PRINCIPIUM

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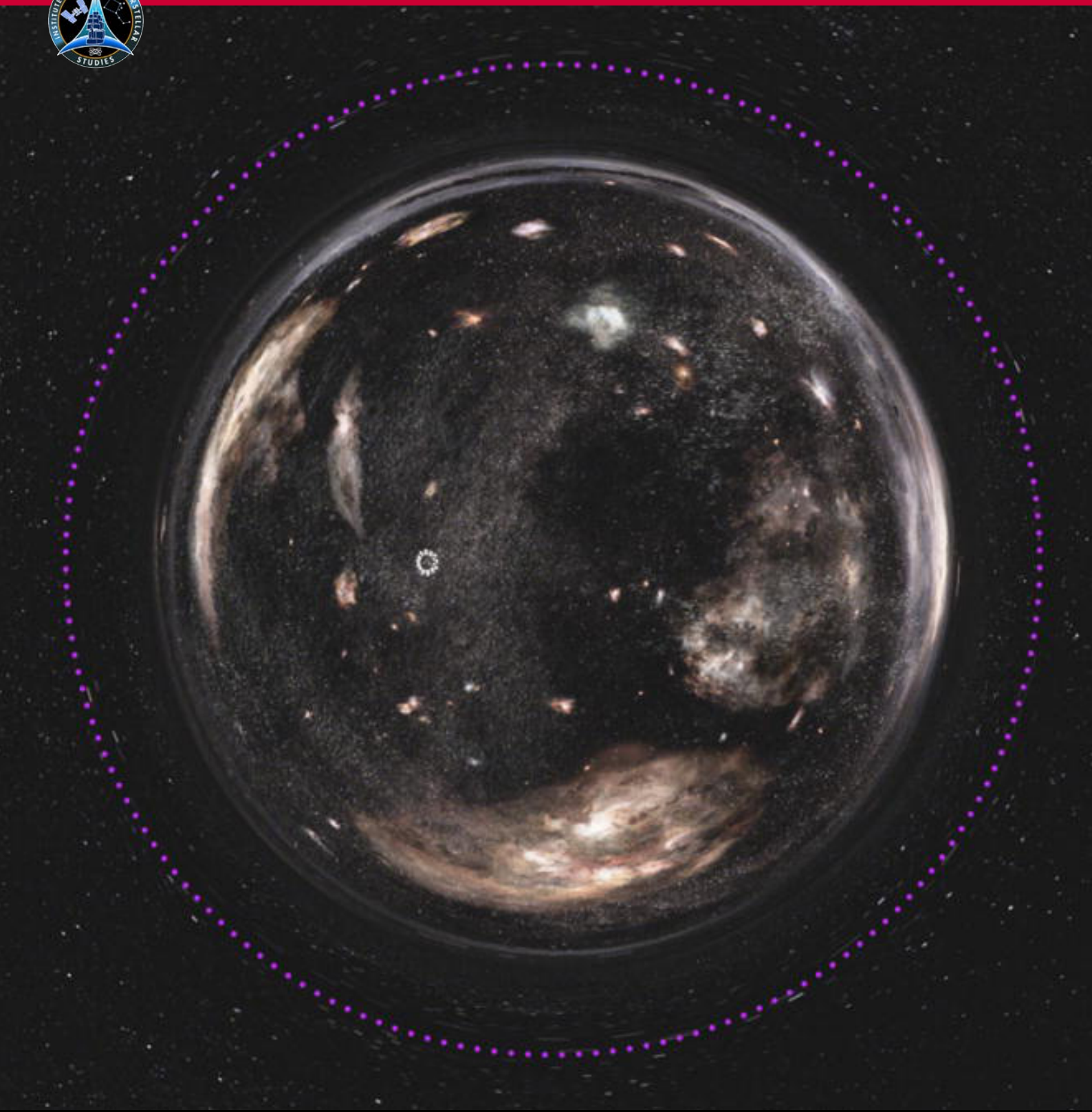

Lead Feature: An Improbable Pursuit: Current Thinking on FTL Travel

Features: Why Quantum Entanglement Won't Deliver The Ansible, Launching politics into outer space, Long Life and the Longest Journey

News Features: IAC24: Interstellar Presentations, Breakthrough Discuss 2024, Project Lyra Update: Starships and Swarms

Interstellar News

The Journals: JBIS and Acta Astronautica

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EDITORIAL

Welcome to issue 46 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is *An Improbable Pursuit: Introduction to the Current Thinking on Faster-Than-Light (FTL) Travel* by Dr Dan Fries, our Deputy Technical Director.
We have three news features *International Astronautical Congress IAC24: The Interstellar Presentations*, a *Project Lyra Update: Starships and Swarms* and a report on Breakthrough Discuss 2024. Also 10 pages of Interstellar News and our regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.
We have other features - *Launching politics into outer space - A review of The Terrestrial Trap: International Relations beyond Earth* by Max Daniels, T*he Cosmic Challenge: Why Quantum Entanglement Won't Deliver The Ansible* by Arya Lal Gonullu and *Long Life and the Longest Journey: Musings on life extension for world ship missions* by Matthew Lehmitz.

Our front cover image shows just one fictional visualisation of FTL travel . The rear cover image is from the new i4is worldship design challenge, Project Hyperion. 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, P47 in November 2024, we will have the first report of interstellar items from October's 2024 International Astronautical Congress in Milan, a full report of the 2024 SF Worldcon in Glasgow this month and more about the upcoming First European Interstellar Symposium to be hosted by our Executive Director Andreas Hein at the University of Luxembourg. And the usual Interstellar News and journal reports. More details on P47 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 21.

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Patrick Mahon, Deputy Editor, patrick.mahon@i4is.org

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

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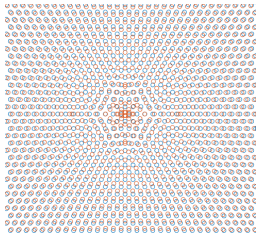

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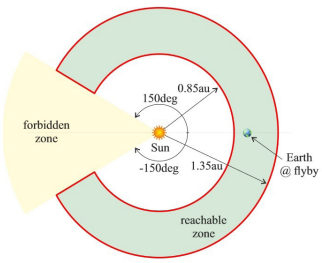

