope (JWST). The maps of DSN duty cycles across all co-ordinate systems (10 images) are available. The complete figure set (10 images) is available. Credit (image and caption): Pinchen Fan et al

The full set of DSN “targets” is at

<https://content.cld.iop.org/journals/2041-8205/990/1/L1/revision2/apjladf6b0figset2.tar.gz>.

The authors state “Our findings suggest several strategies for enhancing the effectiveness of future SETI searches.” Suggested strategies include -

- prioritise the SETI target list
- suggest preferred epochs [1] for detecting DSN-like transmissions
- expect the region within about 5° of our ecliptic plane to be where the most likely “replies” might come from.

They also suggest that future activity including human exploration and exploitation is likely to result in transmissions, and thus possible, “replies” from the same regions.

It’s worth pointing out that terrestrial radar transmissions started even earlier and many have been more powerful but the concentration of the DSN and other nations deep space transmissions are likely to be to similar places in the sky and may well be where we get the answer to the big SETI question “Are we alone?”.

Lots of ways to look at 3I

In *3I/ATLAS (C/2025 N1): Direct Spacecraft Exploration of a Possible Relic of Planetary Formation at “Cosmic Noon”* (<https://arxiv.org/abs/2508.15768>) researchers from Space Initiatives Inc, Jet Propulsion Laboratory, Institute for Interstellar Studies, University of Luxembourg, Observatoire de Paris, CNRS, French-Chilean Laboratory for Astronomy and TU Munich evaluate possibilities of studying this third known interstellar object (ISO). They note that “3I will pass relatively close to a number of already launched interplanetary spacecraft.” including Psyche, Juice, Europa Clipper, Hera and others including the Martian spacecraft array. Research objectives include 3I astrometry, coma dust phase angle measurements, comet coma studies, observation of comet fragmentation and observational implications of a thick disk ISO origin. Intriguing possibilities include possible 3I satellites. They conclude “In this, and in future encounters with interstellar objects in the solar system, we recommend that the opportunities offered by interplanetary spacecraft for interstellar object exploration be seized to the extent possible.”

To stay in touch with the latest on 3I intercept issues keep an eye on Adam Hibberd’s latest blogs for i4is -

3I/ATLAS: What would Juno need to do?

<https://i4is.org/3i-atlas-what-would-juno-need-to-do>

3I/ATLAS: An Interstellar Controversy

<https://i4is.org/3i-atlas-an-interstellar-controversy>

3I/ATLAS: How low should we go?

<https://i4is.org/3i-atlas-how-low-should-we-go>

[1] [https://en.wikipedia.org/wiki/Epoch_\(astronomy\)](https://en.wikipedia.org/wiki/Epoch_(astronomy))

Origins of Life: The Possible and the Actual

In *Origins of Life: The Possible and the Actual* (<https://www.preprints.org/manuscript/202508.1593/v1>) researchers from Universitat Pompeu Fabra, Barcelona (Ricard Sole), Santa Fe Institute USA (Chris Kempes) and University of York, UK (Susan Stepney) consider questions of how life forms, whether life is an inevitable outcome, and how diverse its presentation could be.

When we consider the perennial question “Are we alone?” these underlying questions occur almost immediately. They look at geochemistry, statistical physics, systems and evolutionary biology, artificial life, synthetic biology, and information theory, and thus the inherently interdisciplinary nature of origin-of-life research.

This is a detailed consideration of some very profound issues but its conclusions depend to a large extent on an assumption that replication is essential to life. That this is not necessarily the case is clear from a consideration of the possibility that life can exist in information processing systems and the speculative example of the Black Cloud in Fred Hoyle’s novel suggests even a quasi-biological entity which does not need to reproduce.

There’s watts in them thar skies [1]

A recent paper in the journal *Joule*, *Assess space-based solar power for European-scale power system decarbonization* (<https://arxiv.org/abs/2504.05052>), by Xinyang Che, King’s College London, and Xi’an Jiaotong University, Xi’an, China - and colleagues from both institutions - suggests that satellites in geostationary orbit can harvest continuous sunlight and beam it to Europe as microwaves, delivering dispatchable, zero-carbon power that sidesteps the intermittency plaguing wind and solar.

