PRINCIPIUM

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SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

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EDITORIAL

Welcome to issue 48 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is *Building Our Home Among the Stars: A Report from the First European Interstellar Symposium.*
We have another News Feature, *International Astronautical Congress IAC24 - The Interstellar Presentations Part 2*. And eight pages of Interstellar News and our usual, *The Journals - JBIS and Acta Astronautica*, the regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.
And a Feature - *Can Wormholes Be An Answer to the Ansible Problem?* - following up *Why Quantum Entanglement Won't Deliver The Ansible* in P46.
Our cover images illustrate how your Editor came to think about our long term future in the stars. The front image from the Kon Tiki expedition (a raft across the Pacific in 1946 to test a theory about human migration) and the back a vision of starship launch which appeared in The Eagle comic in 1955. More about both in *Cover Images* inside the rear cover.
And, as always, we have the i4is members' page and our regular call to action, *Become an i4is member*.

Next time, P49 in May 2025, will be a bumper issue including -

- A review by Andreas Hein of the new book, *From Stars to Life: A Quantitative Approach to Astrobiology.*
- A Project Hyperion progress report.
- IAC24 - Third Report, more papers and presentations at the 2024 International Astronautical Congress.
- FEIS report - on papers and presentations at the First European Interstellar Symposium.
- A review of a recent paper by Professor Greg Matloff, *Aerographite: A Candidate Material for Interstellar Photon sails* in JBIS.
- A review of the story collection, *The Ross 248 Project*, edited by Les Johnson and Ken Roy.
- A ground breaking paper, *Novel Technosignatures*, by more interstellar pioneers, Dr Al Jackson and Dr Gregory Benford.

And our regular *Interstellar News*. More details on P49 in *Next Issue* at the end of this issue.
And if you would like to help with any part of ***Working towards the real Final Frontier*** then please take a look at our poster on page 16.

John I Davies, Editor, john.davies@i4is.org
Patrick Mahon, Deputy Editor, patrick.mahon@i4is.org

After 10 years and 41 issues John Davies will be stepping down as Editor after the 50th issue, August 2025. He is working with Deputy Editor Patrick Mahon, Membership/Infrastructure Manager Tam O'Neill and the i4is Board of Directors over the next three months to appoint a successor and a broader team, sharing responsibilities for the magazine, in time for a transition period. If you would like to be part of the Principium team please get in touch with -
John (john.davies@i4is.org), Patrick (patrick.mahon@i4is.org) or Tam O'Neill (tam.oneill@gmail.com).

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Back issues of Principium can be found at www.i4is.org/Principium

The views of our writers are their own. We aim for sound science but not editorial orthodoxy.

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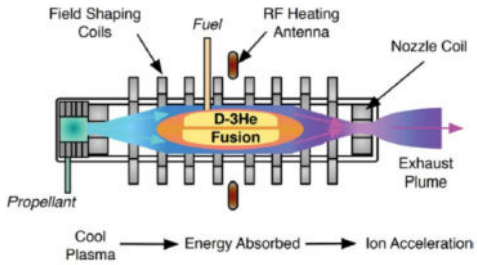

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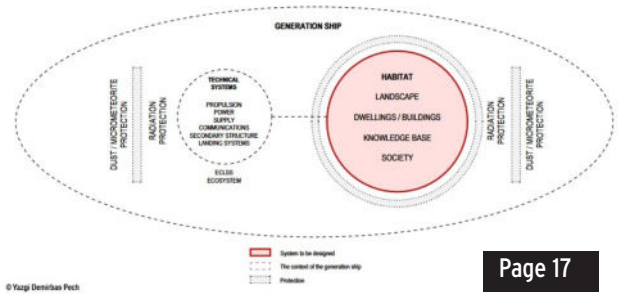

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Building Our Home Among the Stars
A Report from the First European Interstellar Symposium

Nadim Maraqten

The First European Interstellar Symposium (FEIS) 2-5 December 2024 is reported by Nadim Maraqten who has been a researcher with i4is since early 2022. He has reported for Principium on a number of occasions starting with the International Astronautical Congress 2022 (IAC22). We will be reviewing some of the individual FEIS papers in our next issue, P49, in May 2025.

For decades, discussions of interstellar exploration have often been rooted in North American endeavors—both in scientific research programs and visionary conceptual studies. Yet the drive to reach the stars knows no geographic boundary. In December 2024, at the European Convention Center Luxembourg (ECCL), for the first time the premier scientific conference on interstellar research took place on European soil. The First European Interstellar Symposium (FEIS2024) convened a dynamic, international assembly of scientists, engineers, futurists, and science fiction authors. It was hosted in collaboration with the University of Luxembourg, the Initiative for Interstellar Studies (i4is), the Interstellar Research Group (IRG), and the Luxembourg Space Agency.

A Gathering of Visionaries and Experts

Over four days (2–5 December), attendees engaged with keynote lectures, technical presentations, and public events that collectively charted the evolving frontiers of interstellar inquiry. The symposium's breadth was remarkable, reflecting a maturing field that spans propulsion engineering, astrophysics, astrobiology, materials science, habitat design, ethical frameworks, and communication strategies for distant voyages. In a testament to the interdisciplinary spirit at the core of interstellar exploration, the program also included science fiction and outreach sessions open to the public—underlining that interstellar aspirations are as much cultural and philosophical as they are technical.

Pre-Symposium Seminars: Building Foundations

Before the formal opening, a series of seminars offered deep dives into specialized topics. Andreas M Hein (University of Luxembourg, i4is) led a workshop on designing generation ships—self-contained, miniaturized worlds engineered for journeys spanning centuries or millennia. Anders Sandberg (Institute for Future Studies) spoke on planning for the deep long-term, inviting participants to consider the social, economic, and ethical dimensions of ultra-long-duration missions.

Dr Andreas M Hein: Project Hyperion
Andreas M Hein, University of Luxembourg and i4is, leader of i4is Project Hyperion, with a workshop on designing self sufficient generation ships engineered for journeys spanning centuries or millennia.
photo credit: A Bühler / K Kanavouras

Anders Sandberg: Planning for the Truly Long Long-Term
Anders Sandberg is a Swedish researcher, futurist and transhumanist. He holds a PhD in computational neuroscience from Stockholm University, and was a former senior research fellow at the Future of Humanity Institute at the University of Oxford (2005-2024).

The much-anticipated seminar by Les Johnson (NASA Marshall Space Flight Center) on interstellar propulsion sadly had to be postponed to a future interstellar symposium.

Setting the Stage: Keynote Perspectives

A hallmark of FEIS2024 was its series of keynote addresses by internationally renowned experts, each highlighting a unique dimension of the interstellar challenge.

• **Solar Gravitational Lens Imaging of Exoplanets:** Slava Turyshev (NASA JPL) opened the scientific sessions with a forward-looking vision of using the Sun's gravitational lens to achieve multipixel imaging and spectroscopy of exoplanets. By placing a spacecraft beyond 550 AU, this approach could unlock unprecedented clarity in studying distant worlds—crucial if we are to identify biosignatures or even evidence of life.

• **Breakthrough Propulsion**: At TU Dresden, Martin Tajmar leads a dedicated team investigating breakthrough propulsion technologies. By employing advanced instruments—such as (sub-)nano-Newton thrust and nano-gram weight balances—they rigorously test concepts like the EMDrive to rule out experimental artifacts.

• **Extreme-Aspect-Ratio Metamaterials:** In his keynote, Richard A Norte (TU Delft) presented a re-envisioning of nanotechnology for interstellar sails. By extending materials in only two dimensions to extraordinary aspect ratios, the Norte group's work suggests entirely new regimes of laser-driven propulsion.

• **Space Optical Communication:** Paolo Villoresi (University of Padova) examined advanced optical communication methods crucial for data return from an interstellar probe. Leveraging quantum communication insights and phased-array grating couplers, his work outlines the infrastructure required to keep interstellar probes connected with Earth across immense distances.

• **Life in the Universe and Private Sector Initiatives:** Pete Worden (Breakthrough Initiatives) reminded the audience that interstellar exploration is not just the domain of public agencies. With initiatives like Breakthrough Starshot, Breakthrough Watch and Breakthrough Listen, the private sector and philanthropic organizations have emerged as powerful catalysts.

• **From Physics to Spacecraft:** Harry Atwater (Caltech) detailed how nanophotonic design principles enable the creation of ultralight, self-stabilizing metasurface lightsails propelled by high-power lasers toward Alpha Centauri. His talk highlighted the rigorous simulations and measurements addressing dynamical, opto-mechanical stability, and thermal management challenges, showcasing the synergy between fundamental physics and practical spacecraft engineering in advancing interstellar travel.

Slava Turyshev (NASA JPL): using the Sun's gravitational lens
Using the Sun's gravitational lens to achieve multipixel imaging and spectroscopy of exoplanets.
Note the i4is "Coracle" interstellar probe model in the background.
photo credit: A Bühler / K Kanavouras

• **Healthcare in Interstellar Voyages:** How can we adapt clinical research to develop a more responsive and resilient healthcare infrastructure for interstellar ventures? On the final day, Mona Nasser (University of Plymouth) addressed the evolution of clinical research methodologies for interstellar expeditions. Given that any interstellar journey will profoundly test human endurance—physically, psychologically, and societally—Nasser's methods aim to create healthcare infrastructures resilient enough for centuries-long missions, all guided by robust ethical frameworks.

"StarShot – from physics to spacecraft", Harry Atwater (Caltech)
Harry Atwater is the Otis Booth Leadership Chair of the Division of Engineering and Applied Science, and the Howard Hughes Professor of Applied Physics and Materials Science at the California Institute of Technology. He holds a PhD in Electrical Engineering in the Massachusetts Institute of Technology (MIT).

"Transversable Wormholes powered by Casimir Energy with Temperature and Charge",
Remo Garattini (University of Bergamo)

Martin Tajmar (TU Dresden): rigorously testing concepts like the EMDrive
Investigating breakthrough propulsion technologies using advanced instruments—such as (sub-) nano-Newton thrust and nano-gram weight balances.
photo credit: A Bühler / K Kanavouras

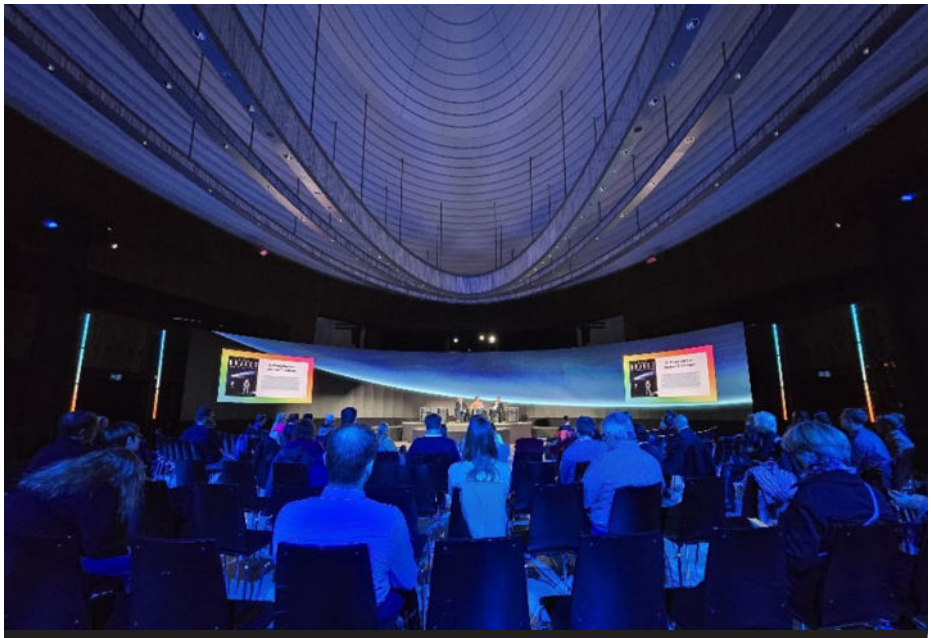
Broad Themes: Propulsion, Ethics, Communication, and More

Propulsion concepts spanned the spectrum from solar sails and beamed-power lightsails to advanced ion thrusters, fusion concepts, and even theoretical antimatter drives. These studies were complemented by discussions on navigating interstellar space—where no established "roads" exist—and how to maintain contact with Earth over light-year distances. In parallel, the symposium did not shy away from challenging philosophical and ethical questions. Should we seed life in other stellar systems, as considered by researchers like Anders Sandberg, Asher Soryl and Pauli Laine? If we do, what are the moral implications of directed panspermia? How do we ensure the long-term survival of complex ecosystems and social structures aboard generation ships? In these dialogues, science blended with philosophy, sociology, and law, reflecting the complexity of sending not just spacecraft, but also human values, into the cosmos.

"To Seed or Not To Seed: The ethical implications of directed panspermia", Anders Sandberg (Institude for Future Studies), and Asher Soryl (University of Otago).
Asher Soryl was a Tutor, Demonstrator, and Marker at the University of Otago and is now looking elsewhere arataki.me/hire-me/

Public Engagement: Science Fiction and Outreach

Another defining characteristic of FEIS2024 was the emphasis on public involvement. Science Fiction Authors Night brought established writers such as Brandon Q Morris, and Joshua T Calvert into the conversation, bridging scientific fact and visionary speculation. Meanwhile, open-to-public lectures like Sara Seager's talk on the search for life beyond Earth kindled interest and imagination in the local community and beyond, ensuring that interstellar dreams resonate not just in laboratories and conference halls, but also in the public sphere.



Science Fiction author's night with featured Brandon Q Morris and Joshua T Calvert
Brandon Q Morris (pseudonym of Matthias Matting, hard-sf.com/) and
Joshua T Calvert (www.joshuatcalvert.com) are two highly successful SF authors

Public Outreach Event: Sara Seager (MIT). "An Enduring Mystery of Astronomy: Can We Find Signs of Life Beyond Earth?"
Sara Seager (physics.mit.edu/faculty/sara-seager/) is Professor of Physics and of Aeronautics and Astronautics,
Class of 1941 Professor of Planetary Science at the Massachusetts Institute of Technology (MIT)

The Conference Delegates

The First European Interstellar Symposium successfully gathered experts from diverse fields to tackle the multifaceted challenges of interstellar exploration. Over four days, FEIS2024 offered a platform for scientists, engineers, futurists and visionaries to exchange ideas and collaborate beyond their traditional domains. The discussions spanned technical debates on propulsion and communication to critical ethical considerations, such as the implications of seeding life on other planets. By integrating scientific advances with philosophical and practical frameworks, the symposium highlighted that interstellar exploration involves not only technological innovation but also the development of sustainable strategies and ethical guidelines. This comprehensive approach set a solid foundation for future endeavours, underscoring the importance of balanced progress as humanity prepares to extend its reach into the cosmos.

A group photo in front of the interstellar lightsail.
See Principium 47, LEAD FEATURE- *Pringles is a Verb: Fabrication and Exhibition of "the Big Object" at WorldCon 82 in Glasgow* (i4is.org/principium-47/)

Initiative for Interstellar Studies*

Your gateway to interstellar exploration
In the 20th century, we explored the planets
In the 21st century, we should explore the stars

i4is is a not-for-profit advocacy organisation which undertakes technical research into all aspects of interstellar exploration. We also run educational outreach activities for students ranging from primary school through to postgraduate degree. And our quarterly magazine, ***Principium***, will keep you up to date with all the key developments in interstellar science and technology.

We're the only organisation in the world advocating to send a spacecraft to the interstellar asteroid 1I/'Oumuamua – and Project Lyra, our peer-reviewed research which shows it can be done, has been featured in such outlets as *Newsweek, Forbes, New Scientist* and *Universe Today*.

* In the USA, we are known as the Institute for Interstellar Studies

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Artwork: David A. Hardy (top left & right); Alex Storer (centre)

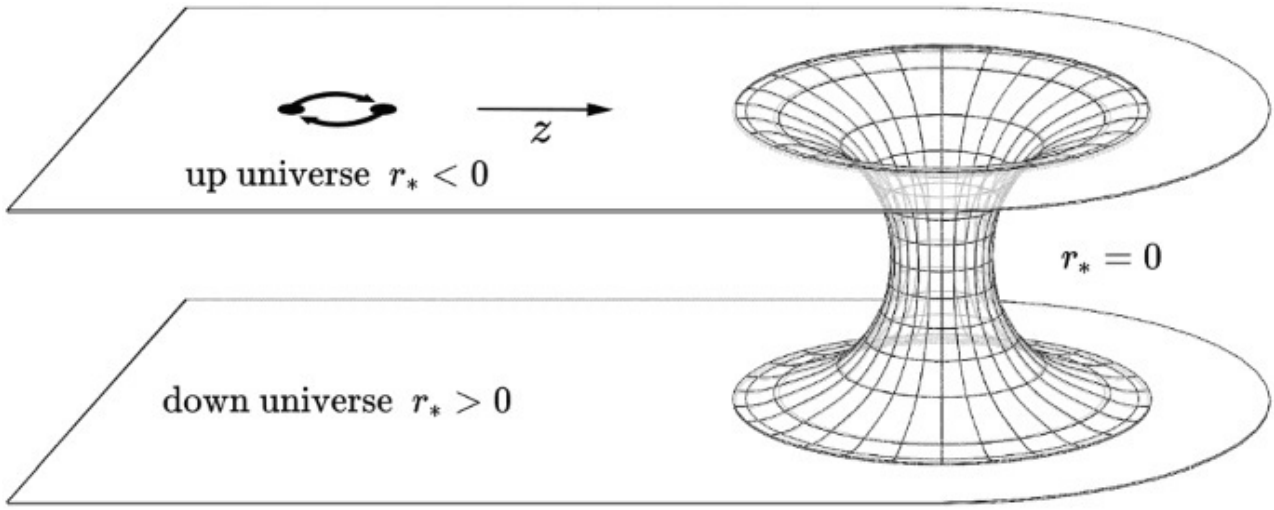
Can Wormholes Be An Answer to the Ansible Problem?