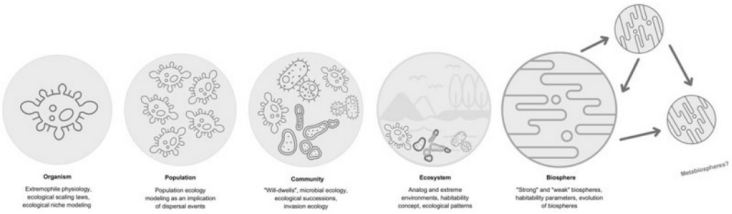

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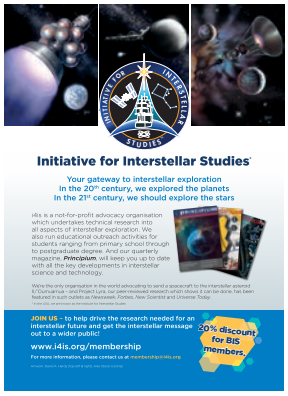
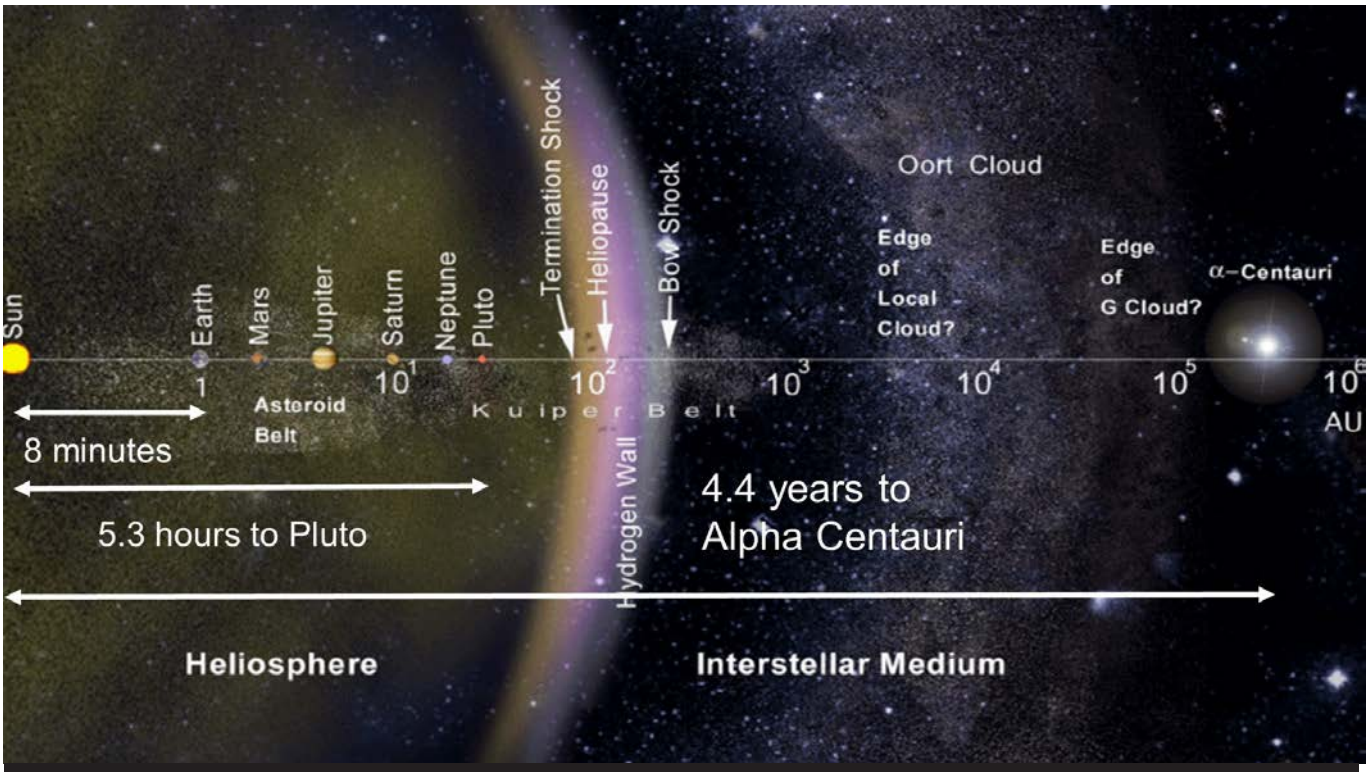


An Improbable Pursuit
Introduction to the Current Thinking on Faster-Than-Light (FTL) Travel

Dan Fries

The enormous distances to even the nearest stars, coupled with the velocity limitation of special relativity, have challenged us since they were first measured in the early 19th century*. In this first of a series, *Current Thinking on Faster-Than-Light (FTL) Travel*, Dr Dan Fries, i4is Deputy Technical Director, introduces the FTL idea.
References are at the end of the article.



The (logarithmic) scale of our interstellar neighbourhood. Credit: Based on work of JHU-APL (interstellarprobe.jhuapl.edu/)

The seemingly impossible has always captured human imagination, especially when the pay-off would change nearly every social and technological paradigm that we are working under. From fusion energy to the multi-verse, increases in our understanding of the universe have always given birth to fantastic ideas, some of which, against all initial odds, eventually become reality in one way or another. Since around 1908, when Minkowski and Einstein first introduced the idea that space and time are really not separate at all, but rather constitute a four-dimensional space-time fabric that makes up our universe, scientists, authors and dreamers have tried to push this idea to its limit, resulting in fantastic philosophical and technological prospects. And sometimes, in ideas for interstellar exploration, communication and civilizations spanning entire galaxies.

* A history of astrometry, sci.esa.int/web/gaia/-/53196-the-oldest-sky-maps

One key aspect of Einstein's theory of relativity is that no object can exceed the vacuum speed of light, ie the propagation speed of electromagnetic waves in a vacuum. In fact, this also implies that information can never travel faster than the speed of light. As a result, even individual photons, the field particles carrying the energy quanta of electromagnetic radiation, take a significant amount of time to travel between celestial objects emitting them. For example, it takes light approximately 8 minutes to travel from the surface of the sun to Earth, or 5 ½ hours from the sun to Pluto. At this point, we are still very much within our own stellar neighborhood. If we could hitch a ride on an electromagnetic wave, or a photon, for interstellar travel, reaching the nearest extra-solar star system (Alpha Centauri) would take about 4.3 years.

Unfortunately, according to special relativity, even "just" reaching the speed of light is impossible for any object or particle besides photons. When an object with a finite mass accelerates, its kinetic energy increases. Approaching the speed of light, the particle would move at "relativistic" velocities. The total relativistic energy of that particle would be given by $E=\gamma mc^2$, where m is its mass at rest, c is the speed of light, and γ is the Lorentz factor* . This factor corresponds to a transformation of time and space coordinates that ensures all physical laws are invariant with respect to arbitrary non-accelerating frames of reference†. In our day-to-day experience this effect rarely seems to play a role, but technologies such as the Global Positioning System (GPS) would not be as precise as they are if we did not account for time dilation (the apparent stretching and contraction of time in frames of reference moving relative to each other) in the signals transmitted by GPS satellites, due to the satellites' significant orbital velocity relative to Earth. The GPS satellites' position within Earth's gravitational well introduces another correction, but this is related to general relativity and the warping of spacetime, which we will get to later. The Lorentz factor takes a value very close to one if the speed of an object is small (below a couple percent of the speed of light of 300,000,000 m/s or 83,333,333 km/h), corresponding to our everyday experience and explaining why we rarely experience time dilation effects when we drive on a highway or even fly on a plane. However, when approaching the speed of light, the Lorentz factor starts approaching infinity, initially slowly but then faster and faster. In the context of the equation mentioned above, this means that an infinite amount of energy, *E*, would be required to travel at the speed of light. And besides, if we want to build a galaxy spanning civilization, even the speed-of-light does not really cut it when we can't even send emojis back and forth in less than a decade.

Enter General Relativity: according to this macroscopic description of the cosmos, mass distorts the fabric of spacetime, resulting in effects that we perceive as gravity. And because mass is equivalent to energy according to special relativity, both mass and energy can cause local distortions in the spacetime continuum. One has to really sit with this idea for a moment and think about its implications to understand how monumental the impact of the theory of relativity is on our understanding of reality: space and time are parts of the same thing and can be distorted by the presence of mass and energy. Coming back to our simple example of GPS satellites, what this means is that, from our perspective deeper in the gravity well of Earth, ie in a region of larger spacetime distortion, the time on board of a GPS satellite moves faster. At the same time, an observer onboard a GPS satellite would perceive that clocks on Earth are moving slower than on the satellite. Of course, these effects still seem small, but they become extremely large near massive objects such as black holes or neutron stars, to the point that at a certain distance from a black hole time would seem to stand still to an outside observer. What else could such massive distortions in the spacetime continuum do?