They examined two designs -

- Representative Design One (RD1), the Innovative Heliostat Swarm: Based on the SPS-ALPHA Mark III concept [2], this lower-TRL [3], design uses mirror-like reflectors (heliostats) to direct sunlight to a central concentrator, enabling nearly 99.7% annual power availability. Key innovations include retro-directive RF transmission arrays, high-efficiency PV cells, lightweight modular structures, and autonomous in-orbit deployment. Reflectors continuously adjust orientation, maximizing solar capture throughout the orbital cycle.
- Representative Design Two (RD2), the Mature Planar Array: Adapted from JAXA’s Tethered Solar Power Satellite [4] and Caltech’s SSPP design, planar design (RD2) includes planar panels whose lower surface faces Earth under gravity-gradient forces. While solar incidence on the upper and lower surfaces varies with orbital geometry, the system achieves roughly 60% annual power availability. This requires a higher TRL, given demonstrated hardware and well-documented performance characteristics. This economic and engineering analysis contributes both directly to the potential of a zero-emission power source on Earth and indirectly to the favourable economics of a space-based, solar powered, beamer accelerating photon propelled probes to Interstellar missions. More about earlier studies in *INTERSTELLAR NEWS: Feasibility of space solar power*, Principium Issue 36 February 2022 page 12 (<https://i4is.org/issue-36-february-2022/>).

[1] As in the California Gold Rush

[2] *Space-Based Solar Power*

<https://www.nasa.gov/wp-content/uploads/2024/01/otps-sbsp-report-final-tagged-approved-1-8-24-tagged-v2.pdf>

[3] Technology Readiness Level : https://en.wikipedia.org/wiki/Technology_readiness_level

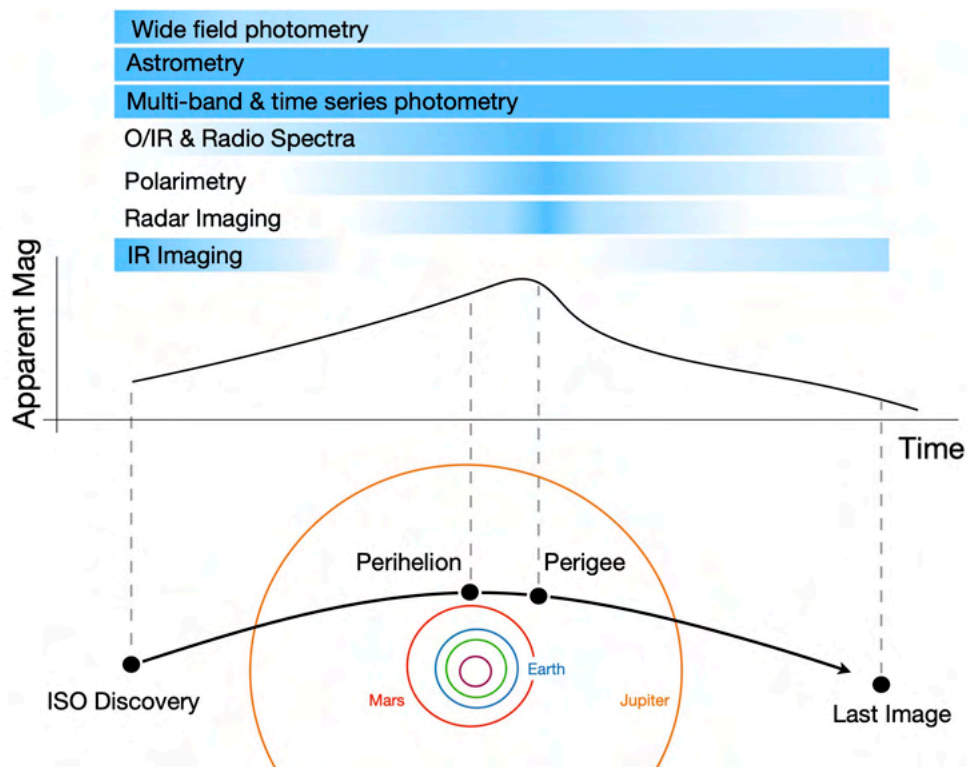
[4] *How Japan Plans to Build an Orbital Solar Farm*