Arya Lal Gonullu

In *The Cosmic Challenge: Why Quantum Entanglement Won't Deliver The Ansible* in Principium 46, August 2024 (i4is.org/principium-46/), Arya Gonullu introduced us to the idea of communicating instantaneously, defying the light speed limit for information transmission. The idea is old in science fiction and it acquired a name in 1969 in *The Left Hand of Darkness* by Ursula K Le Guin.
Here she examines the idea of wormholes as the vehicle for such communication.
References at the end of this article.

The concept of the ansible—a device that enables instantaneous communication across vast cosmic distances faster-than-light—has fascinated science fiction enthusiasts for decades. However, a fundamental obstacle stands in its way: the laws of physics, specifically Einstein's theory of relativity, which prohibit faster-than-light communication due to its potential to violate causality.
In Principium Issue 46, we explored whether quantum communication via quantum entanglement could provide a viable ansible. We highlighted that while entanglement establishes correlations between particles, it does not allow control over the transmitted information. To achieve meaningful communication, classical channels remain essential, a point we explored in detail within the issue.
Now, with a big "if" in mind, we turn to one of the most interesting possibilities: wormholes, and what about entanglement through wormholes? Could wormholes offer a theoretical means to overcome the ansible problem?

Introduction to Wormholes



Wormhole theory did not emerge, as commonly believed, from concerns that quantum entanglement defied the principles of relativity due to its instantaneous nature. Although entanglement exhibits instantaneous correlations between particles, it does not enable faster-than-light communication or violate relativity, instead, entanglement is part of the probabilistic and relational aspects of quantum mechanics.

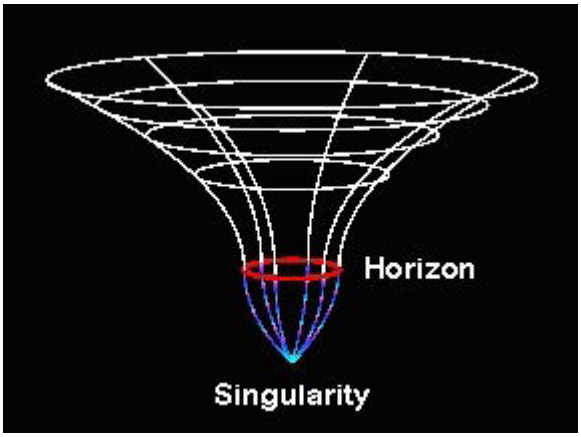
The idea of wormholes traces back to Albert Einstein and Nathan Rosen in 1935, in their attempt to unify electromagnetism with gravity (Lindley, 2005). Their work aimed to achieve a consistent understanding of quantum fields in curved spacetime (Marto et al., 2024). As Einstein and Rosen stated, "a particle in the physical Universe has to be described by mathematical bridges connecting two sheets of spacetime" (Einstein & Rosen, 1935).

To explore this alternative approach, Einstein and Rosen proposed what became known as the Einstein-Rosen bridge, a theoretical construct that arose from their work in general relativity, which describes how massive objects curve spacetime. The bridge was envisioned as a shortcut through spacetime, connecting two distant regions via a tunnel-like structure—a wormhole. A commonly used analogy to describe this concept is a pen piercing through a folded piece of paper, illustrating the idea of traversing between two points in spacetime more efficiently.

Initially, they conceived the bridge not as a means for travel between these two sheets of spacetime but as a way to explain the behaviour of elementary particles, imagining them as objects moving through these tunnels and bypassing conventional spacetime limitations. Einstein and Rosen's primary motivation was to investigate the possibility of an atomistic theory of matter and electricity that, while excluding singularities of the field, relied only on the variables of general relativity ($\mathbf{g}$) and Maxwell's electromagnetism (φ) (ibid).

Einstein and Rosen's wormhole model wasn't originally conceived as a means of communication but rather as an effort to provide a singularity-free description of the physical universe. In classical physics, singularities occur when mathematical quantities, such as spacetime curvature, become infinite—like the idea of a particle having all its mass concentrated into an infinitely small point. In general relativity, a point mass curves spacetime around it in a way first described by Karl Schwarzschild in 1916 where the Schwarzschild solution introduced singularities both at zero and at the Schwarzschild radius (Schwarzschild, 1916).

Einstein and Rosen reinterpreted the Schwarzschild solution to rid physics of these singularities: They proposed an alternative view in which a path tracing radially inward would not encounter a singularity at the Schwarzschild radius. Instead of continuing towards an infinitely dense centre, their model proposed that the inwards trajectory would seamlessly connect to another region of spacetime, emerging outwards again—essentially linking two separate sections of spacetime. This concept can be visualised by imagining two adjacent rubber sheets, each with a funnel shape pulled from their surfaces and connected at their narrowest points, forming a continuous tube-like passage between them.



However, the idea of using such constructs for instantaneous communication emerged later as physicists began to explore the exotic implications of wormholes, leading to speculation about their potential role in enabling faster-than-light travel or information transfer.

Interstellar Travel via Wormholes: Ansible?

In theory, a traversable wormhole could allow information to pass through one "mouth" and emerge instantaneously from the other, regardless of the distance between the two ends. Such a mechanism would effectively permit faster-than-light communication, solving the ansible problem. However, there are several obstacles to making this concept a viable solution.

Wormholes, as described by the equations of general relativity, are dismayingly unstable. Any wormhole connection that happens to form between two points in space should pinch closed again so rapidly that neither material objects nor light-beam messages can pass across the wormhole "bridge" during its brief existence. Thus, at least in its pristine form, a wormhole is unsuitable for the instantaneous space transport that science fiction writers may have in mind. Most physicists will find this result satisfying, for it also avoids a simultaneity paradox (Cramer, 1989).

However, Morris, Thorne, and Yurtsever propose to create a stable wormhole, with the hope that someday we may be able to build one. Empty space, when examined with quantum theory on a sufficiently small distance scale, is not empty at all. Even at nuclear dimensions (10^{-13} cm), empty space is filled with particle-antiparticle pairs that are continually flashing into brief existence, bankrolled on the credit of borrowed mass-energy, only to wink out of existence again as the law of conservation of energy reasserts itself. If the length scale is contracted to a size appropriate to quantum gravity (10^{-33} cm , Planck-Wheeler length), this quantum fireworks intensifies to a "quantum foam" of violent fluctuations in the topology and geometry of space itself (Morris, Thorne and Yurtsever, 1988). In this environment, Morris, Thorne, and Yurtsever speculate, it may be possible for a civilisation considerably more advanced than ours, by "pulling a wormhole out of the quantum foam and enlarging it to classical size," to create a connection between two nearby points in space. This would use the well-known quantum mechanical process called "tunnelling," a jump from one allowed energy state to another across a barrier of intermediate states that are forbidden by energy conservation (Cramer, 1989).

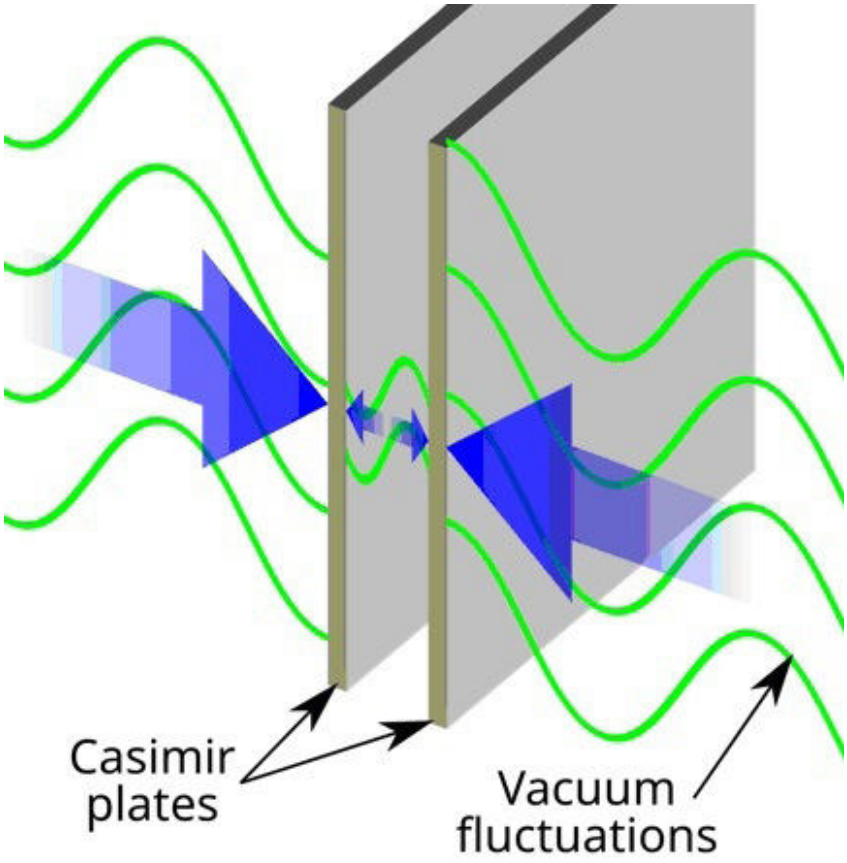
To stabilise the wormhole pulled from the quantum foam, preventing its immediate re-collapse, Morris, Thorne, and Yurtsever propose to use an electric field of such enormous strength that it creates enough energy in the mouth of the wormhole to force it to remain open. They suggest that this might be accomplished by placing a pair of spheres with equal electric charges at the two spatial entrances of the wormhole. The spheres would be held in place by a delicate balance, the force of their gravitational attraction just offsetting the force of their electrical repulsion. Such a system might be very small, an atom-scale opening permitting the passage of only a few photons at a time, or it might be large enough to pass a large vehicle with far-future technology, where instantaneous communication and transport through the wormhole would be available.

Hence, to keep a wormhole stable and traversable, negative energy or exotic matter would be needed to counteract the gravitational forces that would otherwise cause the wormhole to collapse.

Negative energy is found in quantum mechanics, eg, the Casimir effect (see below), but producing and sustaining the required quantities remains beyond our technological capability.

The big deal breaker for our universe, as far as we know today, seems to be the lack of what one might call "exotic" matter (Siegel, 2022). The simplest way of looking at the situation is to think of space as having an average energy density from all sources: matter, radiation, and even the (positive, non-zero) zero-point energy of empty space itself. Where you have positive energy, space curves in response to that; this is why massive particles exhibit the phenomenon of gravitational attraction. So far, all we've ever detected in the universe is matter and energy with positive values to it (ibid).

But if you want to have a traversable wormhole, you need some type of matter and/or energy that has a negative value to it, at least negative relative to the average energy density of the universe. Although we can create small regions of space that have this property – eg, the empty space between two parallel conducting plates, such as a setup exhibiting the Casimir effect (see the diagram below) – there are no species of negative energy quanta known to exist.



The Link Between Wormholes and Entanglement (EPR = ER)

The Link Between Wormholes and Entanglement

In recent years, physicists have begun exploring deep connections between wormholes and quantum entanglement, a conjecture often referred to as "EPR = ER". This conjecture suggests that Einstein-Rosen bridges (wormholes) and Einstein-Podolsky-Rosen entanglement (EPR) are interlinked: In this framework, a wormhole can be thought of as the geometric manifestation of entanglement, entangled particles might be connected by microscopic wormholes, providing a new way to think about the non-local behaviour of quantum systems (Susskind, 2016).

If confirmed, this conjecture would imply that quantum mechanics and spacetime geometry are fundamentally linked. While this doesn't solve the ansible problem outright, to keep an open mind, it might suggest that wormholes and entanglement might work together in some yet-unknown framework to enable faster-than-light communication. However, practical challenges, such as the stability of wormholes and the limitations of entanglement-based communication, remain unresolved.

Can Wormholes Solve the Ansible Problem?

At present, the answer is a tentative "no"—at least within our current understanding of physics. Wormholes offer inspiring glimpses of how nature might allow shortcuts in spacetime or instantaneous connections, but the practical solutions can only come via a breakthrough, or far in the future. For now, the ansible still remains a work of fiction, but it is important to keep an open mind, mathematically and conceptually: as the interplay between our current understanding of physics and what's possible will always keep the field of physics reinvigorating.

References

Cramer, J (1989). Alternate View Column AV-33. [online] www.npl.washington.edu. Available at: www.npl.washington.edu/av/altvw33.html.

Gaztañaga, E, Kumar, KS and Marto, J (2024). A new understanding of Einstein-Rosen bridges. [online] doi:doi.org/10.20944/preprints202410.0190.v1.

K Schwarzschild (1916). On the gravitational field of a mass point according to Einstein's theory. arXiv (Cornell University). doi: doi.org/10.48550/arxiv.physics/9905030.

Lindley, D (2005). The Birth of Wormholes. Physics, [online] 15(47). Available at: physics.aps.org/story/v15/st11 [Accessed 3 Jun. 2019].

Morris, MS, Thorne, KS and Yurtsever, U (1988). Wormholes, Time Machines, and the Weak Energy Condition. Physical Review Letters, 61(13), pp.1446–1449. doi: doi.org/10.1103/physrevlett.61.1446.

Siegel, E (2022). The truth about wormholes and quantum computers. [online] Big Think. Available at: bigthink.com/starts-with-a-bang/wormholes-quantum-computers/ [Accessed 19 Jan. 2025].

Susskind, L (2016). ER=EPR, GHZ, and the consistency of quantum measurements. Fortschritte der Physik, 64(1), pp.72–83. doi: doi.org/10.1002/prop.201500094.

The Initiative & Institute for Interstellar Studies

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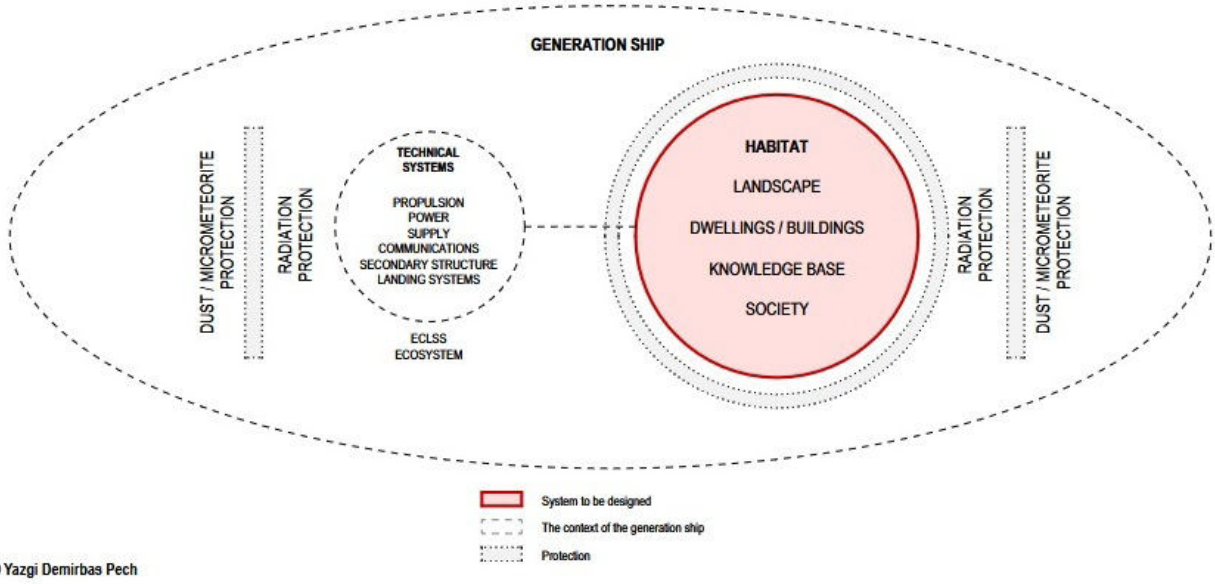
Parnika Singh reports on recent developments in interstellar studies

Project Hyperion Design Competition

The Project Hyperion Design Competition is the first of its kind, exploring the long-term sustainability of a generation ship habitat and society. Registration for the competition to design a generation ship is now over. The registered teams now have until the 9th of March to work on their Phase 1 submissions, involving initial designs and narratives addressing the challenges of a believable society in a generation ship with vernacular architecture and low-tech, knowledge & technology transfer, cultural evolution, environmental and life-support systems. Shortlisted teams will then proceed to Phase 2. Competition results will be announced in June of this year. More about our competition at www.projecthyperion.org.