Already before 1950, John W Campbell and Issac Asimov wrote stories involving a "Warp Drive" to circumvent the speed and time limitations imposed on us during interstellar travel. The warp drive was subsequently popularized in a large number of shows, movies, and books, most notably Gene Roddenberry's Star Trek. Inspired by this science-fiction idea, theoretical physicist Miguel Alcubierre showed in 1994 [1] that the Einstein field equations could, in principle, allow for a solution that produces such a warp drive. The underlying idea is deceptively simple: through a tailored distribution of mass and energy the spacetime fabric can be compressed ahead of a spacecraft and expanded behind it, allowing the craft to globally travel faster than the speed of light without ever locally exceeding it.

* $\gamma=1/\sqrt{(1-v^2/c^2)}$ where v is the speed of an object and c is the speed of light.
† See also "Principle of Relativity" in special relativity. In the framework of general relativity, the laws of physics additionally have the same form in arbitrary frames of reference, see "Equivalence Principle".

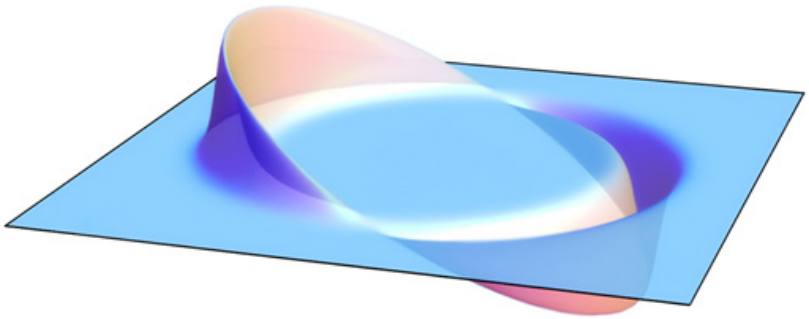


Figure 1: Two-dimensional embedding diagram visualizing how the Alcubierre space-time metric would distort space and create a "warp-bubble". The opposing regions of expanding and contracting spacetime are what displace the bubble. Reproduced under CC BY-SA 3.0.
Credit: AllenMcC. - Wikipedia

The spacecraft would be travelling in a “warp bubble”, as illustrated graphically in Figure 1. However, the solution initially seemed to require amounts of negative energy (or negative mass) exceeding the total mass of the known universe. Not only are negative energy densities a matter of ongoing speculation* and such extraordinarily large amounts of mass are an issue, traveling faster than the speed of light also poses potential problems regarding our understanding of causality.

Using a flat spacetime diagram (Minkowski diagram), one can prove that an FTL spaceship could arrive at a point in time and space before its own construction, potentially leading to a time-travel paradox in which the traveler prevents themselves from journeying through space and time in the first place. Additionally, any observer travelling within the warp bubble would be causally disconnected to some extent from the surrounding universe and even from the bubble itself. Any light source that the superluminal (faster than the speed of light) observer moves towards would be infinitely blueshifted†, while anything the observer moves away from would be infinitely redshifted, meaning electromagnetic waves (eg light or radio transmissions) would be effectively undetectable. The observers would also not be able to send signals to the front of the warp bubble, preventing any attempts at steering or stopping their vessel [2]. Krasnikov tubes [3], permanent superluminal spacetime distortions, could potentially alleviate some of the navigation and causality issues but would still require negative energy densities to establish and stabilize them. Finally, researchers have been arguing that, even if an FTL warp drive could be realized, the effect of the warp bubble on particles encountered during the journey could have devastating consequences on both passengers and target destinations in the flight path. Passengers within the bubble could be exposed to dangerously blueshifted (ie highly energetic) particles, while “people at the destination would be gamma ray and high energy particle blasted into oblivion due to the extreme blueshifts for … particles” [4].

Another approach to FTL travel relies on a special type of black hole. We already mentioned black holes, regions in space of such extreme mass concentration that spacetime is distorted into a singularity from which not even light can escape. The singularity is predicted mathematically but probably exists physically, too, although we are currently unable to directly determine what lies at the core of a black hole beyond the Schwarzschild radius, ie the event horizon (The radius beyond which light cannot escape the black hole). The existence of singularities in solutions to the Einstein field equations was first shown by Karl Schwarzschild in 1916, when he derived the gravitational field around spherical distributions of mass and identified mathematical singularities at the so-called Schwarzschild radius and at the center of the mass distribution. For stars, the Schwarzschild radius always lies within the physical boundaries of the star or planet and, therefore, does not cause any issues for the description of the gravitational field. However, high-enough mass density can cause a situation in which the Schwarzschild radius lies outside the spherical mass itself. About four decades later, the Schwarzschild radius was clearly identified as a surface that can only be crossed in one direction, ie a region in space from which nothing can return. Additionally, researchers realized that the singularity at the center of such gravitational fields is most likely real, representing a physical feature of the general theory of relativity.

* One of the proposed sources of negative energy relies on the exploitation of a quantum phenomenon called the Casimir effect.
† Due to the Doppler effect: a change in the perceived frequency of a wave by an observer moving relative to the source of the wave.

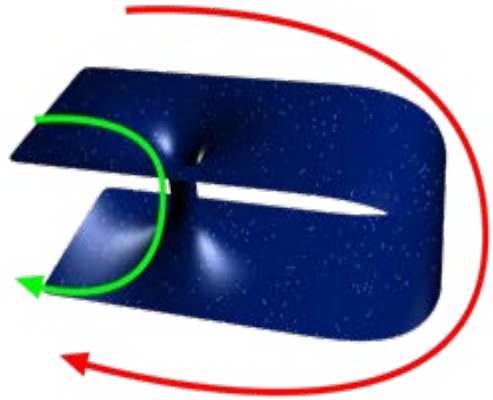


Figure 2: Two-dimensional embedding diagram of a wormhole. The green arrow indicates the path a particle, or light, might take through the wormhole, while the red arrow indicates the much longer path through undistorted space.
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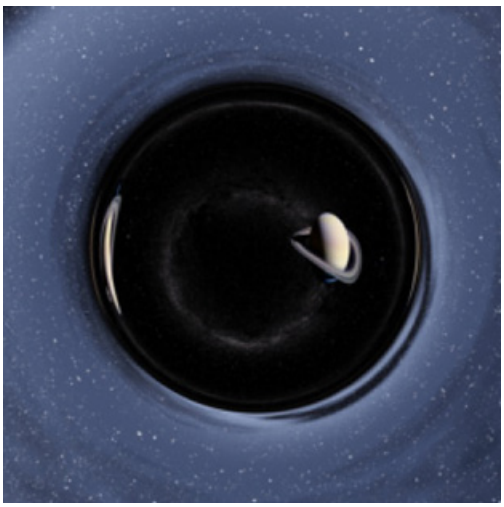

Figure 3: Image of Saturn as seen through a wormhole.
Reproduced from [5] under Creative Commons CC BY-NC-ND 3.0.

Using the Kruskal–Szekeres coordinate transform to obtain a well-behaved solution everywhere except for the singularity itself, it can be shown that in addition to the black hole there could be a white hole, a region from which no particles can escape and a region into which no particles can return, respectively. Graphical representation of this solution results in an object that looks like a tube connecting two outside regions, as shown in Figure 2. This was first discovered by Ludwig Flamm shortly after the publication of the Schwarzschild black hole solution, and then rediscovered by Albert Einstein and Nathan Rosen in 1935. The resulting object is nowadays called an Einstein-Rosen bridge or a Wormhole, after an article by John Wheeler and Charles Misner in 1957 [6]. In principle, such a wormhole could connect two regions of space, that are lightyears away from each other, almost instantaneously. What a traveler might experience on their journey through a wormhole has been impressively visualized in the movie “Interstellar” with the help of leading researchers in the field of general relativity*, see the example shot in Figure 3 and the paper by James et al. [5].

Unfortunately, a wormhole-like structure would also present a potential for causality violations, time-travel like phenomena, and it would again require negative energy densities to stabilize the connection [7].