<https://spectrum.ieee.org/how-japan-plans-to-build-an-orbital-solar-farm>

Technosignature Searches of Interstellar Objects

A recent paper by James R A Davenport (University of Washington, USA) et al, (<https://arxiv.org/abs/2508.16825>), reviews the literature around Interstellar Objects (ISOs) as targets for technosignatures. With the discovery of the third confirmed interstellar object (ISO), 3I/ATLAS, we have entered a new phase in the exploration of these long-predicted objects. Though confirmed discovery of ISOs is quite recent, their utility as targets in the search for technosignatures (historically known as the Search for Extraterrestrial Intelligence - SETI) has been discussed for many decades. With the upcoming NSF-DOE Vera C Rubin Observatory's Legacy Survey of Space and Time (LSST), the discovery and tracking of such objects is expected to become routine, and thus so must our examination of these objects for possible technosignatures.

They outline four broad classes of technosignatures that are well suited for ISO follow-up, including the type of data needed and the best timing for study. Given the limitations in the current understanding of ISOs, they show that care must be taken in identifying technosignatures based primarily on comparison to objects in the Solar System. They provide a roadmap for careful and consistent study of the population of ISOs in the hope of identifying technosignatures.



Schematic trajectory of an ISO as it passes through the Solar System, loosely based on the predicted orbit of 3I/ATLAS. Key phases of the orbit, including closest approach to the Sun (perihelion) and to Earth (perigee), are labelled. An illustrative light curve is shown aligned to the orbit. Observations for constraining ISO technosignatures from Table 1 below are listed, with blue shading indicating the key times for obtaining data. Credit (image and caption): Davenport et al, Figure 5 and Table 1

Table 1. Observing recommendations for ISO technosignatures based on the classes described in §3. Note that the timing here is a suggestion for the most likely detection, and almost all proposed technosignatures benefit from additional data throughout the ISO passage.

Observing Mode	Technosignature Class	Timing
Astrometry & tracking	Accelerations (§3.1)	Full arc of passage
Full sky photometry	Early detection & origin (§3.1)	Earliest possible
Optical/IR spectroscopy	Spectral anomalies, lasers (§3.2, 3.4)	Closest approach
Radio spectroscopy	Transmissions (§3.4)	Closest approach
Multi-band photometry	Color & phase curve anomalies (§3.2, 3.3)	Full arc of passage
High-cadence imaging	Rotational modulation (§3.3)	Multi-night campaign
Infrared photometry	Waste heat (§3.2)	Pre- and post-perihelion
Polarimetry	Unusual surface properties (§3.2)	Closest approach
Radar imaging	Shape anomalies (§3.3)	When within radar range

Responding to a potential detection of a SETI signal

In *SETI Post-Detection Protocols: Progress Towards a New Version* (<https://arxiv.org/abs/2510.14506>), Michael A Garrett (University of Manchester, JBCA, UK and Leiden Observatory, NL), et al, present A Revised Declaration of Principles for responding to a potential detection of a SETI signal. The International Academy of Astronautics (IAA) SETI Committee has long provided guiding principles and the foundational Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence, first formulated in 1989, has been widely recognised by the international scientific community. A supplemental set of draft protocols addressing the possibility of a reply to an extraterrestrial signal was prepared in 1995 by the IAA SETI Permanent Committee, with both documents presented in a position paper to the UN Committee on the Peaceful Uses of Outer Space in 2000. In keeping with the evolving landscape of SETI research, the IAA Declaration of Principles was streamlined and updated in 2010. Recognising the need for continued adaptation, the IAA SETI Committee established a Task Group in 2022 to re-examine the protocols in light of recent advances in search methodologies, the expansion of international participation in SETI, and the increasing complexity of the global information environment. The Group recognises the living document nature of the protocols, which will require ongoing refinement to remain relevant and effective in a rapidly changing world. A draft revised Declaration of Principles was presented at the IAC 2024 in Milan, and initial feedback was received from the community, particularly members of the IAA SETI Committee. Since then, the authors have continued to seek broader community input in a structured process, refining the proposed updates based on further discussions and consultations.