Electric Propulsion for Interstellar Travel

On 28 October 2024, Nadim Maraqten, Dan Fries and Angelo Genovese (all of whom are i4is researchers) released their International Astronautical Congress paper titled *Advanced Electric Propulsion Systems with Optimal Specific Impulses for Fast Interstellar Precursor Missions* affiliated with i4is (www.researchgate.net/publication/385172298). Interstellar exploration is in its early stages, but its potential scientific and cultural impact is immense. To support upcoming interstellar missions, advanced propulsion systems are critical for achieving the high speeds (delta-V) needed and for allowing larger payloads. However, the best propulsion system depends on the specific mission requirements.

This study uses the non-dimensional Tsiolkovsky equation to optimize the combined payload and structural mass fraction of spacecraft based on factors such as specific impulse (efficiency of propulsion), specific power, thruster efficiency, transfer time, and required delta-V. Three mission scenarios are analyzed under the assumption of an advanced power source with a specific power of 1,000 W/kg and a thruster efficiency of 97%: a round trip to Jupiter, a rendezvous with Pluto, a mission to the solar gravitational lens focal point (beyond 500 AU from the Sun). For each mission, the study identifies the ideal specific impulse to maximize the payload mass fraction, the corresponding transit time, the type of electric propulsion system that could achieve these goals, and the total spacecraft mass assuming a launch with NASA's Space Launch System Block 2. The results show that advanced electric propulsion systems could significantly increase payload capacity and reduce travel times compared to conventional methods, making interstellar precursor missions more feasible.

Hot Traversable Wormholes

On 21 January 2025, Remo Garattini and Mir Faizal of the Canadian Quantum research center published a paper in the Journal of Cosmology and Astroparticle Physics titled *Hot Casimir wormholes* (arxiv.org/abs/2403.15174). The paper explores an innovative approach to constructing traversable wormholes using the thermal Casimir effect. Wormholes, theoretical tunnels in spacetime, allow shortcuts between distant points. Traditional wormholes require exotic matter—materials that violate energy conditions in general relativity. The Casimir effect, a quantum phenomenon that generates negative energy between closely spaced metallic plates, offers a promising candidate for such exotic matter.

This study extends the Casimir effect to finite temperatures, examining how thermal fluctuations impact wormhole size and stability. By analyzing both low- and high-temperature regimes, the researchers model scenarios with plates at fixed distances and radially varying configurations. At low temperatures, thermal corrections minimally influence the wormhole's properties, while at high temperatures, they significantly alter the wormhole's throat size and energy density.

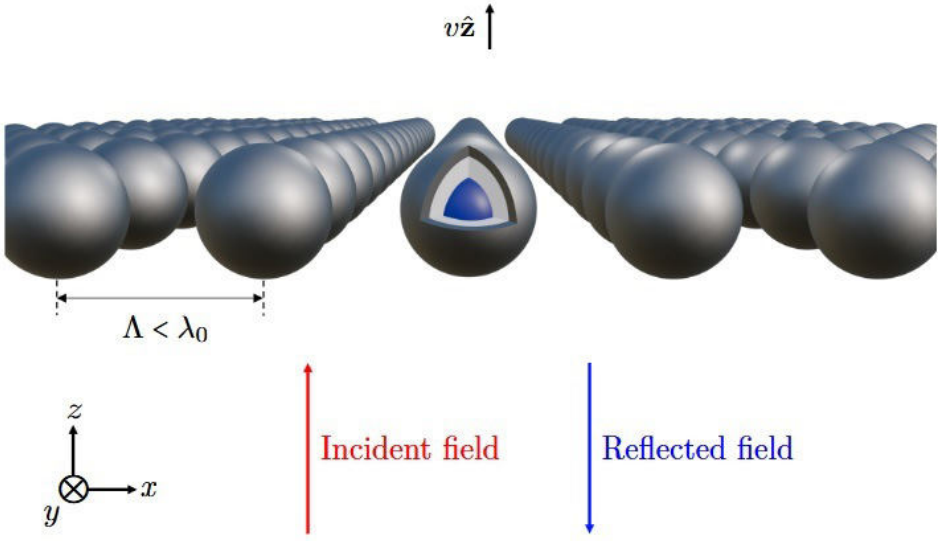
The findings highlight that thermal effects do not disrupt the traversability of Casimir wormholes, though creating a practical wormhole would require temperatures and configurations beyond current technological capabilities. The research also suggests that incorporating superconducting materials or quantum corrections could further refine wormhole designs. Overall, this study deepens our understanding of quantum phenomena in spacetime geometry, opening new possibilities for theoretical physics and futuristic space travel concepts.

Metasurface Materials for Light Sails

On 17 October 2024, Cornell's preprint server arXiv released a paper titled *Analyzing the acceleration time and reflectance of light sails made from homogeneous and core-shell spheres* by Mitchell R Whittam et al of Karlsruhe Institute of Technology (https://arxiv.org/abs/2410.13494). Selecting appropriate materials and designs for light sails, such as those envisioned in the Breakthrough Starshot Initiative, is a critical and complex challenge. This study proposes a potential solution using "metasurfaces" composed of periodically arranged microscopic spheres. These spheres are made from materials like aluminum, silicon, and silicon dioxide.

The research applies Mie theory, a method used to understand how light interacts with small structures, to evaluate the metasurfaces' ability to reflect light, absorb heat, and enable efficient acceleration. The findings highlight the effectiveness of metasurfaces made from silicon spheres combined with an added silicon dioxide layer. This design demonstrates strong broadband reflectance due to the constructive interference of light waves while maintaining low absorption. Furthermore, the study shows that the metasurfaces retain over 90% reflectance even when placed in embedding materials with refractive indices up to 1.13, without requiring significant re-optimization.

A light sail infinitely spanning the x-y plane moving along the +z-axis at speed v illuminated by a linearly polarized incident plane wave reflected in the -z direction. The sail comprises spheres (which we depict here as having a core and two shells) arranged in a square lattice characterized by a lattice constant Λ, which is always smaller than the wavelength λ_0 of the incident field as observed on Earth.
Credit: Whittam fig1.



Market Feasibility of Nuclear Electric Propulsion

On 29 November 2024, i4is Executive Director Andreas Hein et al published a paper titled *Market Study on Nuclear Electric Propulsion for Space Applications* (hal.science/hal-04811171/document). Presented at IAC24 by a colleague from the University of Luxembourg, the paper explores its potential in advanced space missions and logistics. NEP offers a balance between high efficiency and significant power output, making it a promising alternative to chemical and solar electric propulsion for long-duration missions. Unlike solar electric propulsion, NEP can operate in shadowed regions and deep space, enabling continuous functionality.

The study, part of the European Space Agency's RocketRoll project, evaluates NEP's viability for missions like transporting satellites from low Earth orbit (LEO) to geostationary orbit (GEO) and delivering cargo to lunar orbit. NEP is compared with existing propulsion methods, focusing on cost, efficiency, and mission duration. The results indicate that NEP can reduce costs and increase payload capacity, particularly for missions requiring large-scale logistics or extended operations. In addition to traditional applications, the paper explores emerging markets that NEP could enable, such as on-orbit satellite servicing, lunar mining, and deep-space exploration. NEP's ability to provide sustained thrust and power positions it as a critical technology for the future development of lunar bases, interplanetary travel, and space resource utilization.

A Trifecta of Approaches to Interstellar Travel

On 18 November 2024, the Systems Assessment and Engineering Management journal published an article by Victor Christianto and Florentin Smarandache of the University of New Mexico titled *Three Novel Approaches to Deep Space: Interstellar Travel that Transcend the Limitations Imposed by the Rocket Equation* (sciencesforce.com/index.php/saem/article/view/427/593). The paper explores three innovative approaches to interstellar travel that overcome the Tsiolkovsky rocket equation's limitations by leveraging quantum mechanics, superconductivity, and cosmic structures to enable efficient, long-distance space travel.

The first approach, macroquantum tunneling, theorizes macroscopic objects could "tunnel" through energy barriers, bypassing traditional propulsion. Drawing from superfluid and superconductor phenomena, this method could enable spacecraft to travel vast distances without consuming propellant. The second method, non-orientable wormholes, inspired by Möbius strips and superconductors, proposes spacetime curvature through materials like crystals, potentially facilitating faster-than-light travel and revolutionizing propulsion. The third approach examines neuron-like galaxy cluster structures, proposing the cosmic web's interconnected nature could inspire advanced navigation systems or warp drives. These quantum-based ideas promise breakthroughs in interstellar exploration despite significant technical challenges.

Re-estimating the Drake Equation Terms

On 1 December 2024, Cornell's preprint server arXiv released a paper by Lukasz Lamza of Jagiellonian University titled *Chemical Complexity and Prevalence of Life in the Universe: A New Method for the Estimation of Key Terms of Drake Equation* (arxiv.org/abs/2412.01001#). The paper introduces a novel approach to estimating the prevalence of life in the universe by correlating chemical complexity with abundance across cosmic environments. The study proposes that environments with greater chemical complexity, defined by the diversity of molecules present, are less abundant. Using this inverse relationship, the paper quantifies the fraction of the universe's baryonic mass that reaches the minimum chemical complexity required for life. Combining this with statistical models of planetary systems, it predicts the number of planets in a Milky Way-sized galaxy capable of supporting life.

Two models are used: one assumes life forms across planetary systems, while the other focuses on individual planets ("planemos") with the necessary conditions for life. Results suggest a range of possibilities, from a few planets hosting life to thousands, depending on assumptions about chemical complexity and environmental conditions. The study refines the parameters of the Drake Equation and provides a new perspective on estimating the likelihood of extraterrestrial life by focusing on measurable chemical and astrophysical properties.

Technosignatures and Biosignatures

On 16 January 2025, Vinicio Pelino released a preprint titled *Exploring the Entanglement of Biosignatures and Technosignatures: A Quantum Perspective* (www.researchgate.net/publication/387960793). The paper explores a novel framework for searching for extraterrestrial life by combining biosignatures (evidence of biological processes) and technosignatures (evidence of technology) through the lens of quantum mechanics. It proposes that these indicators can be conceptualized as quantum states, providing a unified approach to understanding their relationship and detectability. Biosignatures, such as oxygen or methane, represent biological activity, while technosignatures, like artificial electromagnetic signals, point to intelligent life. The study introduces the idea that these phenomena may be "entangled," suggesting that the presence of one could increase the likelihood of detecting the other.

By modeling biosignatures and technosignatures as quantum states, the paper examines their co-evolution and interdependence, using concepts like superposition and entanglement to describe their relationships. For example, a Dyson sphere—a massive structure built to harness a star's energy—might simultaneously exhibit technosignatures (infrared emissions) and engineered biosignatures (atmospheric changes). The framework allows for new ways to interpret data from astrobiology and SETI (Search for Extraterrestrial Intelligence), emphasizing interdisciplinary methods that combine biology, technology, and quantum physics. The paper concludes that this approach offers deeper insights into the emergence of life and intelligence, potentially transforming how humanity searches for extraterrestrial civilizations and understands its own place in the universe.

Achieving Antimatter Abundance

On 13 December 2024, Douglas C Youvan released a preprint titled "Pathways to Antimatter Abundance" (www.researchgate.net/publication/387029365). The paper explores the potential of antimatter, one of the most energy-dense substances, for transformative applications in energy production, space propulsion, and scientific research. When antimatter annihilates upon contact with matter, it releases massive amounts of energy as described by $E=mc^2$, with just 1 gram producing energy equivalent to 43 kilotons of TNT. This makes antimatter a promising candidate for interstellar travel, clean energy, and medical advancements.

In space exploration, antimatter could power spacecraft to relativistic speeds, significantly reducing travel times. However, the challenges of large-scale production and storage are immense. Current methods, such as particle collisions in facilities like CERN, produce antimatter in minuscule amounts at exorbitant costs—approximately $62.5 trillion per gram. Safely storing antimatter also requires advanced magnetic traps to prevent annihilation. The paper highlights emerging technologies, including laser-based generation and advanced magnetic-optical containment systems, which could improve efficiency and scalability.

Antimatter's explosive potential raises ethical and safety concerns, particularly regarding weaponization. The paper stresses the importance of international regulations and collaborative research to responsibly develop antimatter, unlocking its benefits while mitigating risks for future applications.

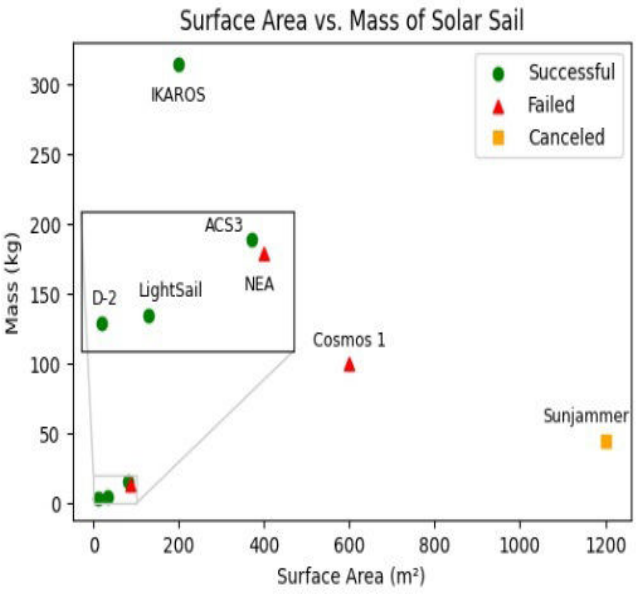
Automating Interstellar Object Classification

On 26 November 2024, Richard Cloete et al of Harvard published a paper in the Astronomy and Astrophysics journal titled *Machine learning methods for automated interstellar object classification with LSST* (www.aanda.org/articles/aa/full_html/2024/11/aa51118-24/aa51118-24.html). The paper explores the application of machine learning (ML) algorithms to identify and classify interstellar objects (ISOs) using data from the upcoming Vera C Rubin Observatory's Legacy Survey of Space and Time (LSST). ISOs, such as `Oumuamua and Borisov, could provide unique insights into other planetary systems, but their detection is challenging due to their rarity and brief observation windows. The LSST's vast datasets require automated methods to efficiently detect and classify ISOs among millions of celestial objects.

The authors tested various ML algorithms, including Gradient Boosting Machines (GBM), Random Forests (RF), Stochastic Gradient Descent (SGD), and Neural Networks (NN). Among these, GBM and RF performed best. The models were validated using simulated LSST datasets and real-world ISO examples, such as `Oumuamua and Borisov, demonstrating promising results. However, challenges remain, such as minimizing false positives and improving performance with limited data. The paper emphasizes the need for more comprehensive observations and continuous model updates as new ISOs are discovered.

Advances in Solar Sailing

On 23 November 2024, Cornell's preprint server arXiv released a paper by Elena Ancona and Roman Ya Kezerashvili of New York City College of Technology titled *Recent advances in space sailing missions and technology: a review of the 6th International Symposium on Space Sailing (ISSS 2023)* (arxiv.org/pdf/2411.12492). The paper provides an overview of ISSS 2023, which gathered experts from 14 countries to discuss recent advances and challenges in solar sailing technology. Solar sails, which harness sunlight for propulsion without requiring fuel, have progressed significantly since the first successful deployment of Japan's IKAROS in 2010. The symposium highlighted innovative concepts, including advanced solar sail materials, trajectory designs for interstellar and deep-space missions, and cutting-edge control systems.
Key missions discussed included NASA's ACS3 and the Solar Cruiser, showcasing the practical applications of solar sails in space exploration. New materials and techniques, such as thermal desorption coatings and diffractive solar sails, were presented to enhance propulsion and durability. Concepts like electric sails and hybrid propulsion systems were also explored to improve performance for future missions. The symposium emphasized the interdisciplinary collaboration required to overcome engineering challenges, including precise attitude control and material degradation. Presentations addressed novel uses of solar sails, from asteroid exploration to orbital debris removal. This gathering underscored the potential of solar sailing to enable long-term, sustainable space exploration, and deep-space missions, setting the stage for continued innovation in this transformative technology.