Clearly, interstellar travel and efforts to build a galaxy spanning civilization, capable of meaningful commerce and information exchange, are severely hamstrung by limitations imposed on us by the finite speed of light and our understanding of the theory of relativity. Nonetheless, as we learn more about the implications of the four-dimensional spacetime continuum and possibilities to manipulate its geometry, ideas have arisen that might allow us one day to circumvent these limits. Past efforts in this direction have yielded deep insights into the physical theories describing our reality and have sometimes hinted at missing links between our macroscopic (general relativity) and microscopic (quantum mechanics) description of the universe. However, these efforts have also shown that realizing faster than light travel often requires a theoretical violation of physical constraints. This has not stopped researchers from considering creative ways to bypass obstacles and to come up with novel solutions that are more likely to work within our current understanding of the natural world. With this article laying the groundwork for the discussion of space-warping FTL propulsion technologies, we will take a deeper dive into more recent developments in this area in a follow-up article.

* See the front cover image of this issue and details with references on page 83, Cover Images.

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Dan Fries Bio

Dan Fries is a researcher at the University of Texas at Austin, Deputy Technical Director of i4is and a board member of the Initiative for Interstellar Studies. He received his PhD in Aerospace Engineering from the Georgia Institute of Technology (USA), and Master’s degrees from both the Georgia Institute of Technology and the University of Stuttgart (Germany). Starting in 2025, he will be a professor at the University of Kentucky (USA). His research interests include high-speed fluid mechanics, aerothermodynamics and aerothermochemistry, plasma and combustion chemistry, reentry, and propulsion systems. As an experimentalist, he uses and develops advanced optical and laser diagnostics, spectroscopic techniques, and methods for uncertainty quantification and the inversion of measurement models. He is also intrigued by the possibilities of breakthrough propulsion systems and the possibilities of interstellar exploration.

Initiative for Interstellar Studies*

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In the 21st century, we should explore the stars

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Launching politics into outer space

A review of *The Terrestrial Trap: International Relations beyond Earth*

Max Daniels

In another thoughtful piece about our interplanetary and interstellar futures, Max Daniels looks at the thinking of two academics in Political Science at the University of Amsterdam, reflecting on the differences and parallels between international relations on and off Earth and how each can inform the other with the benefit of improved perspective to both.
References at the end.

Starlink satellite launches are ongoing; Source: commons.wikimedia.org/wiki/File:B1051.jpg

In *The Terrestrial trap: International Relations beyond Earth* [1], Enrike van Wingerden and Darshan Vigneswaran want us to stop thinking about international relations as if we are stuck on Earth. They point to two assumptions prevalent in how academics, governments and others conduct themselves on the international stage. First, that politics can only happen on the Earth's surface; and second that what happens, and will happen, in outer space is just an extension of Earthly politics.

This is a valuable intervention because it asks us to pause and consider where political practices in space are going and who will benefit from them. It also suggests that we bring in different ideas that already exist on Earth into our space activities, which in turn would have very real and immediate uses on Earth, especially in relation to how we manage the effects of climate change.

The politics of outer space

There is no doubt that space is vital to life on Earth today. Large satellites allow us to communicate, run our militaries, and measure the Earth's climate. Vast numbers of smaller satellites move in low Earth orbit in constellations to provide rapid internet connections globally [2], including over 6,000 Starlink satellites [3]. Looking forward, national space agencies have ambitious plans for crewed and uncrewed missions, including to the Moon [4] and Mars, as well as space mining and in-situ resource utilisation.

Space is political: one example being the importance placed by North Korea on their often-failed military satellite launch programme [5]. The authors agree with this, but argue that we should not just look at international relations on Earth and simply extend this up to space. Rather, we should 'provincialise' it, where the concepts of territory, governance, and political practices are situated in the environment and political history in which they take place. This would allow different areas, such as outer space, to have their own, new, forms of politics, and will be discussed more later in the article.

We need to move away from a flat Earth *

The Earth is not flat, and neither is politics

Van Wingerden and Vigneswaran refer to 'Flat-Earthism' as how people think only in relation to the Earth's surface. International relations only take place as if on a map, with countries drawn out and borders demarcated, as it emerged out of a European-focused political history. The nation-state today rules on Earth, and that means also in space – with international agreements placing responsibility over space launch and vehicles on states [6].

One way to move away from this flat approach is to look at other ways of thinking. This includes looking to other cultures for inspiration and to bring into perspective different dimensions (less flat), and non-Western thinking. Indigenous cosmologies, while not uniform, have long looked up to the stars, and have given greater value to space. For some cultures space engenders a sense of belonging away from the Earth, which would support the viability of habitation in space [7]. This isn't about coming up with a new form of politics for outer space. It is about thinking in such a way that allows us to ask and wonder how we will consider political issues when we are up there.

* Source: commons.wikimedia.org/wiki/File:Colton%27s_Map_of_the_World_on_Mercator%27s_Projection_%281858%29_by_J.H._Colton_%26_Co._Original_from_The_Beinecke_Rare_Book_%26_Manuscript_Library._Digitally_enhanced_by_rawpixel._%2850623708272%29.jpg

The authors are right to acknowledge that we will bring our current political struggles into space, but that these alternative mindsets would allow ourselves the conceptual capacity to address and adapt them.

The boundary between Earth and space

Space is materially different, and this means you cannot just extend 'Flat-Earthism' upwards. Where this difference first begins – the boundary between Earth's atmosphere and space – is not universally agreed, though commonly considered to be at the von Kármán line of 100 km above the Earth's surface [8].

Space's distinct material nature will result in different political arrangements, the authors rightly put forward. This argument has been made for other areas that are not terrestrial land, such as with icebergs [9], the deep seabed [10], or in airspace [11], while the ocean's surface has historically provided a space across which people have moved, or traded [12]. Some of these have different international agreements, but all are recognitions of the reality that different social, economic and political relationships exist away from land.

To link these back to contemporary terrestrial issues, these differences are important to consider because climate change will force changes upon us, alongside our own encroachment into outer space [13].

The deep sea is a different political space to land *

Human habitability

We also need to move away from Earthly thinking when in space because it is a harsh environment to live in. Governance needs to be adapted to account for this, just like in Antarctica and other Earthly extremes, where "challenging environmental conditions do not eliminate but transform the possibility and conduct of politics" (p 615).

Constructing a habitat, and the context in which it is made, are political processes worth examining. The extraction of space resources are, "unlikely to produce an extension... of human history and politics as it has emerged on the habitable surface of planet Earth, as the material conditions of space demand that these phenomena manifest differently." [14] This necessitates alternative forms of human society and so their political structure.

While it is important to consider how habitats are made, this argument does not quite go far enough: you have a habitable base, but then what? This next conceptual step has been examined by others, such as Charles Cockell looking at the concept of liberty in outer space [15]. He agrees that humans must devise ways of sustaining life, including with food, water, and oxygen.

This puts a society in space at risk of authoritarianism, as one who controls the supply of oxygen controls how people live and work. Resources can be rationed and distributed, but also restricted to certain groups [16]. A space station's design could affect how 'citizens' are treated, and which areas are deemed private spaces and which areas are public areas, determining what freedom they have [17]. This has grim Earthly connections, as seen during times of conflict, including in the Middle East [18]. As I explored in Prinicipium 39 (Book Review: Freedom in outer space. i4is.org/principium-39) this can also be extended to physical spaces such as prisons.