Wind Power as a Technosignature on M-dwarf Planets

The Institute of Physics recently released a paper by Jacob Haqq-Misra and Mykhaylo Danylov (<https://iopscience.iop.org/article/10.3847/2515-5172/ae13a7>). They suggest that the large-scale deployment of wind turbines on an M-dwarf planet could produce observable technosignatures. Motivated by observations of hypersonic wind velocities on WASP-127 b, they note that the atmospheres of such planets could serve as vast reservoirs of energy for an extraterrestrial civilization. A large-scale deployment of wind turbines in a hypersonic environment would produce heated shock waves in the hypersonic stream, cause strong frictional heating from the rotation of the blades, and be a source of infrared radiation. They mention possible scenarios that could lead to the deployment of wind turbines on a gas giant and also note that similar features could exist on terrestrial M-dwarf planets. The idea that aerodynamic peculiarities could be a technosignature is worth keeping in mind as ground- and space-based exoplanet observations continue to improve.

Interstellar Networking: A Theoretical Framework

In *Interstellar Networking: Theoretical Framework for Communication Beyond the Solar System* (https://d197for5662m48.cloudfront.net/documents/publicationstatus/283229/preprint_pdf/7a7cdb9ffe15e8821b6655de3dc1c08b.pdf), Bhuvaneshwari Madadi (Vaagdevi College of Engineering, Telangana, India) discusses the idea that interstellar networking signifies a future advancement in space communications, allowing humankind to maintain contact with deep-space missions and prospective interstellar probes. Existing interstellar communication models encounter three significant challenges: vast distances necessitating years-long signal transmission, severe energy limitations for spacecraft functionality, and the infeasibility of the dense relay networks suggested by current theoretical paradigms. This study presents a novel lightweight theoretical model for interplanetary networking, based on incremental deployment, energy-efficient Delay-Tolerant Networking (DTN), and forward error correction without acknowledgements. Their methodology minimises relay necessities from thousands to hundreds of nodes, employs solar and nuclear energy for sustainable operations, and avoids costly acknowledgement-based error handling via redundant transmission and forward error correction (FEC). The proposed framework provides a viable foundation for future interstellar communication missions while ensuring scalability for prospective expansion to adjacent star systems.

How long does the human civilization need to last in order to observe another advanced intelligence in the Universe? [1]

Soumya Banerjee (University of Cambridge, UK) presents a mathematical model for estimating the probability of detecting radio-transmitting advanced civilizations. (See https://www.researchgate.net/publication/395989367_How_long_does_the_human_civilization_need_to_last_in_order_to_observe_another_advanced_intelligence_in_the_Universe)

[1] This paper also appears in our roundup of The Journals

They argue that even if an advanced civilization in another galaxy evolved to be remarkably similar to us - using radio waves for communication - it would still be highly unlikely for us to detect them. For instance, if such a civilization were located 10^6 light-years away, by the time our radio signals reached them, their civilization (and possibly ours) may no longer exist. The central idea is that the spatio-temporal separation between intelligent civilizations may be so vast that, even if a radio-transmitting civilization does emerge, it is unlikely to be noticed by others.

This is because, at any given moment, there may be no other civilizations both advanced enough and close enough to detect its presence.