Sail area and mass (including the sail and its associated hardware) for some missions of the past decades.
Credit: Ancona and Kezerashvili; Figure 1

Space Nanotechnology

Salaheldin Elabiad of Girne American University published a paper on 9 January 2025 titled *Nanotechnology for Space Exploration* in SSRN (papers.ssrn.com/sol3/papers.cfm?abstract_id=5080329). The paper examines how nanotechnology is revolutionizing space exploration by addressing critical challenges like weight reduction, energy efficiency, radiation protection, and system durability. Nanotechnology enables the development of advanced materials and systems that are lightweight yet robust, such as carbon nanotubes (CNTs), graphene, and boron nitride nanotubes (BNNTs). These materials enhance spacecraft performance by providing superior strength-to-weight ratios, thermal stability, and radiation resistance, making them ideal for extreme space environments.
Nanotechnology also advances sensors and instruments, enabling highly sensitive, compact, and multifunctional devices for monitoring spacecraft environments and conducting planetary research. Innovations in energy systems, including quantum dot-based solar cells and thermoelectric materials, improve energy efficiency for long-duration missions. Similarly, nanotechnology contributes to life support systems through water purification, air filtration, and radiation shielding, ensuring sustainable human presence in space. In propulsion, nano-thrusters and nanomaterials in ion propulsion systems enhance fuel efficiency and enable precise maneuvering, which is critical for interplanetary and interstellar missions. However, the paper also highlights ethical concerns, such as the environmental risks of deploying nanomaterials in extraterrestrial settings and the need for international regulations.

Studying Interstellar Objects

Cornell's preprint server arXiv published a paper titled *Information-Optimal Multi-Spacecraft Positioning for Interstellar Object Exploration* by Arna Bhardwaj et al of University of Illinois at Urbana-Champaign on 14 November 2024 (arxiv.org/abs/2411.09110). Interstellar objects (ISOs) are astronomical objects that travel through space without being bound to the Sun's gravity. These objects offer valuable insights into the formation and composition of the universe. However, detecting and studying them is challenging because their appearances are unpredictable, and their positions and movements are uncertain.

This paper introduces a new framework that uses multiple spacecraft to study ISOs more effectively. The method ensures that information collected during ISO encounters is maximized, even with large uncertainties about the object's location. The approach relies on a mathematical system that predicts where an ISO is likely to be, represented as a three-dimensional ellipsoid. It ensures this uncertainty is managed efficiently using advanced probabilistic techniques. The proposed framework determines the best positions for multiple spacecraft around the predicted ISO location to capture the most useful data, such as visual images, while considering factors like spacecraft camera capabilities and the uncertainty of the ISO's position. Simulations using hypothetical ISOs show that this method effectively allows each spacecraft to decide where to go and how many areas of interest to study, maximizing the scientific return while minimizing resource use.

The Future of Antimatter Propulsion

The International Journal of Thermofluids published a preprint on 7 December 2024, titled *Future of Antimatter Production, Storage, Control, and Annihilation Applications in Propulsion Technologies* by Sawsan Ammar Omira et al of United Arab Emirates University (www.sciencedirect.com/science/article/pii/S2666202724004518). The paper explores the potential of antimatter as a propulsion technology for space exploration, emphasizing its unparalleled energy density and efficiency compared to conventional and nuclear propulsion methods. Antimatter-matter annihilation releases energy at an extraordinary rate, with up to 70% of the energy being harnessed for propulsion. This technology could make interstellar travel feasible within a human lifetime, enabling missions to distant stars in weeks or months instead of decades.

The study addresses the challenges of antimatter production, storage, and control, which are significant barriers to its practical application. Current technologies allow for the production and trapping of small amounts of antimatter, but scaling this for propulsion remains a challenge due to the immense energy costs and technological limitations. Proposed solutions include advanced magnetic and cryogenic traps for stable storage and innovative propulsion system designs like beamed-core and plasma-core engines.

Self-Sustaining Space Habitats

R Wordsworth and C Cockell of Harvard released a paper on arXiv on 5 December 2024 titled *Self-sustaining living habitats in extraterrestrial environments* (arxiv.org/abs/2409.14477). The paper explores the concept of creating biologically self-sustaining habitats in extraterrestrial environments, challenging the traditional assumption that life requires Earth-like planetary conditions. The authors propose that ecosystems capable of generating and maintaining their own habitable conditions are theoretically feasible, even in harsh environments like space or planets with thin atmospheres.

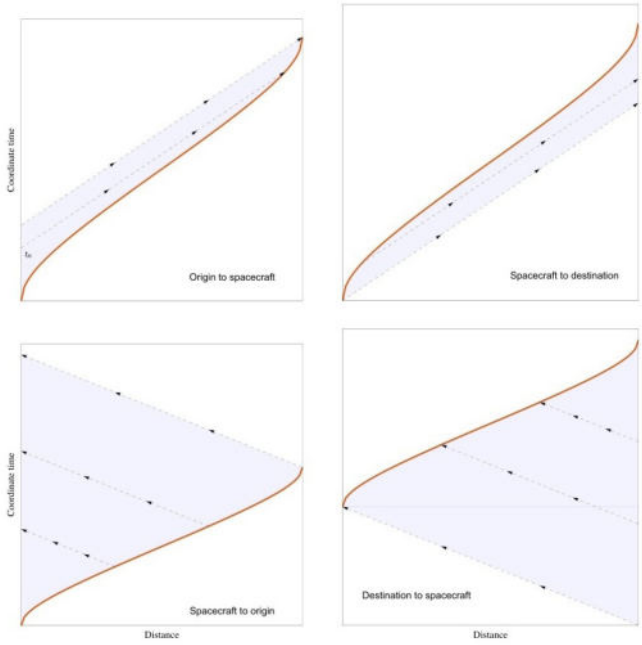
Key challenges to life in such environments—pressure, temperature, volatile loss, radiation, and nutrient availability—are analyzed, with potential solutions rooted in biological materials and processes. For example, biologically generated barriers could regulate temperature and pressure, prevent volatile loss, and shield against harmful radiation while allowing sufficient light for photosynthesis. The study also highlights the potential for using bioplastics and biominerals to construct habitat walls, drawing parallels to naturally occurring biological structures. These self-contained habitats have implications not only for astrobiology but also for human space exploration. The research also considers the detectability of such systems on other planets, offering a new perspective on biosignatures in the search for extraterrestrial life.

Prototyping a Plasma Thruster

Yuxuan Huang et al of the Chinese Academy of Sciences published a paper on 26 December 2024 in IOP's Plasma Science and Technology Journal titled *Design and experimental study of a field-reversed configuration plasma thruster prototype* (iopscience.iop.org/article/10.1088/2058-6272/ada376/meta). The study introduces the design and experimental testing of a prototype Field-Reversed Configuration (FRC) plasma thruster powered by a rotating magnetic field (RMF). This advanced propulsion system is intended for deep-space exploration, promising higher efficiency, longer operational lifespans, and higher specific impulses compared to traditional chemical and electric thrusters. The RMF-FRC thruster works by ionizing a propellant to create plasma, which is then driven by RMF to form a reversed magnetic field configuration, propelling the spacecraft through electromagnetic forces.

The research involved building a prototype with a 210 kHz RMF and a peak current of 2 kA. Experimental tests achieved a plasma density increase from $5*10^{17}$ m^{-3} to $2.2*10^{15}$ m^{-3} and a plasma current peak of 1.9 kA, confirming successful FRC formation. Optimizing the magnetic field bias to 100 Gauss resulted in the best plasma performance. The prototype demonstrated an RMF coupling efficiency of 53%, surpassing existing FRC thruster designs.

While promising, challenges such as low initial plasma density and energy losses during ionization remain. Future improvements will focus on enhancing the RMF strength and pre-ionization techniques to maximize efficiency. The study highlights the RMF-FRC thruster's potential as a cutting-edge propulsion solution for future space missions.



Communications Challenges in Interstellar Travel

Illustration of the time constraints on communication during a spacecraft's travel from launch to landing for the canonical mission. The spacecraft trajectory is the solid line, and photon trajectories to and from the spacecraft and to and from the origin and destination are shown as dashed lines. Each shaded region represents the ensemble of all feasible photon trajectories which intersect the spacecraft trajectory during its cruise phase. The most significant influence on this ensemble shape is the direction of photon propagation.
Credit: Messerschmitt et al Figure 4

Comparing Propulsion Technologies

Aun Abbas released a preprint on engrXiv titled *Comparative Analysis of Rocket Engine Technologies for Long-Term Space Exploration* on 26 December 2024 (engrxiv.org/preprint/view/4258). The paper provides a comparative analysis of five major rocket engine technologies—Nuclear Thermal Propulsion (NTP), Chemical Rocket Engines, Ion Thrusters, Nuclear Electric Propulsion (NEP), and Plasma Propulsion Systems—evaluating their suitability for long-term space exploration. The study examines these technologies across several criteria, including efficiency, thrust, energy consumption, safety, cost, scalability, environmental impact, reliability, and technological readiness.

NTP systems are highlighted for their high efficiency and moderate thrust, making them suitable for missions requiring rapid acceleration and significant payload capacity, such as crewed Mars missions. However, their implementation is hindered by safety risks, regulatory challenges, and high development costs. Chemical rockets, the most mature technology, remain indispensable for launch phases due to their high thrust but are less efficient and unsuitable for prolonged missions. Ion Thrusters and Plasma Propulsion Systems excel in efficiency, achieving exceptionally high specific impulses, which reduce propellant needs for long-duration missions. However, their low thrust levels and high energy demands limit their use in deep-space propulsion. NEP offers a balanced approach with moderate thrust and efficiency, but its complexity and high costs present significant challenges. The paper concludes that the optimal propulsion technology depends on mission-specific requirements, and further research into hybrid systems is necessary.

Communications Challenges in Interstellar Travel

David Messerschmitt et al of the University of California at Berkeley recently released a preprint on arXiv titled *Timing relationships and resulting communications challenges in relativistic travel* (arxiv.org/abs/2311.14039). The paper explores the challenges and timing intricacies involved in communication during interstellar travel, specifically for spacecraft travelling near the speed of light. It investigates how classical and relativistic effects, such as large photon propagation delays and time dilation, impact the transmission and reception of messages between a spacecraft and entities at its origin and destination. Two mission profiles are considered: one involving indefinite constant acceleration and another with a cruise phase featuring acceleration followed by deceleration. These scenarios highlight the difficulties of maintaining real-time communication due to effects like clock inconsistency and communication blackouts.

The study emphasizes key issues, such as query-response latencies, which can severely delay two-way interactions, and the warping of time experienced during one-way message streaming. For example, photons traveling in the same direction as the spacecraft may not reach their target until much later in the journey, leading to significant delays in communication. The findings underline the necessity for autonomous spacecraft operations during most of the mission and demonstrate that maintaining continuous communication with the spacecraft, while theoretically beneficial, faces profound practical challenges. The study concludes by suggesting that interstellar communication systems must account for these effects to ensure mission success and data integrity.

Gravitational Communication

Cornell's preprint server arXiv released a preprint by Houtianfu Wang on 26 December 2024. titled *Gravitational Communication: Fundamentals, State-of-the-Art, and Future Vision* (arxiv.org/abs/2501.03251). The paper explores the emerging field of gravitational communication, examining the fundamental principles, challenges, and future possibilities of using gravitational waves as a medium for information transmission. Gravitational waves, ripples in spacetime caused by massive accelerating objects like merging black holes, have unique propagation characteristics that allow them to penetrate dense materials and travel across vast cosmic distances with minimal signal loss. This makes them a promising alternative to traditional electromagnetic communication, particularly in extreme or shielded environments.

The paper reviews methods for generating gravitational waves in laboratory conditions, including mechanical resonance, superconducting materials, and particle collisions, although practical generation remains a significant hurdle. Detection technologies, such as laser interferometry and emerging techniques leveraging deep learning, have improved sensitivity but are primarily optimized for astrophysical signals rather than engineered communication systems. Modulation techniques are also explored, highlighting the potential to encode and transmit information through gravitational waves. Despite its promise, the field faces challenges such as weak signal generation, low detection sensitivity, and the impact of cosmic environments on wave propagation. The paper calls for interdisciplinary research to address these barriers, envisioning gravitational communication as a revolutionary advancement in both physics and information technology.

High-Frequency Radio SETI Searches

The Royal Astronomical Society published a paper by Louisa A Mason et al of University of Manchester on 10 December 2024, titled *Conducting high-frequency radio SETI searches using ALMA* (academic.oup.com/mnras/advance-article/doi/10.1093/mnras/stae2714/7920797?login=false). The paper presents the first search for technosignatures—signals potentially from extraterrestrial intelligence—using the Atacama Large Millimeter/Submillimeter Array (ALMA). The study focuses on high-frequency radio observations, exploring ALMA's unique capability to detect narrowband signals in the millimeter and submillimeter wavelength ranges, an area largely unexplored in previous SETI (Search for Extraterrestrial Intelligence) research.

The researchers analyzed archival ALMA data targeting 28 stars identified in the Gaia DR3 catalog. The search specifically looked for narrowband signals with high signal-to-noise ratios, which could indicate artificial transmitters. Despite the high sensitivity of ALMA, no technosignatures were detected at the analyzed frequencies. The study highlights ALMA's potential for SETI research, emphasizing its sensitivity, ability to reduce interference, and capability to explore new frequency ranges. However, challenges like signal drift due to relative motion and spectral confusion from natural astrophysical emissions were noted. The authors propose future improvements, including dedicated SETI backends and advanced signal processing techniques, to enhance ALMA's effectiveness for detecting extraterrestrial signals.

International Astronautical Congress IAC24

The Interstellar Presentations Part 2

Here are our second reports from the 2024 International Astronautical Congress held in Milan.

Edited by John I Davies

Introduction

i4is reports on presentations that relate to interstellar travel and communications - and to the Solar System infrastructure which must precede the extension of our species beyond it.
It is the second news feature following the Congress. The first was in P47, November 2024 (i4is.org/principium-47/). All of the programme items listed here are text credited to the International Astronautical Federation (IAF) and are visible via the IAC24 Programme: iafastro.directory/iac/browse/IAC-24/.

First Report Contents

These are the presentations and papers we reported on in issue P47 - in order of IAC24 reference -

IAC24 reference	Title	Presenter	Reporter
A4,2,1,x81576	KEYNOTE: Billingham Cutting-Edge Lecture - Global outreach and cultural impact of A Sign in Space, an interdisciplinary simulation of a First Contact scenario	Ms Daniela De Paulis	Simone Caroti
A4.2.2,x80945	Re-examining AI as a "Great Filter" for Advanced Civilizations: The Transition to Post-Biological Life and its Implications for Technosignatures	Prof Mike Garrett	Simone Caroti
A4,2,3,x89071	Causal Impotence and Cosmic Messaging: A Logical Response	Dr Chelsea Haramia	John I Davies
D4,1,3,x83992	Artificial Magnetic Field as Active Shield against Cosmic Radiation	Dr Alessandro Bartoloni	John I Davies
D4,4,9,x81405	Space Arks for the Nearest Stars: a Feasibility Evaluation	Prof Giancarlo Genta	Patrick J Mahon

The reports in P47, *International Astronautical Congress IAC24: The Interstellar Presentations Part 1*, can be found at - i4is.org/principium-47/

The Programme

Here are the reports with IAF identifying codes for the symposium sessions. Shown alphabetically by IAF identifying code.
Format of programme reports -

IAF identifying code	Title	Presenter	Institution	Country

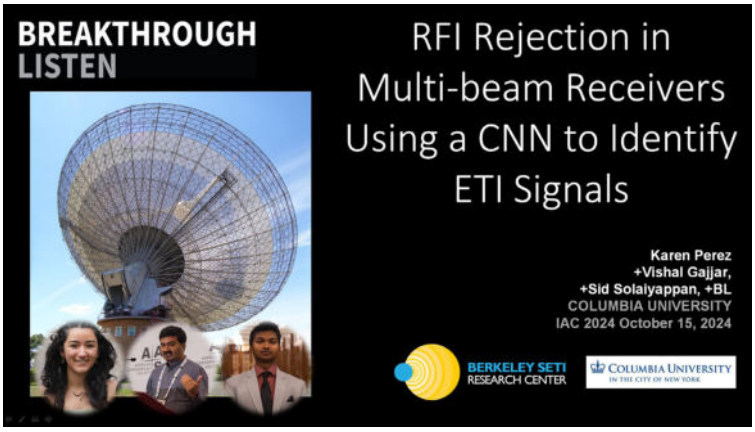
The Interstellar Programme reports

A4,1,12,x91290	RFI Rejection in Multi-Beam Receivers using a CNN	Ms Karen Perez	Columbia University	USA

IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,1,12,x91290.brief.pdf
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/1/manuscripts/IAC-24,A4,1,12,x91290.pdf
IAF Cited Presentation/Video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/1/presentations/IAC-24,A4,1,12,x91290.show.pptx
Open Paper: if available	None found
Reported By:	Peter Milne

Ms Karen Perez, of Columbia University, presented a student paper at IAC-24, detailing research into the rejection of terrestrial interference while scanning for extra-terrestrial signals. A machine learning [1] approach, using Convolutional Neural Networks (CNN) [2], was taken to analysing the received signals, to be able to identify and reject false positive identifications..