* commons.wikimedia.org/wiki/File:Colton%27s_Map_of_the_World_on_Mercator%27s_Projection_%281858%29_by_J.H._Colton_%26_Co._Original_from_The_Beinecke_Rare_Book_%26_Manuscript_Library._Digitally_enhanced_by_rawpixel._%2850623708272%29.jpg

Looking to the future: getting involved in space flight

The authors argue that international relations theorists should become involved in discussions about how upcoming space flights, tests, and launches should run, and the precedents they set for politics in space. This is a good recommendation, in that having projects informed by critical theory means that politics is not lazily reproduced from its Earthly practices. They suggest one benefit that this collaboration could bring is a link to environmental thinking. If their focus on non-terrestrial – as in non-traditional – politics helps policymakers to bring the environment more to the centre of our thinking both on Earth and in outer space, so much the better.

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The Cosmic Challenge

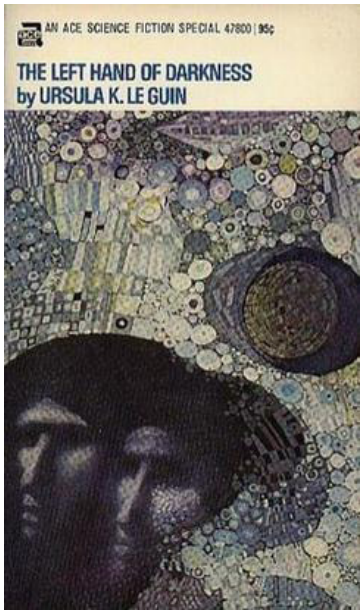
Why Quantum Entanglement Won't Deliver The Ansible

Arya Lal Gonullu

The idea of communicating instantaneously or, perhaps, simply faster than Einstein's cosmic speed limit of c, the speed of light, about 300,000 kilometres per second, has been around in science fiction since the 1940s. In 1974 Ursula K Le Guin named the ansible [1], a device which transmitted to all others of its type instantaneously. And the term has since been used for similar ideas by many other writers, though not all.

Here Arya Gonullu, student of Theoretical Physics at King's College London, examines the quantum mechanical phenomenon of entanglement. Though it does appear to imply Einstein's bugbear "spooky at a distance" it is sadly not a loophole in his speed limit we can use.

References are at the end of this article.



In *The Left Hand of Darkness* (Ace Books, 1969) Ursula K Le Guin imagines interstellar travel at near light speed but simultaneous communication via devices called ansibles. James Blish later named his similar device a Dirac communicator (he had a fondness for naming his fictional technologies after real scientists and principles).
Image Credit: Cover of first edition of *The Left Hand of Darkness*

As humanity sets its sights on exploring the deep cosmos, the question of how to communicate across the vast distances of space becomes increasingly urgent. Science fiction has long offered a tantalising solution: the ansible, a device enabling information to be sent faster than light, without violating special relativity [Hedemann, 2018].

Another captivating concept is quantum entanglement. Quantum entanglement is one of the most fascinating phenomena in modern physics. When two particles become entangled, their properties become linked (properties such as spin) so that the state of one particle instantaneously influences the state of the other, regardless of the distance between them. This "spooky action at a distance" suggests the potential for instant communication, an idea that has naturally captured the imagination of those dreaming of reaching out to distant worlds.

A remarkable feature of this process is that the distance between the particles does not matter. The process works as long as the entanglement between the photons is preserved. Even if one particle is on Alpha Centauri and the other is on Earth, it appears as if one photon is magically affected by the other photon's distant measurement, and vice versa [Zeilinger, 2000].

Entanglement is a phenomenon where multiple quantum systems exist in a coherent superposition, demonstrating that the universe does not adhere to local realism. One way to achieve entanglement involves electrons, which have a magnetic moment that causes them to interact with one another. When one electron is placed in a superposition state, the other electron responds by entering a similar superposition, resulting in entanglement between them. Another method involves particle-antiparticle creation, where properties like momentum are conserved. In this process, when one measures the momentum of one particle, the momentum state of the other particle collapses instantaneously, illustrating the entangled nature of their relationship.

[1] *Ansible* in The Encyclopedia of Science Fiction sf-encyclopedia.com/entry/ansible

Therefore, science fiction authors thought, as many scientists did, quantum entanglement could possibly provide the "ansible" that could make our job to have an interstellar communication system easier. But while the concept is captivating, the principles of quantum mechanics – and in particular, quantum entanglement – might not be the answer to the "ansible" problem with our current understanding. Despite its allure, quantum entanglement cannot break the speed-of-light barrier for transmitting information across interstellar distances.

At first glance, quantum entanglement seems to offer a possibility for faster-than-light communication. When one measures one particle in an entangled pair, information about the other particle's spin becomes known instantaneously. This seems to suggest that we can know what's happening at the other end of the experiment not only faster than light but potentially tens of thousands of times faster. Does this mean information is being transmitted at a superluminal speed? Unfortunately, the answer is no. While it might appear that information is being communicated faster than light, the outcomes of quantum measurements are inherently random. One cannot encode a specific outcome into a quantum measurement. There is a significant difference between making a measurement (where the entanglement between pairs is maintained) and forcing a particular result, which changes the state and breaks the entanglement [Orzel, 2016]. If one attempts to control, rather than just measure, the state of a quantum particle, the knowledge of the full state of the combined system is lost as soon as that change-of-state operation is made.

Quantum entanglement allows us to gain information about one component of a quantum system by measuring the other, but only as long as the entanglement remains intact. What one cannot do is create information at one end of an entangled system and somehow send it to the other end. If we could make identical copies of a quantum state, faster-than-light communication might be possible, but this is prohibited by the no-cloning theorem. The no-cloning theorem states that it is impossible to create an exact copy of an arbitrary unknown quantum state, and it is not possible to produce exact copies of all the input states while retaining the originals intact [Lindblad, 1999].

In the world of quantum teleportation, Alice and Bob are characters often used to explain complex quantum communication concepts. Alice is typically the sender, and Bob is the receiver. To achieve teleportation, Alice starts by performing a two-qubit (quantum bit) measurement involving an unknown quantum state and her half of an entangled pair of qubits shared with Bob. Once the measurement is complete, she communicates the results to Bob through a classical communication channel. With this information, Bob applies a specific quantum rotation to his qubit, determined by the outcome of Alice's measurement. This process effectively transfers the unknown quantum state from Alice to Bob without physically moving the original particle.

In quantum communication, information cannot be copied but can be transmitted using quantum teleportation, which involves both entanglement and classical communication. While measurements on entangled particles are correlated, the specific outcomes are random. This randomness means observers cannot control or predict the results to send meaningful information. The correlation becomes apparent only when results are compared after the fact. In conclusion, quantum mechanics dictates that entanglement cannot be used to transmit information faster than light. Any attempt to communicate using entangled particles requires classical communication channels to exchange measurement results, which are limited by the speed of light. When one of the entangled particles is measured, its state is randomly determined, collapsing the wave function of the system into a definite state. This process does not convey any information to the distant observer because the outcome cannot be controlled. To understand the correlation in the outcomes of entangled particles, observers must rely on classical communication, which inherently cannot achieve instantaneity due to the constraints of the speed of light.

Quantum entanglement is used for communication regardless, however classical channels are needed, so even though we're faster than before in our classical world via quantum, we're still stuck with the limit of the speed of light.

The Future of Interstellar Communication

While quantum entanglement cannot deliver an ansible for interstellar communication, it continues to inspire innovations in other areas. Quantum technologies promise advancements in computing and secure communications, leveraging the unique properties of quantum states. However, when it comes to reaching out across the stars, we must rely on different approaches for now.

Technologies like laser communication systems and radio waves, though limited by the speed of light, remain our best tools for bridging the cosmic expanse [NASA, 2024]. These methods require us to think creatively about how to communicate effectively across the voids of space, managing the delays and challenges inherent in such vast distances.