This model highlights the profound difficulty involved in such detection. A further important consideration is that other civilizations may not communicate using the electromagnetic spectrum or think in symbolic terms as we do. Their work suggests that, in order to detect or be detected, advanced civilizations must endure for very long periods. This mathematical perspective not only underscores the challenges of discovering extraterrestrial intelligence, but also invites us to reflect on the uniqueness of our planet and the conditions necessary for mutual detection in the cosmos.

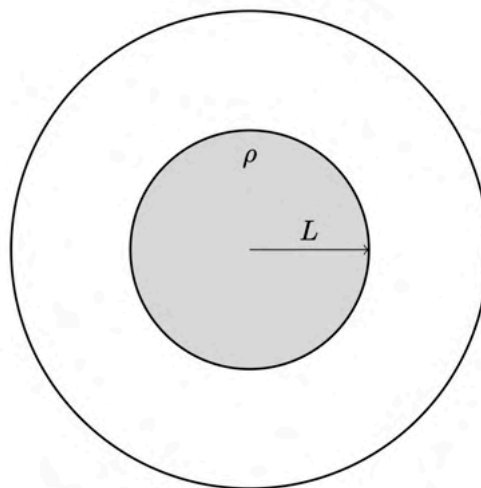


Figure 1. In this figure, light or information has spread for a distance of L light years in the L years that an advanced civilization has existed. The civilization is assumed to exist at the center of the sphere. The lifetime of the radio-transmitting phase of this civilization is L years. In these years, the information transmitted by the civilization has covered a sphere or radius L . ρ denotes the probability, per unit volume of space, of bearing a civilization that is advanced enough to detect radio transmission. The volume of the spherical annular region is given by $\frac{4}{3}\pi L^3$. The probability that another advanced civilization co-occurs in this volume is given by the product of this volume and the probability (per unit volume) that a living civilization that is also advanced enough to detect radio transmissions (ρ). This leads to the following condition that should be approximately equal to 1 if we are to observe radio transmissions from other intelligent civilizations: $\frac{4}{3}\pi L^3 \rho \approx 1$

Figure 1 Credit : Banerjee

ESA's ExoMars and Mars Express observe comet 3I/ATLAS

Between 1 and 7 October, ESA's ExoMars Trace Gas Orbiter (TGO) and Mars Express spacecraft turned their eyes towards interstellar comet 3I/ATLAS, as it passed close to Mars. See https://www.esa.int/Science_Exploration/Space_Science/ESA_s_ExoMars_and_Mars_Express_observe_comet_3I_ATLAS.

The two Mars orbiters had the closest view of the comet of all ESA spacecraft. During its closest approach to the Red Planet on 3 October, the interstellar interloper was 30 million km away from them. Each spacecraft used its dedicated camera to watch the comet pass. Both cameras are designed to photograph the bright surface of Mars just a few hundred to a few thousand km below. Scientists were unsure what to expect from observations of a relatively dim target so far away. Nick Thomas, Principal Investigator of the CaSSIS camera explains, "This was a very challenging observation for the instrument. The comet is around 10,000 to 100,000 times fainter than our usual target." See our lead article in this issue for more about 3I/ATLAS.



ExoMars TGO captured a series of images - one of which is shown above - with its Colour and Stereo Surface Imaging System (CaSSIS). Comet 3I/ATLAS is the slightly fuzzy white dot a quarter of the way down and to the right of centre of the image. This dot is the centre of the comet, comprising its icy-rocky nucleus and its surrounding coma.
Credit ESA/TGO/CaSSIS

Strategic Communication Protocols for Interstellar Objects Using a Threat-Communication Viability Index and the Information-Communication Paradox

From David R Gruber (University of Nevada, USA) (see <https://arxiv.org/abs/2510.03973>). Strategic Communication Protocols (SCPs) provide a structured approach for first contact with interstellar objects (ISOs) that demonstrate technological characteristics and high levels of threat. The SCPs find their starting point in an ISO Information-Communication Paradox, namely, as our knowledge of an ISO's threatening capabilities increases, the probability of successful communication decreases while the urgency of communication attempts simultaneously intensifies. From this paradox, a Threat-Communication Viability Index (TCVI) is created to describe when the value of communication attempts outweighs strategic silence. The TCVI scores the situation and operates as a decision-making tool for stakeholders tracking ISOs. The SCPs subsequently outline several diplomatic communication strategies in cases where the TCVI recommends communication.