Over 1000 hours of data, received at the Parkes 21 cm Multibeam Receiver [3] were used to create a background, while the setigen tool [4] was used to generate simulated extra-terrestrial signals. The ResNet50 [5]) CNN tool was then trained to identify candidate extra-terrestrial signals. This approach analyses each spectrogram independently, assigning a predicted signal probability, which can then be verified by comparing the received signals in each beam of the multibeam array to reject those observed in multiple beams.



Traditional filtering of the received signals was applied, followed by the CNN tool. This reduces the number of candidate signals requiring visual inspection to 0.2%! (The training of ResNet 50 achieved a model validation accuracy of 98.46%, itself.)

The conclusions of the study are;

- Combine traditional filtering criteria with Machine Learning to decrease candidates
- Apply multi-beam rejection techniques to future interferometric arrays
- Apply different Machine Learning techniques to improve search algorithms
- Continue pushing sensitivity curve bounds with large surveys

Co-authors	Dr Vishal Gajjar (SETI Institute), Mr Sid Solaiyappan (University of Michigan)

[1] www.ibm.com/think/topics/machine-learning
[2] www.ibm.com/think/topics/convolutional-neural-networks
[3] www.parkes.atnf.csiro.au/research/multibeam/.overview.htm
[4] iopscience.iop.org/article/10.3847/1538-3881/ac5e3d
[5] blog.roboflow.com/what-is-resnet-50

A4,1,13, x82932	Fine-tuning the Narrowband SETI Signal Processing Pipeline	Mr Kenneth M Houston	University of California, Berkeley	USA
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,1,13,x82932.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/1/manuscripts/IAC-24,A4,1,13,x82932.pdf			
IAF Cited Presentation/ Video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/1/presentations/IAC-24,A4,1,13,x82932.show.pptx			
Open Paper: if available	None found			
Reported By:	Peter Milne			

Mr Kenneth M Houston, a corresponding author at Breakthrough Listen, University of Berkeley, presented a paper on potential improvements to the signal processing employed in the search for extra-terrestrial signals. The first of these concerns the averaging of multiple receptions in order to improve the signal to noise ratio. When wide bandwidths are averaged, the frequency response of the channel causes the extremities to have lower signal levels, potentially bringing any signal below the detection threshold, as illustrated in Figure 1.

A transmitted constant frequency signal will exhibit frequency drift at Earth, due to the relative movement of the source and Earth, and often referred to as the Doppler effect [1]. De-Doppler integration must, therefore, follow the initial averaging of the received bandwidth. In the paper, the algorithms used by three SETI receiving arrays (MeerKAT [2], Greenbank Telescope [3], and COSMIC [4]) are discussed, and their parameters traded-off in order to optimise search time and signal to noise ratio.

Data storage requirements can be reduced if the received spectrum is stored only when a potential signal is detected. A further improvement is possible when only the output of the Fast Fourier Transform [5] of the limited bandwidth around that potential signal is stored. Note, however, that for interferometric arrays, this requires the storage of the FFT transform of the output from each array element. These stored data samples are referred to as "stamps".

Potential future enhancements are also considered in the paper.

- Characterising RFI (Radio Frequency Interference) in different bands from existing data so that bands with high RFI levels can be ignored, or signals conforming to those characteristics can be ignored,
- Adaptive beamforming methods can achieve narrower beams and enhance the signal to noise ratio.
- In beamforming arrays, the relative phases of the received signals can be used to estimate the direction of arrival.
- Modulation might be detected using cyclostationarity [6] or excess kurtosis [7]. The former is a method of classifying modulations and the latter is a statistical measure used to distinguish modulation from white noise.

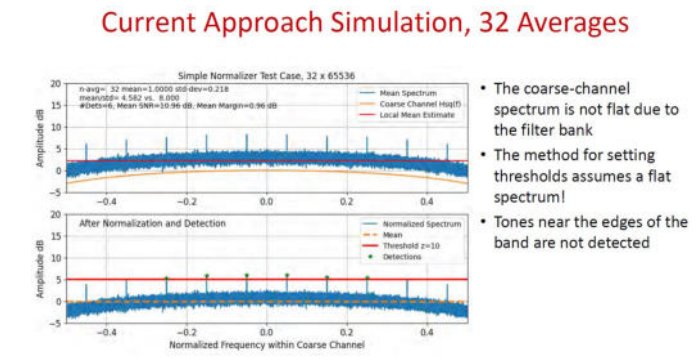


Figure 1 Effect of Channel filtering on Wide Bandwidths, However, by splitting the bandwidth of interest into smaller bands, that filter response is flattened in each of those narrow bandwidths, and the impact of the wide channel filter is is nullified, as illustrated in Figure 2.

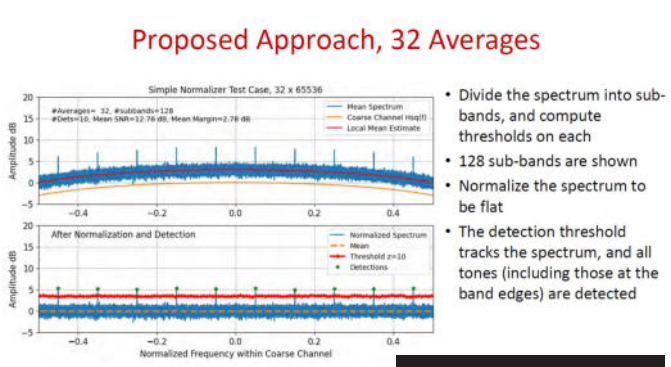


Figure 2 Effect of averaging Narrow Sub-Band

[1] en.wikipedia.org/wiki/Doppler_effect
[2] www.sarao.ac.za/gallery/meerkat/
[3] public.nrao.edu/telescopes/gbt/
[4] science.nrao.edu/facilities/vla/observing/cosmic-seti
[5] en.wikipedia.org/wiki/Fast_Fourier_transform
[6] en.wikipedia.org/wiki/Cyclostationary_process
[7] en.wikipedia.org/wiki/Kurtosis

IAC-24-A4,2,6 x84417	The Future of the SETI Post-Detection Protocols: Progress Towards Revisions	Leslie I Tennen	Law Offices of Sterns and Tennen	USA

IAF cited paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,6,x84417.pdf
IAF cited presentation video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/presentations/IAC-24,A4,2,6,x84417.show.ppt
Open paper:	None found
Reported by:	Max Daniels

This article presents a revised draft of the principles that the international community should follow, if the search for extraterrestrial intelligence (SETI) led to potential contact. It does not consider whether (or how) we should respond.

In 1989, the IAA SETI Committee developed the 'Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence', known as the Post-Detection Protocols. In 1995, the SETI Committee added the 'Draft Declaration of Principles Concerning Sending Communications with Extraterrestrial Intelligence', known as the Draft Reply Protocols, to the Post-Detection Protocols. Both were presented to and accepted by the UN, although the Reply Protocols only ever remained in draft form. The IAA SETI Committee therefore tried to address this by creating the 'Declaration of Principles Concerning the Conduct of the Search for Extraterrestrial Intelligence', known as the Declaration of Principles. An updated document was needed anyway to reflect advances in both SETI technology but also the significant global changes in communications, such as the widespread use of the internet and social media.

SETI has been an active field for more than half a century. A concise but comprehensive history is provided by The Planetary Society [1]. After some initial efforts from 1959 [2], SETI was picked up further in the 1970s, going on to receive NASA backing, before that was withdrawn in the face of political opposition. It then relied on social society and private funding, before more consistent and extensive funding was received in recent years such that there are more resources for SETI now than ever before.

So why have Tennen and colleagues revised these principles? They wanted to provide clarity in who exactly the document refers to; reference to how to engage with social media platforms; and an express reference to technosignatures. It also would add best practice guidelines and a code of conduct, both of which can be continually updated.

It avoids reference to what, if any, response should be given to contact, as this is not an issue with widespread agreement, and specific details should be decided later. This is a realistic position that reflects the international agreement-making process.

The principles it adopts cover handling candidate evidence; searching; confirmed detections; data accessibility; monitoring and archiving; data and frequency protection; post-detection protocol; communications with ETI following a confirmed detection; and ethical and legal considerations.

Are these revisions worthwhile? It is sensible to update the proposals to reflect changes in communications and media, not least social media. The details of how scientists or researchers should handle the sharing of news are important, and it would be wise to be cautious while having clear communications with the public. The points about misinformation could be expanded, given today's climate where facts are not sacred [3].

How should SETI be governed? Some have argued that we should put in place, or at least think about, a treaty or other legally binding mechanism [4]. It would bring in more researchers globally into the SETI field, spurring a comprehensive approach to SETI, including about responses to contact. Others have sought to be more specific, with detection meriting a treaty but not the process for responding [5]. Building on this, the problem with conferring international legal status on SETI is that its principles have already been given thought by the practitioners likely to have that first contact; and many UN members may feel this issue is of little immediate concern [6]. Another criticism of trying to establish a legally defined process, or any process at all, are explained with the Fermi Paradox [7]. The principles offered here are sensible, non-binding ways to govern part of the post-detection SETI process, despite these concerns.

[1] www.planetary.org/articles/20171025-seti-anybody-out-there
[2] www.bigear.org/vol1no1/interste.htm
[3] about.fb.com/news/2025/01/meta-more-speech-fewer-mistakes/
[4] www.sciencedirect.com/science/article/abs/pii/S026596469800006X
[5] www.elevenjournals.com/tijdschrift/iisl/1998/5%20Addenda/IISL_1998_041_005_009
[6] www.cambridge.org/core/journals/american-journal-of-international-law/article/on-the-search-for-extraterrestrial-intelligence-seti/F6EB673C1E3F670D1DE68588824636B1#fn21
[7] www.seti.org/fermi-paradox-0; see also en.wikipedia.org/wiki/Fermi_paradox for a succinct overview.

IAC-24 A4,2,9, x81864	Moon Farside Regulated by a United Nations Treaty	Claudio Maccone	International Academy of Astronautics; Istituto Nazionale di Astrofisica	Italy

IAF cited paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,9,x81864.pdf
IAF cited presentation / video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/presentations/IAC-24,A4,2,9,x81864.show.pdf iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/talk/IAC-24,A4,2,9,x81864.talk.mp4
Open paper:	None found
Reported by:	Max Daniels

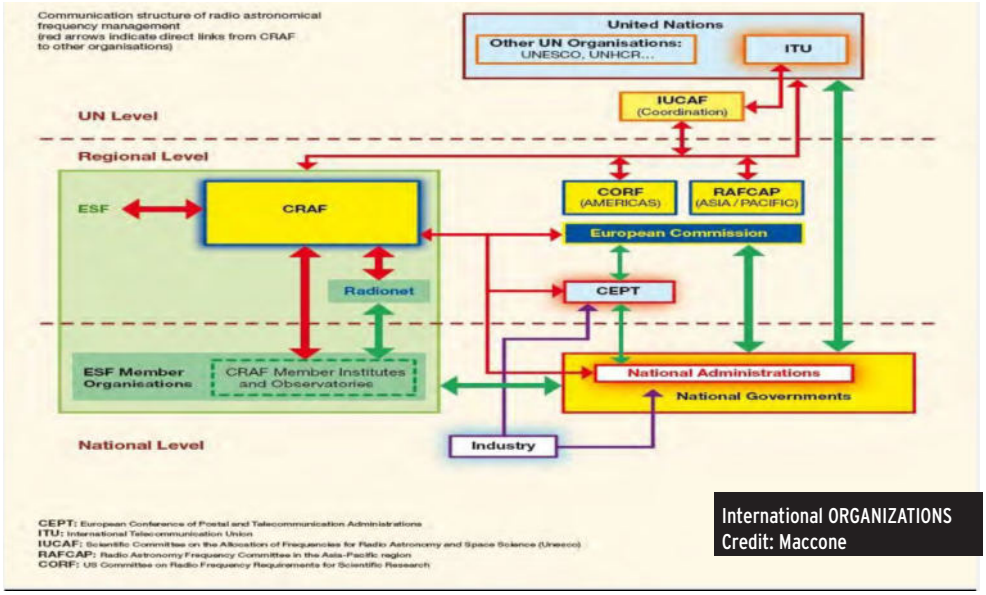
Maccone and colleagues outline their call for an international treaty to govern activities on the far side of the Moon. They argue that it is an important place for scientific study, and its unique properties should be protected before one group dominates or excludes others from making use of the area.

The far side of the Moon is important as it is always facing away from the Earth. This means that it is protected from radio or other electromagnetic waves, creating an area known as the 'shielded zone'. There are four studies that can be pursued in this zone, Maccone outlines: cosmology, including certain lower frequencies; astrobiology, involving looking for pre-biological molecules using weak lines that are best observed without interference; planetary defence, as a lack of interference gives more time to prepare for potential threats to Earth; and SETI and technosignatures, again because isolating their signals is easier without Earth-bound electromagnetic interference.

Will there be a Moon far-side treaty? In all likelihood, no. There is already a suite of existing treaties that govern states' activities in outer space. These include the Outer Space Treaty [1], which says that activities – for example, sending a rover to the Moon – are carried out with due regard for others who may also want to carry out similar activities. It has been difficult to find wide agreement for other instruments, such as the Moon Agreement [2].

Instead, there have been attempts to define best practices in space. Recent principles include the US-led Artemis Accords [3], which has broad (though certainly not universal) support. Others have looked at the concept of safety zones [4], where activities are carried out at suitable distance from each other such that they do not interfere, such as through their electromagnetic activities or even dust.

These are still being developed. It will be curious to see how states with less experience in outer space but who clearly have set their targets on lunar activities, including India with Chandrayaan-3 [5], interact with others. This is especially true as the China National Space Agency has successfully returned samples from the far side of the Moon [6], while the US continues to push both public and private missions to the Moon [7] .



International ORGANIZATIONS
Credit: Maccone

[1] www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html
[2] www.unoosa.org/oosa/en/ourwork/spacelaw/treaties/outerspacetreaty.html
[3] www.nasa.gov/specials/artemis-accords/index.html see also Principium 32, February 2021, *The Artemis Accords: what comes after the Moon?*
[4] www.thespacereview.com/article/3962/1
[5] www.isro.gov.in/Chandrayaan3_Details.html
[6] www.theguardian.com/world/article/2024/jun/25/chinas-change-6-lunar-probe-returns-world-first-samples-from-far-side-of-the-moon
[7] www.bbc.co.uk/news/articles/cn8x5gm4k1xo#:~:text=Two%20lunar%20landers%20built%20by,a%20rideshare%20to%20the%20Moon

A4,2,12,x85455	Possible extraterrestrial Focal SETI and its implications for terrestrial SETI	Dr Nicolò Antonietti	INAF	Italy
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,2,12,x85455.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,12,x85455.pdf			
IAF Cited Presentation/ Video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/presentations/IAC-24,A4,2,12,x85455.show.pptx			
Open Paper: if available	None found			
Reported By:	Simone Caroti			

This paper presents us with a thought experiment in three parts:
1. What is the likelihood that an extraterrestrial civilization may have discovered the presence of humanity on Earth by means of gravitational lensing?
2. If such a scenario were possible or even probable, where and at what distance from us could this civilization reside, given the potentially useful range(s) of detection by gravitational lensing?
3. If this scenario were to become a reality, what would the impact on our own civilization be?

The current status of SETI's work, the authors argue, seems hampered by the low probability of receiving an explicit message from an extraterrestrial civilization. The probability appears low because the only way for ETs to know that they should or could send a message to us would be to know there is someone on Earth in the first place, and that could only happen if they had already received a signal from us. However, our signals so far have only reached into our own solar system, so that barring the unexpected discovery of another advanced civilization within this system, nobody knows we're here.
But the above calculation may not be very accurate. What if, the authors point out, there were a way for technologically advanced civilizations to peer far into space without travelling away from their home system? What if one could develop the astral equivalent of a pair of binoculars and just... look?
It turns out that both the technique and its attending technology already exist, and we ourselves have them. In fact, the authors tell us, NASA is planning to use them to look deep into space by the year 2030, when "the first optical terrestrial mission to the focus of the gravitational lens of the Sun" – the gravitational field of a star has much greater lensing power than that of a planet – will launch.
But if we have this capability, or will have it soon, then it follows that it is at least possible for a similarly advanced extraterrestrial civilization to have that capability as well. It therefore stands to reason that we might soon receive an explicit message from outside, with or without broadcasting signals of our own. Using gravitational lensing, these hypothetical civilizations could well have been aware of us for a long while.
The paper is devoted to the theoretical working out of two crucial elements in this scenario: the distance at which it would be possible to detect the presence of a civilization on a distant planet, depending on the diameters of the telescopes used and the masses of the stars targeted for the endeavour, and the impact on our planetary culture of discovering we were indeed the target of one or more such efforts at detection.
Although the specific calculations of masses, distances, and diameters are intelligible only to those conversant with the discipline, the paper remains accessible to all because the authors have 1) made sure to explain what gravitational lensing is, and 2) taken the trouble to translate the general meanings of the formulas into discursive terms, thereby allowing the layperson (I myself belong to this category) to grasp the import of this theoretical study. And the import is startling: I will not do the authors a disservice by revealing it here, but the outcomes of this thought experiment are well worth the audience's time. There's hope – and more than hope – at the end of this readerly journey.