Embracing the Boundaries of Physics

The dream of the ansible represents our desire to transcend the limitations imposed by the cosmos. While entanglement remains a marvel of quantum mechanics, it is not the key to instantaneous interstellar communication. Instead, it highlights the beauty and complexity of the universe, urging us to explore and understand its fundamental laws.

As we continue our quest to reach the stars, we must embrace the challenges and work within the constraints of physics to develop new solutions. The journey to communicate across the universe is as much about innovation and discovery as it is about accepting and understanding the profound rules that govern our reality.

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Arya Lal Gonullu is a student of Theoretical Physics in her penultimate year at King's College London. She aspires to work as a theoretical physicist to pursue her fascination with the universe by constructing new theories to gain an understanding of the unknown.

She has been active in the Global Society of Young Physicists since early 2022 where she is Chief Scientific Officer and has led work in their Research Mentorship Program (RMP) and specifically in quantum mechanics. Prior to King's she took part in the Quantum Cryptography School for Young Students at the University of Waterloo, Canada.

Arya was a Teaching Assistant in our fifth Royal Institution *Skateboards to Starships* workshop - as reported in Principium 45 May 2024 (i4is.org/principium-45).

Long Life and the Longest Journey

Musings on life extension for world ship missions

Matthew Lehmitz

Effectively doubling human lifespan implies changes in every facet of human existence, from initially reducing the death rate to economic shifts in long term investing to changes in medical costs and planning. Astronautically it could mean health improvements for long duration spaceflight and possibly reducing astronaut physical deterioration.
In the interstellar context it could even make fast Worldship journeys to the nearest star systems fit into two generations with children born enroute, and reaching the destination in later life, having known their parents who started the journey.
This is the first of a planned series considering the implications of life extension for world ship missions. References are at the end.

Rotating Worldship imagined by Michel Lemontagne

Going to the stars is a long journey. Just getting to the moon in 1969 was a three day trip either way. While technologies continue to improve and we may well be able to go faster in the future it is still going to take a very long time. Faster than light travel like that seen on Star Trek is a fantastic technology for storytelling. Allowing the cosmos to be visited and explored in a reasonable span of time. Sadly, it remains only fiction. While there are some physics theories that suggest it may be possible, there is nothing foreseeable that will make the dream of FTL a reality. Given our current understanding even the nearest star will only be reached in time spans measured in centuries at any kind of acceleration and deceleration that humans can tolerate.
So how do we get humans to other worlds then? Humans don't live and work for centuries. A generous figure for human productivity would put it at a mere 60 years for a given person if they start in their teens and continuously work until their 70s. After that we have no working crew to carry on the voyage. A number of solutions have been suggested such as stasis chambers (Bradford J 2024). Perhaps chief among these alternatives though is the generation ship.

The generation ship is a concept where people build entire civilizations on board massive vessels capable of carrying people, and all the things they require, across the vast emptiness between the stars. Given that the Earth itself is, in effect, a spaceship and recycles almost everything indefinitely this isn't outside the realm of feasibility. You get multiple generations to replace the ones that came before. Examples in fiction include Robert Heinlein's novel "Orphans of the Sky" and Disney's film "Wall-E". Much has been written about them and I won't belabor the idea here. As popular and widely used as this idea is, it has some aspects that require additional consideration. One of the most important is generational turnover. Whether because reproduction is too fast, focus on the mission is lost, resources are pressured, people aren't breeding enough, vital skills are diluted etc there are myriad potential issues and concerns as the generations pass. One way to mitigate these is to have people live longer and healthier. This fundamentally alters the timetables and how we think about this issue.

Significantly extending lifespan is something that is already happening. Average human life expectancy has increased by nearly double in the last few centuries in the developed world (Bengtsson T 2006). Several developments in recent research papers regarding aging such as (Young S 2021) and the recent announcement of a new longevity X-Prize (XPRIZE Healthspan) suggest even greater healthspan increases are on the horizon. This makes it a good time to think about how life extension might work on a generation ship. What problems it might address and challenges it could create.

It should be noted that in this work I am going to use the term healthspan much more than lifespan. Extending life is a key goal but if that life is not healthy and vigorous it may not be as desirable. Nor would it provide many of the benefits both to the individual and society that we are looking for. So we want to extend not just life but health and vigor.

For this exploration we will be looking at extending the healthspan to be effectively twice as long as it currently stands. This expands the functional age by around 60 years, producing individuals who can work from their teens until their 140s with a typical productive and active span of about 120 years. We assume here that the individuals otherwise follow a normal human aging path growing to maturity around age 20 and peaking sometime before thirty but with a vastly slower rate of decline from there. The interesting impacts that this has will be examined in segments as we go along looking at different aspects of human experience and activity. Segments will be divided but there will necessarily be some topical overlap as all human activity is inextricably linked between various parts of existence and action.

Economics is a good place to start. There are any number of economic systems that might exist on future generation ships depending on how the people on that particular mission choose to set up their society. Those systems might shift or be intentionally changed along the way for a variety of reasons. However, many of the economic effects of much longer healthspans are fairly general and would apply across many systems as they are borne of fundamental needs and functions.

Let's consider the idea of retirement. Traditionally people retire because they are getting older. Historically this represented a point when they were becoming so damaged from age that they were unable to work. As life quality and healthspan improvements have continued there has been some chance to take a few years off toward the end of life to also enjoy what are known as the 'golden years' but they still represent that issue of aging. This is reflected quite distinctly in the official retirement age of many governments and organizations.

Most militaries have age limits for service for example. More and more we see people choosing to stop earlier and may switch careers during their lives finishing their first career out of choice rather than necessity or the vagaries of time.

There will also be others who will choose to stay with a career for far longer and become extremely adept at it. Having so many more healthy years to work with they would develop levels of competence that would be significantly higher than current career professionals are able to attain. Having many such supremely capable individuals in a field would lead to much faster and more efficient productivity in whatever domain they were working in. The outcomes of such efficiencies would be very valuable and would enable much greater overall productivity.

Hyper productivity remains probable even if an individual should choose to shift careers however. Over the course of many extra years an individual could become expert in not just one or two additional fields but several. Especially as the experience and knowledge build on one another. Related areas would be complementary and the interdisciplinary skills and knowledge would be greater than their individual parts. This would allow for levels of competence and creativity that are rarely seen in the current paradigm. Such capabilities would be all the more impressive as individuals retained their youthful state longer. With stronger bodies and healthier minds people could more readily grasp and integrate new subjects. In the end then we see roughly the same outcome.

In the case of a world ship this kind of enhanced productivity and efficiency would allow for fewer people to be needed to take care of specific tasks or work in a particular field. A crucial capacity given the limited space and resources available.

But then what of the next generation? Even with doubled lifespans population growth and reproduction will still be moving along. It will need to be controlled somewhat on a world ship to ensure it does not grow or shrink in such a way that it threatens resource stability so there will always be a next generation ready to take its place. We will discuss this at greater length in a later segment. Following generations will have a barrier to taking on the top roles within the society and this will include any position at the top of companies, boards, research institutions and more. Such positions are the goal of many aspiring younger individuals and in general become available chiefly as previous generations begin to retire at the end of their careers. While there will be some turnover due to the decision of some individuals to change careers and seek other interests, many will be filled by a single individual for extensive periods lasting many decades. The younger generations will have a long time to wait to take their turn at opportunities that are retained by their elders. Such a situation is likely to cause a great deal of consternation over time. Even in the shorter lifespans we see in modern societies there is a degree of restlessness by younger generations and a desire to disrupt the system toward a newer paradigm that emerges with novel perspectives. This causes a degree of frustration and such a frustration would be enhanced by many more decades of enforced patience. It is likely that there would be a greater degree of younger noncompliance over time especially if multiple generations build up behind this wall. The economic impacts would be significant as we would see people taking a variety of actions. Some would choose not to work or work as little as they could get away with. This is a natural choice by some individuals in any society but would be magnified in a case where the potential for growth and promotion were very limited. Others would choose to try and change the system by political means. What this would look like in practice would depend on the politics of the society but would ultimately result in various forms of disruption to the economic system as various laws and reforms were enacted. Others still would look to less savory means of achievement seeking to find means of sabotage or intrigue to finagle their way to the top. The majority though, would likely fall in and do their jobs and wait it out. After all, in this scenario they also have much longer healthy lifespans and can afford to bide their time. Again none of these are new or surprising outcomes. They reflect only a much higher degree of what we normally see in existing society. On a world ship though they are not likely to be contained and any event that transpires like this will doubtless have much more severe ripples through the economy. After all, there is nowhere to go. There is no chance to take the pressure off of the system and if it is disrupted it isn't a local failure. The entire economic and productive system is affected.