Existing interstellar communication efforts inadequately address the unique challenges posed by interstellar objects (ISOs). METI International's messaging to distant star systems [1] and the SETI Permanent Committee's reply guidelines [2] both assume static, distant targets with extended communication windows. However, ISOs present fundamentally different circumstances. They are mobile, potentially threatening, and operate within compressed timelines that demand immediate decision-making.

The creation of the Loeb Scale for classification of ISOs based on threat (Eldadi, Tenenbaum and Loeb, 2025) provides a foundation for communication protocols. The SCP framework does not assume communication is appropriate at every level of the scale. Instead, SCPs rely on a Threat-Communication Viability Index (TCVI) that considers the Loeb Scale in conjunction with time until ISO contact, available time frames for sending and receiving messages, as well as additional threat factors tied to hostility toward Earth and not within the Loeb Scale. That is, SCPs are designed for diplomatic communications, and communication attempts are reserved for circumstances with clear threats from technological ISOs. Choosing communication over silence in such cases is justified through five core propositions that define the context as well as nine base assumptions about ISOs that would make communication worth initiating. To move forward, this paper first details the Information-Communication Paradox and then presents the five core propositions and nine assumptions about ISOs. After this, the paper describes the TCVI and how to use it, for example:

- **TCVI < 0.15:** Extended observation and intelligence gathering
- **TCVI 0.15-0.24:** Prepare communication systems and protocols
- **TCVI 0.25-1.50:** Debate the value of communication attempts and decide
- **TCVI 1.51-3.50:** Begin immediate communication attempts
- **TCVI > 3.50:** Emergency communication with defensive activation

The TCVI recommendations. Credit David R Gruber

[1] <https://meti.org/mission>

[2] <https://iaaseti.org/en/protocols/>

The final section outlines the SCP framework and concludes that the SCPs seek interstellar diplomatic engagement, adapting conflict resolution principles for first contact with a technological ISO. While the framework cannot guarantee successful outcomes, it provides structured approaches and seeks to maximize peaceful resolution probabilities.

The solitude zone

In *The solitude zone: A probabilistic window for singular lifeform existence* (<https://www.sciencedirect.com/science/article/pii/S0094576525006599>), Antal Veres (Hungarian University of Agriculture and Life Sciences, Hungary) introduces a probabilistic framework to assess the likelihood that lifeforms of a given complexity level are statistically solitary in the universe. Building on the concepts of existence distributions and emergence scenarios, they define the solitude zone - the range of emergence probabilities where exactly one such lifeform is more likely than multiple instances - and the corresponding solitude probability, which quantifies how plausibly the universe resides in this regime. Their analysis yields general mathematical results characterizing when solitude is possible, how it behaves asymptotically as the universe expands, and what upper limits it may reach. Scenario-based estimates show that, under pessimistic assumptions such as the Rare Earth hypothesis, solitude may be plausible but remains bounded, while in more extreme scenarios it vanishes entirely. This approach treats the Fermi paradox not as a contradiction, but as a probabilistic landscape – one that reflects our assumptions more than our observations.

Table 1. Summary of the emergence scenarios considered in this study.

Code	Scenario	Description
AO	Astrobiological Optimism	Life arises easily and frequently on Earth-like planets, possibly due to natural biochemical inevitability [13], [14].
AL	Anthropic Limit Argument	The existence of observers constrains the observable range of emergence probabilities [15], [16].
RE	Rare Earth Hypothesis	Complex life is extremely rare, requiring a highly improbable chain of events [7].
EH	Evolutionary Hard Step	Intelligent life must overcome multiple improbable evolutionary bottlenecks [8].

The scenarios considered in the paper. Credit: Antal Veres