A4,2,14,x88183	Plurality in Post Detection Scenarios	Ms Kate Genevieve	University of Sussex	UK
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,2,14,x88183.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,14,x88183.pdf			
IAF Cited Presentation/ Video:	none			
Open Paper: if available	None found			
Reported By:	Simone Caroti			

This document constitutes a progress report on the work conducted by the SETI Post-Detection Hub that opened in 2022 at the University of St Andrews, UK. The Hub, which "combines emerging scientific research and varied disciplines to explore issues around the detection of extraterrestrial life," and specifically the consequences of the aftermath of positive contact, has now been in operation for two years, while the specific project this report addresses – the George Profitiliotis-led Scenario Working Group – began work in June 2023. Its task consists in "initiat[ing] a collaborative process for exploring alternative future contexts," and this report presents the preliminary results of a specific part of the Group's work.

These preliminary results are, as the authors themselves point out, a work in progress: the Group has thus far developed four separate scenarios for what they call the "2050 'post-detection ecosystem,'" and it is specifically on the scenario developed by George Profitiliotis that the report focuses.

Profitiliotis's scenario, the authors tell us, results from a process that "followed a participatory strategic foresight approach aligned with the 'Intuitive Logics' school of thought in scenario development," and the report concludes by listing the basic structure of the larger document that will follow once the content is ready to be shared.

Co-authors	Dr George Profitiliotis (Blue Marble Space Institute), Dr Emily Finer (University of St Andrews), Dr William Lempert, Dr Chelsea Haramia (University of Bonn), Dr John Elliott (University of St Andrews)

C4,9,6,x85994	Feasibility study of a mission to Sedna - Nuclear propulsion and advanced solar sailing concepts	Elena Ancona	Politecnico di Bari	Italy
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,C4,9,6,x85994.brief.pdf			
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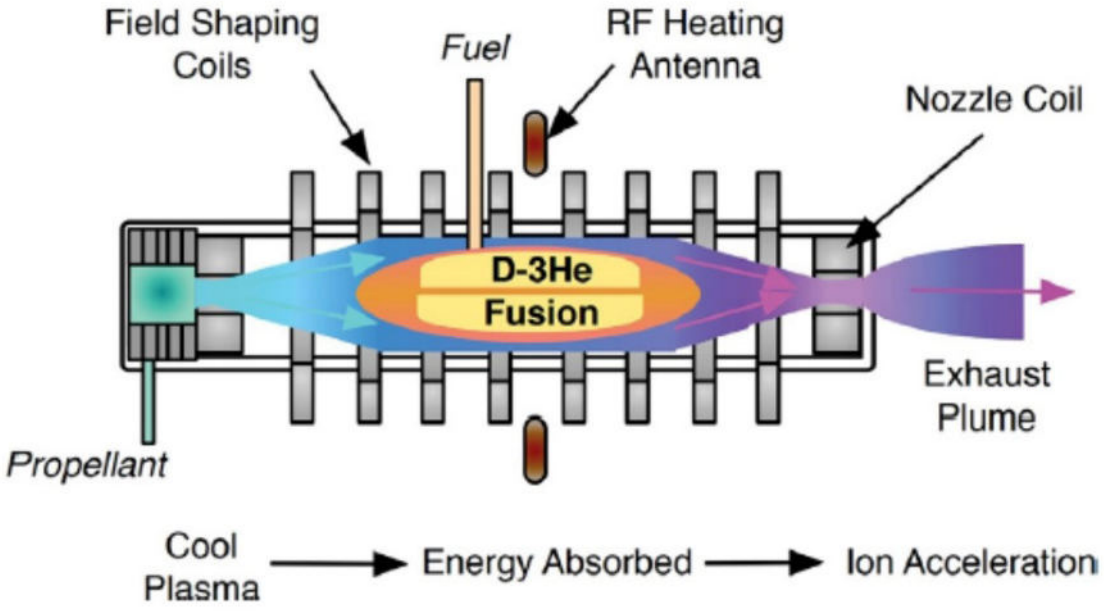
IAF Cited Presentation/ Video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/9/presentations/IAC-24,C4,9,6,x85994.show.pptx			
Open Paper: if available	None found			
Reported By:	Michel Lamontagne			

This paper presents two different propulsion systems and mission plans for the exploration of Sedna: A Direct Fusion Drive (DFD) with a rendezvous mission and a sundiver Solar Sail with thrust augmentation by thermal desorption for a fly-by mission. The two missions might be complementary, with the fly-by mission going first for preliminary exploration, carrying a light 1.5 kg scientific payload. The DFD would follow later, with a more substantial 1,500 kg robotic payload.
The DFD mission plan requires 0.3 kg of He^3 fuel. About 30 kg are presently available on Earth, it seems possible that the fuel can be obtained if the mission is prioritized. An additional 4,000 kg of propellant, to be heated by the fusion fuel reaction, is required.
The following parameters are assumed for the sail: lightness number $\beta = 0.75$, areal mass $\sigma = 5$ g/m^2 , coating mass M_0 =1 kg, mass of payload M_P = 1.5 kg, desorption rate m_0= 1 g/s. For a perihelion of 0.3 AU, the resulting cruise speed would reach about 100 km/s.
The Solar sail mission is faster, with a 7 year transit time, while the DFD mission would take 10 years to reach Sedna.
More information about the fusion drive is available here: psatellite.com/technology/fusion/

Co-authors: Roman Ya Kezerashvili, Savino Longo



Schematic diagram of the Direct Fusion Drive (DFD) engine subsystems.
Credit: Ancona et al, Fig 1 and S A Cohen et al, *Direct fusion drive for interstellar exploration*, Journal of the British Interplanetary Society, vol. 72, pp. 37–50, 2019.

C4,10-C3.5,2,x90149	United Kingdom's Contributions to Enhancing Nuclear Power Systems for Space Exploration	Dr Mauro Augellia	UK Space Agency	UK

IAF Abstract: iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,C4,10-C3.5,2,x90149.brief.pdf
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IAF Cited Presentation/Video: iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/10-C3.5/presentations/IAC-24,C4,10-C3.5,2,x90149.show.pptx
Open Paper: None Found
Reported By: Parnika Singh

The paper highlights the United Kingdom's significant contributions to advancing nuclear power systems for space exploration, focusing on their critical role in missions to the Moon, Mars, and beyond. These efforts center on two key areas: providing sustainable power for robotic and human missions, and developing advanced propulsion technologies. For robotic spacecraft, the UK leverages Radioisotope Power Systems (RPS), which convert heat from radioactive decay into electricity. These systems are vital for missions where solar power is insufficient, such as in deep space or on planets with long nights. The UK has pioneered the use of Americium-241 (241Am), a byproduct of nuclear waste, as a scalable and cost-effective alternative to Plutonium-238 (238Pu). Through facilities like PuMA-2, 241Am is refined efficiently, offering a sustainable and abundant power source for long-duration missions.

For human exploration, particularly on the Moon and Mars, fission-based microreactors are highlighted as a reliable and continuous energy solution. These modular reactors are designed to power habitats, rovers, and operations under extreme conditions, such as extended lunar nights or Martian dust storms. UK-based companies, including Rolls-Royce, are advancing these technologies, with operational prototypes expected by 2025. In addition to power systems, the UK is driving innovation in nuclear propulsion technologies. Nuclear Thermal Propulsion (NTP) offers high thrust for rapid transit, while Nuclear Electric Propulsion (NEP) provides fuel efficiency for long-duration missions, enabling deeper exploration of the outer Solar System.

The UK also plays a pivotal role in shaping international regulatory frameworks to ensure the safe, sustainable, and peaceful use of nuclear technologies in space. These regulations, developed under the UN's Committee on the Peaceful Uses of Outer Space (COPUOS), address safety concerns, including radiation shielding, containment, and planetary protection. While nuclear power presents promising solutions, challenges remain, such as refining reactor materials, ensuring safety during launch and operation, and addressing environmental concerns.

Co-authors: Mr Andrew Kuh, Mr Tony Forsythe, Mr Joshua Brayford, Dr Sarah-Jane Gill, Mr Karl Kane-Collery (all UK Space Agency)

C4,10-C3.5,8,x86317	Addressing Challenges to Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	Dr Dale Thomas	University of Alabama in Huntsville	USA
IAF Abstract:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,C4,10-C3.5,8,x86317.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/10-C3.5/manuscripts/IAC-24,C4,10-C3.5,8,x86317.pdf			
IAF Cited Presentation:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/C4/10-C3.5/presentations/IAC-24,C4,10-C3.5,8,x86317.show.pptx			
Open Paper:	None Found			
Reported By:	Parnika Singh			

In this paper, Dr Dale Thomas of the University of Alabama in Huntsville explores the Centrifugal Nuclear Thermal Rocket (CNTR), an innovative propulsion system designed to surpass the limitations of traditional Nuclear Thermal Propulsion (NTP). Unlike solid-core reactors, the CNTR uses liquid uranium fuel confined within rotating cylinders, enabling operations at temperatures above uranium's melting point and achieving a high specific impulse of 1,800 seconds. This advanced design promises faster and more efficient space missions, such as a 420-day round trip to Mars and direct journeys to distant solar system destinations like Europa or Titan.

The CNTR's key advantage lies in its ability to transfer heat more effectively to hydrogen propellant, resulting in higher thrust. Rotating cylinders use centrifugal force to contain the liquid uranium, preventing contact with the walls and improving durability. Advanced simulations, including Smooth Particle Hydrodynamics (SPH), analyze bubble dynamics and optimize heat transfer while addressing challenges like uranium vaporization and structural stresses. Electrodynamic techniques, such as dielectrophoresis, are proposed to capture and recycle vaporized uranium, enhancing efficiency and sustainability.

The UAH-CNTR-A reference configuration serves as a baseline for refining the design and addressing technical challenges. The study explores suitable materials for constructing the reactor to withstand extreme temperatures and stresses. By doubling the performance of traditional NTP systems, the CNTR could enable transformative capabilities, reducing mission durations, minimizing astronaut radiation exposure, and reaching previously inaccessible targets.

While still in development, the CNTR represents a groundbreaking advancement in propulsion technology. Dr Dale Thomas's research team aims to refine the concept and develop a prototype, potentially unlocking a new era of human and robotic exploration across the solar system.

Co-authors:	Michael Houts (NASA Marshall Space Flight Center, Huntsville), Dean Wang (Ohio State University), Keith Hollingsworth, Robert Frederick, and Jason Cassibry. All University of Alabama in Huntsville except as noted.

D4,1,9,x80842	Self-Replication Technology for Ubiquitous Space Exploration	Alex Ellery	Carleton University	Canada
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,1,9,x80842.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/1/manuscripts/IAC-24,D4,1,9,x80842.pdf			
IAF Cited Presentation/ Video:	none			
Open Paper: if available	None found			
Reported By:	Michel Lamontagne			

In this paper Ellery presents the state of the art in the field of self replicating machines to be built on the Moon. In an extremely condensed form, he covers all the elements required to create a self replicating system on the the Moon, and grow it into a large system capable of being reprogrammed to manufacture practically any industrial product.

Ellery identifies the required resources, materials and systems and qualifies the demands of the self replicating system. He updates the Freitas studies done for NASA in the eighties and proposes that a single seed factory massing about 10 tonnes would be sufficient to start the self replication process. This process could progress exponentially at a growth rate of one copy every six months, with three offsprings per generation (1-½ years) and could reach a number of about 1.6 million machines in thirteen generations, or about 20 years.

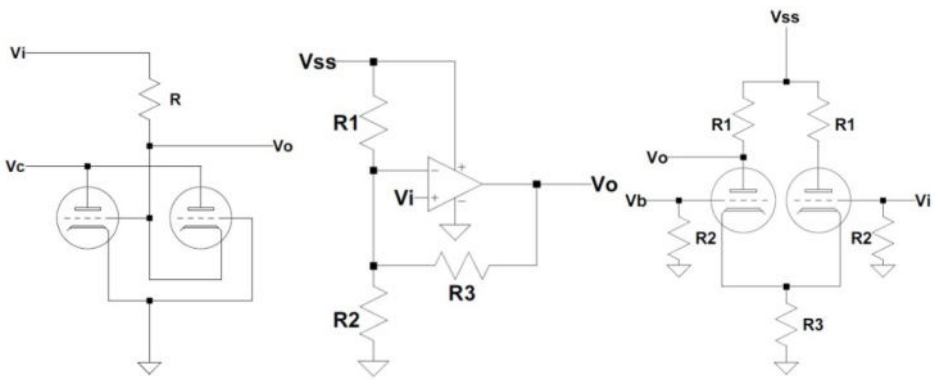
Self replication implies a complete knowledge of the equipment and of the processes used, as well as complete replicability, and therefore recyclability, of all the system's elements. In this sense, it is in opposition to the current fragmented technological system on Earth where maintenance is often actively discouraged.

Some bottlenecks are identified, and some minerals, particularly chemical reagents, that are scarce on the Moon might have to come from Earth. Prototypes of self replication system elements are demonstrated, such as 3D printed electric motors. An extensive chart of the chemical refining processes required to extract elements from the regolith and lunar minerals is presented in the paper and the required energy is given as well.

In this proposal, vacuum tubes replace silicon microprocessors in neural networks.

The author concludes: "Self-replication technology would revolutionise space exploration by amortising the capital cost of launch of a single factory unit to the Moon through its subsequent exponential production of further units across the Moon, to Mars, etc. Self-replication technology represents a revolutionary approach to space exploration whose time has come."

Co-authors: none



(a) Voltage-controlled resistor; (b) linear activation function; (c) vacuum tube-based differential amplifier from *Bootstrapping Neural Electronics from Lunar Resources for In-Situ Artificial Intelligence Applications* (www.carleton.ca/ceser/wp-content/uploads/Bootstrapping-neural-electronics-from-lunar-resources.pdf)
Credit: Alex Ellery Fig 1.

D4,4,1 x89587	Advanced Electric Propulsion Systems with Optimal Specific Impulses for Fast Interstellar Precursor Missions.	Nadim Maraqten	Initiative for Interstellar Studies	UK
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,4,1,x89587.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/manuscripts/IAC-24,D4,4,1,x89587.pdf			
IAF Cited Presentation/ Video:	None			
Open Paper: if available	None found			
Reported By:	Adam Hibberd			

This insightful paper will no doubt be influential to those in this field who know, since it stands back and takes a long-term look on the matter of electric propulsion for enabling high ΔV missions.
Most readers will be aware that electric propulsion is a low thrust yet very high specific impulse option which means given enough thrust time and electrical power, high ΔVs can be generated.
The variables input to this investigation are design parameters of the electric-propelled spacecraft, though there are also certain design parameters set in stone for this paper which are rather futuristic in their prediction.
The parameters assumed constant are the power to mass ratio (proposed to be 1,000 Wkg^{-1}), the fraction of potential thrust from the power source converted into real thrust (97%) and other fiducial figures. The paper further proposes that these assumptions are valid, given the developments will eventually happen, or at least the results are interesting nonetheless.
Certain design parameters are varied, such as specific impulse and overall thrust time, the former increases with more sophisticated propulsion system (and therefore mass) and a relationship between the level of specific impulse and propulsion mass is adopted. There is therefore a trade-off between the mass of the propulsion system and the specific impulse. I noticed this trade-off is on a continuum and therefore ignores the possibility of 'paradigm shifts' in development which would entail discontinuous advances in performance.
However there is a happy house – or optimal combination of these two quantities in terms of maximising payload fraction which the authors look into and play around with by applying the so-called 'non-dimensional Tsiolkovsky equation' to three different mission objectives. These are summarised in the table below.

Mission	ΔT (years)	τ (years)	Δv (km/s)
Pluto Rendezvous	4.10	3.69	185
Solar Gravity Lens Focus at 550 AU	13.00	11.70	191
Round Trip to Jupiter (with 180-day stay at Jupiter)	2.80	2.52	122

Results? The optimal payload mass fractions occur at high specific impulses which are unattainable by current electric propulsion systems and the paper is an impetus for development of such systems so that these electric propulsion missions can be realised.