Wealth accumulation and disparity is something to consider. Whether that wealth takes the form of currency, influence, power, objects, or simply knowledge would become significantly greater between individuals and generations. With existing lifetimes a few people can accumulate vast wealth within a society. For the greatest accumulation this does require large societies that we will not see on a generation ship. The number of people will be lower and thus capital accumulation will be smaller though this may not affect knowledge as much. With so much additional healthy time though the standout individuals would continue to build up what they possess. Such disparities would persist much longer as well without turnover so even families might notice greater separation in this area. The economic effects would see power shifts within the system regardless of how it was set up on paper.

This would not pull the wealthy as far out of the normal economy nor society as we see in existing systems. With only a small population to begin with there would be little room for a stock market to function to a significant degree though ownership in companies and stakes may be part of wealth. Nor the society separate as completely because of their necessary interdependence. Those who hold the wealth are going to be working with those who have less in order to make sure the air continues to circulate.

This leads us to think about economic systems. As I will discuss in more detail later the social structure will likely be much like that of existing space missions at least to start. This means that we are looking at shared resources for the most part. Individuals will have their own small cache of private goods and currency but these will be limited due to space and mass restrictions. This will likely last longer with long lived individuals as those initially chosen will be highly dedicated to the mission and its goals. Their economic interests will dovetail with that and will likely be less on personal wealth accumulation as boarding a world ship and launching off into the universe is not the best way to get rich. This attitude and the more rigid economic structure that accompanies it will likely persist for many generations at least. The longer lifespan and overlap of healthy and productive years means that there will be a greater sense of peer group over multi-decade spans. The blurring of generational lines gives both more time and more connection to pass on traditions to the young.

There is more in economics but as it continues to further overlap we will get to additional elements as we push on with other topics. There is perhaps no greater overlap than society with the economic choices and prerogatives of a society and that is where we will travel next.

At this point we've got a good overview of the economic conditions that our long-lived crew will see. It is the first of many factors that we will look at as this series progresses. The next paper will focus on social structures, interpersonal interactions and family.

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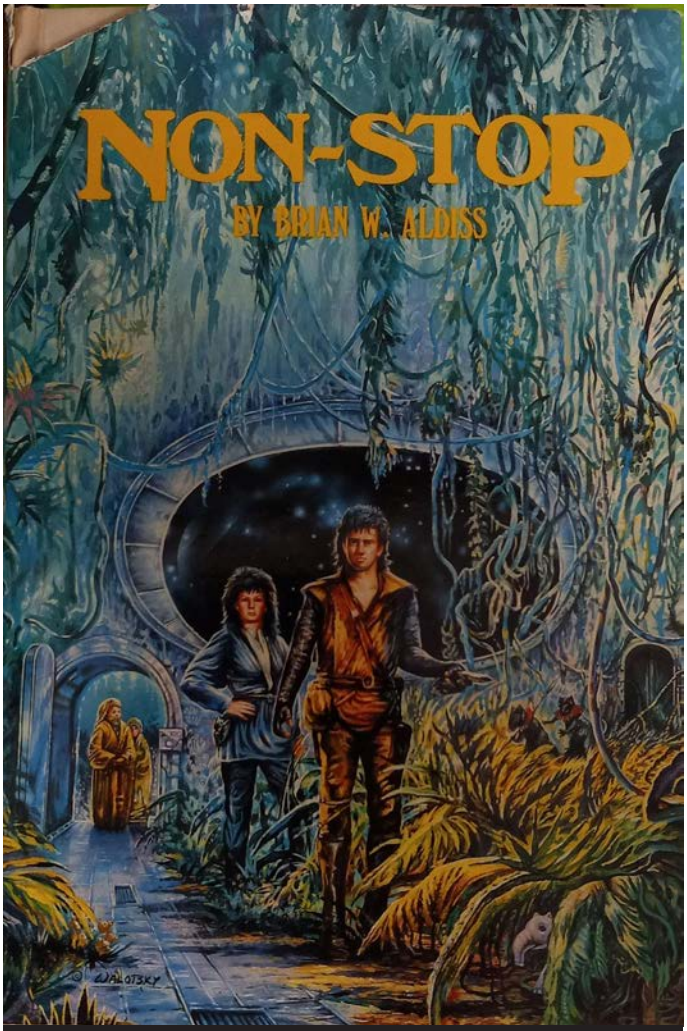

A Worldship run wild. Early UK cover of *Non-Stop*, Brian Aldiss, Faber and Faber, 1958

About the Author

Matthew Lehmitz is a creative individual with a diverse background. Highlights include stints as an Analog Astronaut, Drone Research Pilot, and Wyoming Research Scholar. Matthew has also worked on the PlantSat project. Matthew has travelled extensively in more than a dozen countries and every state in the United States. As a futurist and transhumanist Matthew has a strong interest in how we will build a better tomorrow. This is part of the drive to explore and learn both around the world and in the realm of ideas.

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Parnika Singh & John Davies report on recent developments in interstellar studies

First European Interstellar Symposium

The University of Luxembourg's First European Interstellar Symposium will take place in December 2024. The Symposium and an Interstellar Art Show will be held at the European Convention Center in Luxembourg City, Luxembourg. This symposium will feature many leading voices in space exploration, culture, and more.

The theme for the event is Building Our Home Among the Stars. Thus, there will be a particular focus on potential near-term demonstrations and missions that align with the technologies and systems required for future interstellar travel. This European Interstellar Symposium aims to bring together a multidisciplinary community dedicated to interstellar travel - an unprecedented event in the development of interstellar studies and an opportunity to hear, see and meet world leaders working in all aspects of the subject. More informationcan be found on the IRG website: irg.space/first-european-interstellar-symposium.

LED Sails

A recent preprint by Chang Shen "*Travel In Deep Dark Space with Giant LED Sail* (engrxiv.org/preprint/view/3692/6566) discusses the scientific feasibility of sending spacecraft to a neighboring star beyond our solar system using a giant LED sail. Shen first explains the LED sail concept, which is very similar to a light sail, except with an attached LED light source. He compares the efficiency of this propulsion mechanism to nuclear propulsion and traditional chemical propulsion, noting its promising nature. Shen then creates a model LED sail probe for a mission to Proxima Centauri. Based on this design, the paper estimates the travel time for various velocities, acceleration, and other parameters of the probe. He derives equations for calculating the amount of light and thus power needed for the sail, finding that LED sails could be feasible with a few technological advancements.

Making Independent Spacecraft

Junwei Zhang and Liangqing Lyu recently published a paper *A Spacecraft Onboard Autonomous Task Scheduling Method Based on Hierarchical Task Network-Timeline* (www.mdpi.com/2226-4310/11/5/350). To address the inherent challenges of deep space exploration – such as communication delays and the unpredictability of spacecraft environments – Zhang and Lyu focus on enhancing spacecraft adaptability and autonomy, which are essential for Autonomous Space Scientific Exploration. A pivotal aspect of this undertaking is the advancement of spacecraft task scheduling, which is integral to increasing spacecraft autonomy.