Co-authors: Dan Fries, Angelo Genovese

D4,4,3,x84524	Nuclear Electric Propulsion for Fast Interstellar Precursor Missions: Problems and Promises	Dr Ralph L McNutt Jr	The Johns Hopkins University	United States

IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,4,3,x84524.brief.pdf
IAF cited paper:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,4,3,x84524.brief.pdf
IAF cited presentation video:	None
Open paper:	None found
Reported by:	Angelo Genovese

This technical paper examines the potential and challenges of using Nuclear Electric Propulsion (NEP) for fast interstellar precursor missions. The authors analyze both historical developments and current technological limitations in achieving high-speed space travel beyond our solar system.

The paper begins by establishing that while current chemical rockets with planetary gravity assists can potentially double Voyager 1's escape speed of 3.6 AU/year, even advanced concepts using orbital propellant depots and super heavy-lift launch vehicles would only achieve about 10 AU/year. This falls short of earlier mission goals like the Thousand AU (TAU) mission, which aimed for 20 AU/year to reach 1,000 AU in 50 years.

The paper revisits prior NEP studies and assesses whether nuclear-powered propulsion could achieve higher escape speeds, potentially exceeding 20 AU per year. While advances in ion thrusters and Hall thrusters have been significant, the development of space nuclear reactors remains a critical bottleneck. NEP functions by using a nuclear reactor to generate electricity, which then powers ion thrusters to provide low but continuous thrust. Ernst Stuhlinger showed that in gravity-free space, there are two figures of merit for NEP systems.

1. Specific Impulse (Isp): Determines how efficiently fuel is used. Higher values enable longer thrusting periods and higher total velocity changes (ΔV).
2. Specific Power (α): Represents power-to-mass ratio (kW/kg), affecting the overall efficiency and feasibility of the propulsion system.

The authors provide a detailed mathematical analysis of NEP systems' performance metrics, focusing on these two key parameters. The relationship between payload mass, propellant mass, and power plant mass is explored through complex optimization equations that demonstrate the inherent trade-offs in NEP system design.

Several major NEP mission studies are analyzed, including JPL's 1977 Interstellar Precursor concept (500 kWe system), the SP-100 project (100 kWe system), the TAU mission (1 MWe system), and Project Prometheus's Jupiter Icy Moons Orbiter (JIMO). These studies consistently revealed that the main challenges lie in:

- Reactor Development: Past NEP concepts, such as NASA's Project Prometheus and the SP-100 reactor program, faced substantial technical and budgetary challenges, leading to their cancellation.
- Heat Rejection Systems: Managing waste heat from a nuclear reactor in space is difficult, requiring large radiator systems that add significant mass.
- Autonomous Operation: Unlike terrestrial reactors, space reactors must function autonomously for years or decades without maintenance.
- Thruster Lifespan: Existing electric propulsion systems (eg gridded ion thrusters, Hall-effect thrusters) must demonstrate the ability to operate reliably for mission durations exceeding a decade.

The paper emphasizes that specific power α of NEP systems remains problematically low due to thermal-to-electrical conversion inefficiencies and the substantial mass of required heat radiators. While higher radiator temperatures could reduce mass, material limitations prevent this solution. The authors note that power plant mass fundamentally limits overall system performance, with NEP's specific power playing a role analogous to specific impulse in chemical propulsion or mass per unit area in solar sail designs.

The paper concludes that while NEP remains a promising avenue for fast interstellar precursor missions, significant engineering challenges remain. Addressing these issues requires further research in reactor efficiency, materials science, and system integration. In the near term, chemical propulsion combined with gravity assists remains the most viable method for deep-space exploration. However, future advances in NEP, particularly in lightweight reactor designs and long-duration autonomous operation, could eventually enable missions to interstellar space at unprecedented speeds.

D4,4,7,x91195	Interstellar Systems at the Edge of Chaos	Dr Angelo Vermeulen	TU Delft	Netherlands
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,4,7,x91195.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/manuscripts/IAC-24,D4,4,7,x91195.pdf			
IAF Cited Presentation/ Video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/presentations/IAC-24,D4,4,7,x91195.show.pptx			
Open Paper: if available	None found			
Reported By:	Patrick Mahon			

The aim of this paper is to propose a new approach to the design of interstellar spacecraft, which focuses on ways to deal with the inherent uncertainties of an interstellar voyage. Vermeulen et al. reject the standard approach of a spacecraft whose design is fixed prior to launch, and instead investigate concepts for a spacecraft which can evolve dynamically over time in response to whatever happens to it on the journey.

The authors start by reviewing key interstellar spacecraft designs in the literature, including Project Orion, Project Daedalus, Breakthrough Starshot and the various Worldship concepts discussed in Andreas Hein's 2020 review paper. They note that all of these designs are static – the spacecraft's shape, systems and resources are fixed at launch, and if anything unexpected happens during the journey, it will have to be dealt with as well as possible using preset contingency plans. They then summarise the many ways in which interstellar space is unpredictably hostile, including high-energy cosmic rays, and interstellar dust encountered at high velocities.

Taking inspiration from natural ecosystems, a 1982 NASA study into a self-replicating lunar factory, and ESA's MELiSSA research programme into a closed-loop life support system, the authors propose a new class of crewed interstellar spacecraft design, 'Evolving Asteroid Starships', which combines these innovations into a spacecraft which can dynamically evolve over time in response to the environmental pressures it faces.

To do this, the spacecraft carries a C-type asteroid on the journey with it. The asteroid provides structural shielding and radiation protection, but in addition, during the voyage, robots mine the asteroid for critical materials. These are fed to 3D printers, enabling the production of spares to repair damaged components, but also allowing the creation of new structures, so that the starship can evolve over time in response to environmental conditions. Crucially, this evolution applies not just to the physical structures of the vessel, but also to its life-support systems.

The authors have developed computer models of the structural and life-support systems, which they couple together and run in parallel. The results from the modelling demonstrate that these systems display complex behaviour, reflecting the fact that the starship they model is a chaotic system, where small changes in the inputs can lead to large variances in outputs.

While this chaotic behaviour could lead to system failure, it is also possible to harness it through the use of decentralised autonomous systems which recognise when chaos is near and take pre-emptive action to prevent it. Operating at 'the edge of chaos' like this, the system has the potential for emergent behaviour, generating novel outcomes that could not have been predicted, which improve efficiency, adaptability and resilience – all clearly highly beneficial qualities for a long duration interstellar mission.

Co-authors	Arpi Derm, Alvaro Papic, Farshad Goldoust, Igor Nikolic, Frances Brazier

D4,4,8,x90437	Technology Development Pace Coefficient for Reliable Interstellar Travel Timeline	Antoine G Faddoul	Tony Shy Designs Group	USA

IAF Abstract:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,4,8,x90437.brief.pdf
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/manuscripts/IAC-24,D4,4,8,x90437.pdf
IAF Cited Presentation/Video:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/presentations/IAC-24,D4,4,8,x90437.show.pptx
Open Paper:	None Found
Reported By:	Parnika Singh

The paper introduces a novel framework for predicting the timeline for interstellar travel, focusing on the unique challenges of long-term space exploration projects. These projects, which require incremental missions from Low Earth Orbit (LEO) to interstellar space, face a wide range of uncertainties, including technological breakthroughs, funding fluctuations, and global disruptions like pandemics or wars. To address this, the study develops a "Technology Development Pace (TDP) Coefficient" to create more realistic schedules for interstellar travel by quantifying the impact of various factors over time.
The TDP Coefficient incorporates key parameters such as the frequency of scientific breakthroughs, delays in technology adoption, funding stability, and the pace of private space exploration. It also accounts for rare but disruptive events, including natural disasters and geopolitical conflicts. By applying this coefficient to existing interstellar roadmaps, such as the "Roadmap to the Stars" (RMTS), the study identifies patterns of delay and acceleration, refining long-term projections for space exploration milestones.

Using Monte Carlo simulations, the study models the uncertainty of these factors over a 100-year period, demonstrating that delays tend to increase as projects approach later milestones. This highlights the need for dynamic, time-specific adjustments to planning rather than relying on linear projections. The results show that while technological progress remains steady, the cumulative impact of external disruptions can significantly shift timelines for interstellar travel.

The paper concludes by emphasizing the importance of continuously updating the TDP Coefficient as more data becomes available. This framework could also be applied to other large-scale, long-term projects beyond space exploration. By integrating dynamic adjustments, the study provides a robust tool for addressing the inherent uncertainties of planning humanity's journey to the stars.

D4,IPB,17,x86336	Beyond the Limits – Arbitrarily Large Rotating Space Habitats through Structural Decoupling	Elliott Orion Ruzicka	Orbital Design,	USA
IAF Abstract See also P46 report:	iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,IPB,17,x86336.brief.pdf			
IAF Cited Paper:	iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/IPB/manuscripts/IAC-24,D4,IPB,17,x86336.pdf			
IAF Cited Presentation/ Video:	none			
Open Paper: if available	none found			
Reported By:	Michel Lamontagne			

This interesting paper explores the possibility of creating arbitrarily large rotating space habitats by separating the structural envelope function from the pressure envelope function using magnetic decoupling. This should greatly reduce the structural strain on the habitat.

In conventional rotating structure design, the entire structure rotates to create artificial gravity while also resisting internal atmospheric pressure. Since it needs to support its own mass against centrifugal forces, the structural mass acts as an additional pressure element. This pressure grows higher with the habitat diameter until eventually the strain overcomes the resistance of the sectional area, and the structure breaks. The author includes a table giving the maximum dimensions for habitats using this conventional design, from about 16 km for steel to 9,000 km for carbon nanotubes.

In this proposal, only a relatively thin internal envelope, designed to hold in the required air pressure, rotates. This membrane is supported via magnetic fields that transmit strain to an external structure that is non rotating. As the structure is not rotating it creates no additional stress on itself, and there is always a possible structural section that can resist the stress coming from the inner membrane.

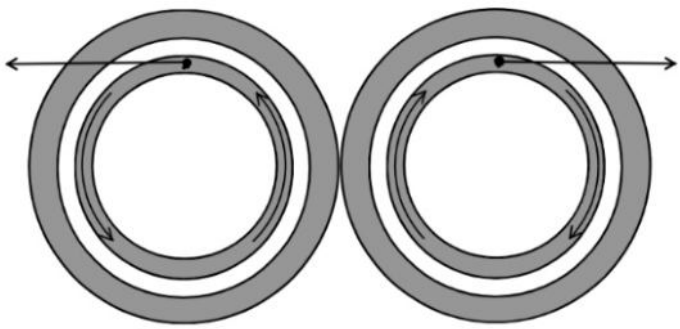
This essentially replaces a tensile strength limited design by an available mass limited design. A boundary is defined where the mass of the non rotating structure starts to create significant gravity from its own mass. However, this limit seems unlikely to be reached in a foreseeable future.

The author addressees stability issues and identifies null flux coil suspension as the best method of magnetic support.

Regarding the acceleration of the habitat to the speeds required for a centripetal gravity equal to Earth's gravity, the author explores both magnetic acceleration and reaction drives. The analysis favors reaction drives, as these can accelerate the interior structure while keeping the outer structure still.

Some arrangements of twinned contra rotating habitats might allow for similar results with magnetic acceleration, integrating linear motors into the magnetic suspension system, but the strain on the non rotating structure might be unacceptable. Furthermore, this would have the benefit of canceling angular momentum in the structure in a way similar to the contra rotating cylinders proposed by O'Neil, facilitating sun pointing habitat designs.

The author describes a demonstrator created to test the design hypothesis, and presents experimental results validating the idea.

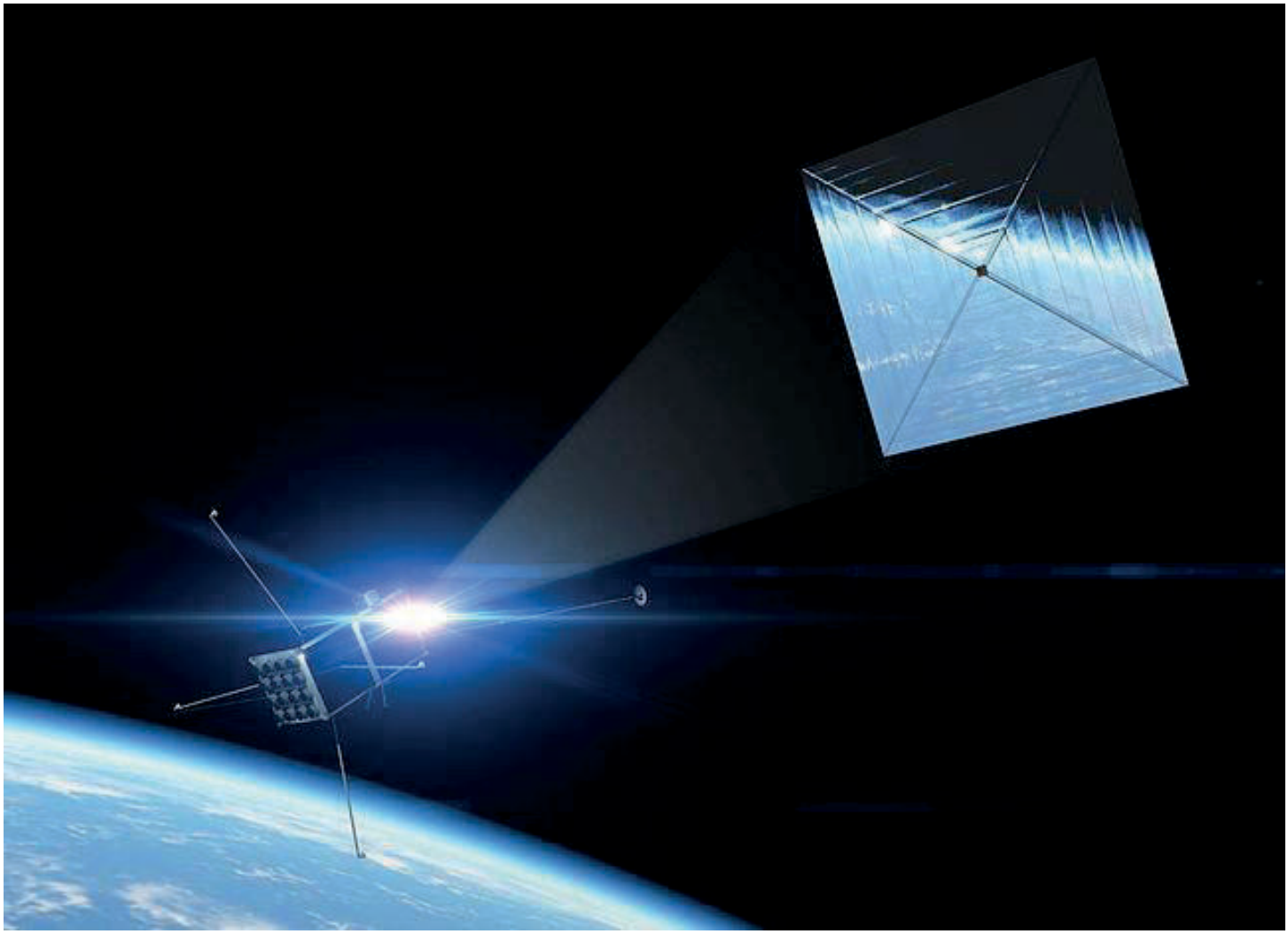


Twinned habitats to add counter-rotation.
Credit: Ruzicka Fig 7

JOIN I4IS ON A JOURNEY TO THE STARS!

Do you think humanity should aim for the stars?

Would you like to help drive the research needed for an interstellar future...
... and get the interstellar message to all humanity?



The Initiative for Interstellar Studies (i4is) has launched a membership scheme intended to build an active community of space enthusiasts whose sights are set firmly on the stars. We are an interstellar advocacy organisation which:

- conducts theoretical and experimental research and development projects; and
- supports interstellar education and research in schools and universities.

Join us and get:

- early access to select Principium articles before publicly released;
- member exclusive email newsletters featuring significant interstellar news;
- access to our growing catalogue of videos;
- participate in livestreams of i4is events and activities;
- download and read our annual report.

To find out more, see www.i4is.org/membership

90% discount for full time students!

The Journals

John I Davies

Here we list recent interstellar-related papers in the **Journal of the British Interplanetary Society (JBIS)**, which has been published since the 1930s and in **Acta Astronautica (ActaA)**, the commercial journal published by Elsevier, with the endorsement of the International Academy of Astronautics.

Acta Astronautica

Acta Astronautica papers are published online before print. No interstellar-related papers have been found since our last issue, Principium P47, in final Acta Astronautica volumes up to #227 February 2025 and "in progress" volumes up to #229 April 2025.

JBIS

Three issues of JBIS, May, June and July 2024, have appeared since the report in our last issue. P47. May and June had interstellar-related papers.

JBIS VOLUME 77 #5 MAY 2024 Interstellar Issue		
Aerographite: a Candidate Material for Interstellar Photon Sailing	**Gregory L Matloff & Joseph E Meany**	**USA**
Aerographite has been suggested in a recent paper as a possible candidate for interstellar photon sailing. This paper begins by presenting known properties of this extremely low density, light absorptive, material. After a review of analytical tools, a number of possible interstellar missions are then considered. The first confirms that a thin-film Sun-accelerated probe deployed at the 0.4-AU perihelion of an initially parabolic solar orbit could reach Proxima/Alpha Centauri after a voyage duration of about two centuries. The next case examined is a thin-film probe accelerated to about 0.033 c by an in-space laser array. Finally, it is shown that a combined aerographite-graphene hollow-body solar-photon sail may have significant advantages in accelerating a generation ship to an interstellar cruise velocity in excess of 900 km/s. Some of the unknowns regarding this substance that must be addressed before this material can be applied to interstellar sail application, including the closest feasible perihelion distance and aerographite performance in the space environment, are also discussed.		

JBIS VOLUME 77 #5 MAY 2024 Interstellar Issue		
In the Hypothetical Scenario of an Interception of the Voyagers by an ETI Probe	**Kelvin F Long**	**UK**
The Voyager 1 and 2 spacecraft were first launched in 1977 and have been travelling in deep space ever since. Currently they are outside of the solar heliosphere at a distance of approximately 163 and 136 AU respectively. The Voyager probes were also designed to carry a Golden Record in the case of contact with an extraterrestrial civilization or its representative robotic probe so that they may learn about humanity. In late 2023 the flight data subsystem on-board Voyager 1 began transmitting unusable data that differed from the usual data stream. An investigation by the engineers found that in fact the downlink transmission contained a readout of the entire system memory. In this paper we speculate on a hypothetical scenario where the data issue is indicative of an attempted forced downlink, to include command data, from a passing ETI probe that may have been curious about the Voyager 1 spacecraft origin, nature, function and purpose. This is not a claim that this was the cause, but more the construction of a scenario for the consideration of other probes that may be launched in the future.		

JBIS VOLUME 77 #5 MAY 2024 Interstellar Issue		
The Spider Stellar Engine: a Fully Steerable Extraterrestrial Design?	**Clément Vidal**	**Belgium**

A long-lived civilization will inevitably have to migrate towards a nearby star as its home star runs out of nuclear fuel. One way to achieve such a migration is by transforming its star into a stellar engine, and to control its motion in the galaxy. We first provide a brief overview of stellar engines and conclude that looking for technosignatures of stellar engines has taken two roads: on the observational side, hypervelocity stars have been the target of such searches, but without good candidates. On the theoretical side, stellar engine concepts have been proposed but are poorly linked to observable technosignatures. Since about half the stars in our galaxy are in binary systems where life might develop too, we introduce a model of a binary stellar engine. We propose mechanisms for acceleration, deceleration, steering in the orbital plane and outside of the orbital plane. We apply the model to candidate systems, spider pulsars, which are binary stars composed of one millisecond pulsar and a very low-mass companion star that is heavily irradiated by the pulsar wind. We discuss potential signatures of acceleration, deceleration, steering, as well as maneuvers such as gravitational assists or captures.

JBIS VOLUME 77 #5 MAY 2024 Interstellar Issue		
Constraints on Interstellar Sovereignty	**Jacob Haqq-Misra**	**USA**

Human space exploration and settlement of other planets is becoming increasingly technologically feasible, while mission concepts for remote and crewed missions to nearby star systems continue to be developed. But the long-term success of space settlement also requires extensions and advances in models of governance. This paper provides a synthesis of the physical factors that will constrain the application of sovereignty in space as well as legal precedent on Earth that likely applies to any crewed or uncrewed missions to other stellar systems. The Outer Space Treaty limits the territorial expansion of states into space, but the requirements for oversight of nongovernmental agencies and retention of property ownership enable the extension of state jurisdiction into space. Pragmatic constraints from historical precedent on Earth suggest that new space treaties will be unlikely to succeed and new global space agencies may have limited jurisdiction over states, while hard constraints of the space environment require adherence to technical capabilities, political feasibility, and long-term sustainability. These factors form a three-prong test for assessing the viability of interstellar governance models. This discussion of interstellar governance is intended to further the conversation about sovereignty in space prior to the first intentional launch of any interstellar spacecraft.

JBIS VOLUME 77 #6 JUNE 2024		
Research Progress Toward Engineering Feasibility of the Centrifugal Nuclear Thermal Rocket	**Dale Thomas, Michael Houts, Dean Wang, Keith Hollingsworth, Robert Frederick & Jason Cassibry**	**USA**

The Centrifugal Nuclear Thermal Rocket (CNTR) is a Nuclear Thermal Propulsion (NTP) concept designed to heat propellant directly by the reactor fuel. The primary difference between the CNTR concept and traditional NTP systems is that rather than using traditional solid fuel elements, the CNTR uses liquid fuel with the liquid contained in rotating cylinders by centrifugal force. Research continues to determine resolutions for the significant engineering challenges that the CNTR concept presents, and this paper describes the advances resulting from the most recent analyses, simulations, and experiments. In particular, this paper describes strategies and key results to date on leveling the heat generation gradient in the liquid uranium annulus through use of a burnable poison. Coupled with the significantly improved power gradient, inclusion of a ZrC liner allows significant higher core operating temperatures and yields significantly improved performance estimates. Progress is also described for the 3D modeling of the gaseous hydrogen bubbles in the liquid uranium and experimental results on gaseous and liquid analogs to validate the analytical models. Finally, mission analyses are described for scientific missions to various Solar System destinations including Jupiter and Kuiper belt objects Pluto and Quaoar.

Dreaming of distant worlds?
Excited to push the boundaries of exploration?
Ready to turn the impossible into reality?
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Parnika Singh

The Initiative and Institute for Interstellar Studies (i4is) invites you to join a bold and inspiring mission: bringing humanity closer to the stars. As a nonprofit organization, we are driven by an unyielding curiosity and the relentless pursuit of breakthroughs in interstellar exploration. Together, we can turn humanity's most ambitious dreams—once confined to the pages of science fiction—into tangible, groundbreaking achievements.

When you become an i4is member, you won't just be a spectator to history in the making—you'll be part of the force driving it forward. Our efforts encompass everything from cutting-edge theoretical research that redefines what's possible, to hands-on development of technologies that could one day take humanity to other star systems. By joining us, you'll help lay the foundation for a new chapter in exploration, while also inspiring and equipping the next generation of scientists, engineers, and visionaries who will make it happen.

This is your opportunity to be part of something bigger than yourself—a movement that dares to dream of a future where the stars are within reach.

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- Insider Insights: Stay ahead of the curve with member-only newsletters highlighting the latest breakthroughs in space research.
- Inspiring Resources: Explore our growing library of videos, designed to spark curiosity and fuel learning.
- Special Events: Be part of exclusive live streams featuring i4is events and expert discussions, connecting you directly with the pioneers of interstellar exploration.
- Progress Reports: Access our annual report to see how your support propels us closer to the stars.

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Becoming an i4is member isn't just about supporting a cause—it's about taking action. It's about saying yes to innovation, yes to exploration, and yes to a future where humanity reaches for the stars. Whether you're a student or a seasoned space enthusiast, there's a place for you in this movement.

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Together, we'll turn humanity's greatest dream into reality. The stars are waiting—let's go meet them!

THE i4iS MEMBERS' PAGE

John I Davies

The i4is membership scheme exists for anyone who wants to help us achieve an interstellar future. By being a member of i4is, you help to fund our technical research and educational outreach projects. Members can access the members-only area of the website including our video talks, members' newsletter and Principium preprints.

i4is and friends with the i4is "Coracle" model of a laser pushed interstellar probe at the First European Interstellar Synposium (FEIS). Hosted by the University of Luxembourg. FEIS is reported in the lead feature of this issue.

Recent member newsletters

There have been 2 member newsletters since P47, our last issue. All member newsletters are emailed to members and also available from the members-only area on the website - i4is.org/members.
The most recent, January 2024, included the month's Interstellar News and featured the *i4is Members' Report for 2022 and 2023* which has now been published.

Getting more actively involved

There is lots to do whether your skills are technical, educational, administrative or financial. The more volunteers we have, the more we can achieve! Please get in touch at info@i4is.org.

Writing for Principium

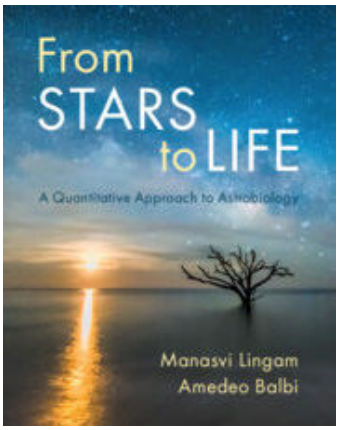
If you have a particular topic which interests you then please propose an article to the Editors. Email john.davies@i4is.org or patrick.mahon@i4is.org with a brief summary of your idea and a little about yourself.

"As we look out into the Universe and identify the many accidents of physics and astronomy that have worked together to our benefit, it almost seems as if the Universe must in some sense have known that we were coming."

Freeman John Dyson FRS

NEXT ISSUE

Next time, in P49 - May 2025



From Stars to Life
A Quantitative Approach to Astrobiology
A review by Andreas Hein of the new book by Manasvi Lingam, Florida Institute of Technology andAmedeo Balbi, Università degli Studi di Roma 'Tor Vergata'.

Envisaged interior of a worldship. Credit: Project Hyperion (https://irg.space/first-european-interstellar-symposium/)

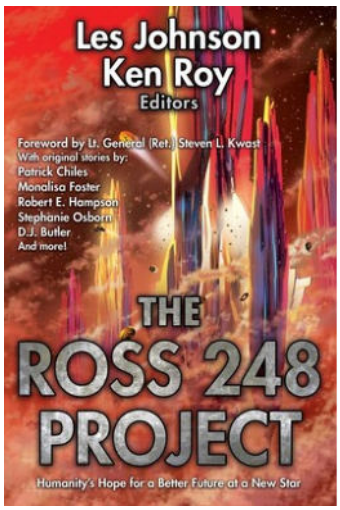
Project Hyperion progress report
i4is world ship competition to design multi generation ships using current and near-future technologies with self-sustaining ecosystems, featuring agriculture, habitation, and other necessary life-support systems.

IAC24 - Third Report
More papers and presentations from the 2024 International Astronautical Congress.

FEIS report
Papers and presentations at the First European Interstellar Symposium.

Aerographite: a Candidate Material for Interstellar Photon Sailing

Aerographene and Aerographite, a review of a recent paper by Professor Greg Matloff in JBIS.



A team coordinated by Les Johnson and Ken Roy, two engineers who have pioneered interstellar studies, have produced a shared world anthology about the arrival of a mission to a known star - and the problems they confront from arrival onwards. Reviewed by Patrick Mahon.

Novel Technosignatures
A ground breaking paper by more interstellar pioneers, Dr Al Jackson and Dr Gregory Benford.
"My rule is there is nothing so big nor so crazy that one out of a million technological societies may not feel itself driven to do, provided it is physically possible." — Freeman Dyson.

And of course there will be the usual Interstellar News and journal reports.

Altogether a bumper issue!

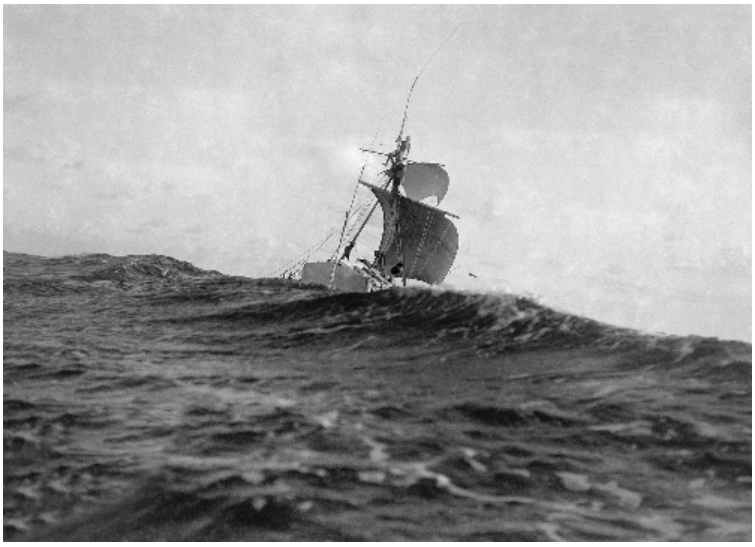
COVER IMAGES

Cover images for this issue 48

Our cover images for this issue are visions from the youth of your humble editor.

FRONT COVER

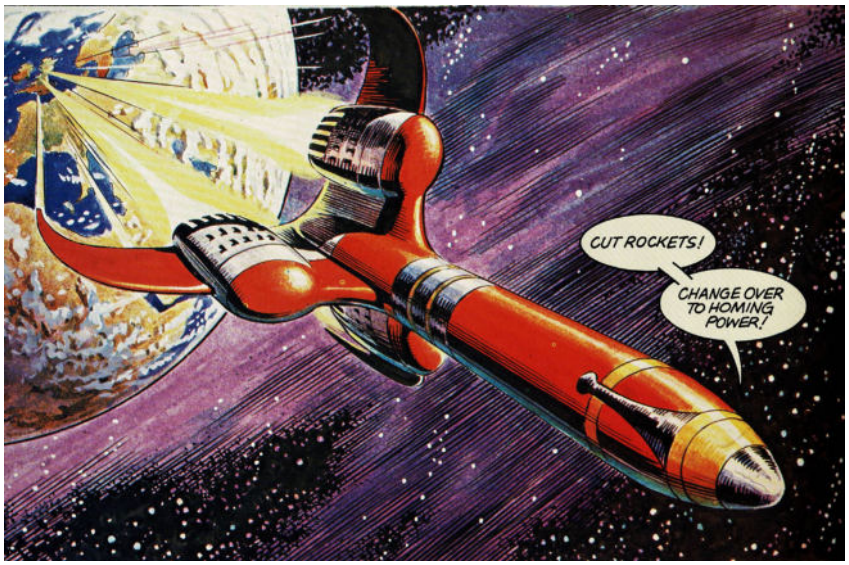
A voyage to inspire our species



In 1956 a 10 year old boy was presented with a beautiful edition of *The Kon Tiki Expedition* by Thor Heyerdahl by his older cousin. It told the story of an amusing bunch of Norwegians and one very serious Swede who attempted to prove that Polynesia could have been populated from South America to the east. Years later it was proved that the migration was in the opposite direction. But the courageous pursuit of an anthropological objective remains inspirational. Both the adventure and the migration show what humanity could achieve both 80 years ago and a 1,000 years earlier. An inspiration to all of us who aim to show that an adventure and maybe a migration beyond our solar system is feasible and may even be inevitable.
The picture was taken by a member of the Kon Tiki crew from an inflatable dinghy in mid-Pacific - credit Thor Heyerdahl.

BACK COVER

The first launch of an interstellar spacecraft from the UK!



In 1955 a primary schoolboy in Warrington Lancashire was reading a story "The Man from Nowhere" in the comic, "The Eagle". In this story a Scot, Dan Dare, an Irishman, Lex O'Malley and a Lancashireman, Albert Digby fly to another star system to help their new friend, Lero of the planet Cryptos, to defend his people from the inhabitants of their twin planet, Phantos, who have themselves been enslaved by an evilly programmed computer. The Crypts have been rendered pacific by their diet while the Phants have been made aggressive by the food provided by their computer overlord.
Do I detect an echo in our present circumstances?
Image credit: Frank Hampson
en.wikipedia.org/wiki/Frank_Hampson

The Initiative for Interstellar Studies is a pending institute, established in the UK in 2012 and incorporated in 2014 as a not-for-profit company limited by guarantee.

The Institute for Interstellar Studies was incorporated in 2014 as a non-profit corporation in the State of Tennessee, USA.

Mission
The mission of the Initiative & Institute for Interstellar Studies is to foster and promote education, knowledge and technical capabilities which lead to designs, technologies or enterprise that will enable the construction and launch of interstellar spacecraft.

Vision
We look to a positive future for humans on Earth and in space. Our vision is to be an organisation catalysing the conditions in society supporting a sustainable space-based economy. Over the next century and beyond we aim to enable robotic and human exploration of space beyond our Solar System and to other stars. Ultimately we envisage our species as the basis for an interstellar civilisation.

Values
To demonstrate inspiring leadership and ethical governance, to initiate visionary and bold programmes co-operating with partners inclusively, to be objective in our assessments yet keeping an open mind to alternative solutions, acting with honesty, integrity and scientific rigour.

Front cover: The Kon Tiki in mid-Pacific with crew member aloft.
Credit: Thor Heyerdahl

Back cover: Cryptosian starship returning home.
Credit: Frank Hampson

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

EDITOR: John I Davies
DEPUTY EDITORS: Patrick J Mahon, Andreas M Hein
LAYOUT/PROOF: John I Davies, Carol Wright, Patrick J Mahon