Current research in this domain predominantly revolves around mission timing planning and is primarily executed from ground stations. However, these plans often lack the granularity required for direct implementation by spacecraft. In response, Zhang and Lyu propose an innovative approach to augment spacecraft autonomy, introducing a method that articulately describes mission objectives and resource information. They design a novel hierarchical task network-timeline (HTN-T) algorithm that addresses time constraints through horizontal and vertical expansions, building upon the resolution of logical constraints found in conventional planning methods. Furthermore, they introduce a priority-based strategy for resolving resource conflicts in spacecraft tasks.

Strategies for Interstellar Exploration

Recently, Johannes Lebert, Martin Dziura, and i4is's own Andreas M Hein published a paper titled *Optimal strategies for the exploration of nearby stars* (www.sciencedirect.com/science/article/pii/S0273117724003351). Despite various proposals for interstellar probe concepts and relevant technologies, there is a lack of extensive literature on viable exploration strategies for journeys beyond single star systems. The authors thus present optimal strategies for the exploration of a large number of nearby stars. After extensively discussing and defining variables and parameters, the paper uses computer simulations to determine the optimal route. They provide a detailed breakdown of the algorithm used and how it works, as well as an analysis of the optimization results.

As one would expect from intuition, the mission return for a given mission duration increases with the probe number. For a certain range (number of probes smaller than 256) and given mission duration one finds that the number of explored stars, J1, scales with mission duration, J2, and probe number m according to $J1 \sim J2m^{0.66}$, which provides an initial guidance for future interstellar mission design. Furthermore, the routes and selection of stars vary depending on the number of probes used: When conducting missions with many probes, stars close to the Solar System are given more focus. On the other hand, missions with a few probes include more distant stars to facilitate shorter transfers along the route.

Thermal Conversion Technology

A paper titled *Comparative Analysis of Thermal Conversion Technologies for Deep Space Missions* (ntrs.nasa.gov/api/citations/20220002940/downloads/2022%20NETS%20paper%20v4%20-%20Copy.pdf) by Sabah K Bux et al was recently released by NASA. It analyses recent innovations and improvements to thermal energy technologies showing potential increases in radioisotope system efficiencies from current measurements of ~5-7% to efficiencies upwards of 20%. Radioisotope power systems (RPS) utilizing Plutonium-238 as a heat source for thermal-to-electric energy conversion are well established and have been used as a reliable power source for NASA's deep space missions for sixty years. The report surveys and ranks recent, innovative thermal-to-electric energy conversion research technologies. Technologies being developed at universities and in industry are compared with respect to thermal conversion methods and relevant key performance parameters. It identifies key performance parameters such as system-specific power per kg, efficiency, power output, technology readiness level, and system mass. It then utilizes an Analytical Hierarchy Process (AHP) to create weighted values for each evaluation criterion. The AHP tables combined with decision matrices create table scores for past, present, and potential future propulsion systems.

Ethical Considerations of Interstellar Colonization

Douglas Youvan recently published a paper titled *Ethical and Practical Considerations for Populating a Distant Exoplanet: AI and Robotic Support vs. AI and Humanity* (dx.doi.org/10.13140/RG.2.2.10704.93444) in which he examines the ethical and practical considerations involved in choosing between two colonization strategies: AI and robotic support only, versus a combined approach involving both AI and humanity. The decision between these strategies carries profound implications for the efficiency, sustainability, and ethical integrity of such missions. By exploring key factors such as operational efficiency, risk management, resource allocation, ethical considerations, and innovation potential, Youvan strives to provide a balanced analysis that informs policymakers, scientists, and ethicists. This comprehensive examination is crucial for ensuring that future exoplanet exploration – and eventually colonization – efforts are not only technically feasible but also ethically sound and sustainable.

Is CNEOS14 Interstellar?

In his recent paper *How likely is the interstellar origin of CNEOS14? On the reliability of the CNEOS database* (arxiv.org/abs/2405.17219) Hector Socas-Navarro investigates the likelihood that the CNEOS 2014-01-08 superbolide (CNEOS14) was caused by an interstellar object. This issue has remained controversial due to a lack of information on the capabilities of the classified satellite sensors that recorded the fireball. Navarro critically evaluates previous studies, specifically addressing the reliability of the CNEOS database and the associated measurement uncertainties. With proper statistical analysis of existing data and the addition of a relevant new event (the 2024 Iberian superbolide), he disproves some claims in previous work, such as a) the existence of a purported correlation between CNEOS velocity errors and bolide speed; b) the presence of large velocity errors of 10-15 km/s in the CNEOS database; and c) the assertion that CNEOS14 is most likely a solar system object with a hyperbolic trajectory due to measurement errors.

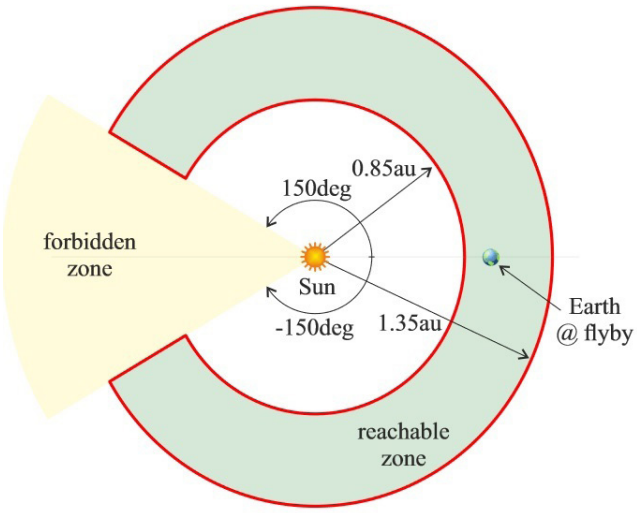
He presents a quantitative estimate of the probability that CNEOS14 is interstellar; if its measurement errors are drawn from the same underlying distribution as the 18 calibrated events, then the probability that CNEOS14 is interstellar is 94.1%. This probability is lower than the 99.7% confidence (3-sigma) generally required to claim a scientific discovery. However, it is sufficiently high to be considered significant and, by far, the most likely explanation for the currently available empirical evidence.

Proxima b's Weather

Recently a paper titled *MHD simulations of the space weather in Proxima b: Habitability conditions and radio emission* (arxiv.org/abs/2405.19116) was published by L Peña-Moñino et al. The authors aim at characterizing the magneto-plasma environment and thus the habitability of the Earth-like planet Proxima b, which is inside the habitable zone of its host M-dwarf star Proxima, when it is subject to average, calm space weather conditions. They also examine more extreme space weather conditions such as a CME-like event [1]. The role of the stellar wind and planetary magnetic field, and their mutual orientation are examined, and it is found that if Proxima b has a magnetosphere similar to or larger in size than the Earth's, it is sufficiently protected from stellar wind and extreme space weather. This thus implies that Proxima b could perhaps be a habitable planet. The authors also study the radio emissions from Proxima b which are quite high, thereby supporting the idea that Proxima b has a large magnetosphere as large magnetospheres cause greater radio emission. However, the authors find that the radio emissions vary quite a bit – which is rather surprising.

Heliocentric Solar Sail Flyby

Giovanni Mengali et al recently published a paper titled *Solar Sail Optimal Performance in Heliocentric Nodal Flyby Missions* (doi.org/10.3390/aerospace11060427). The authors investigate the optimal performance of a solar sail-based spacecraft in performing two-dimensional heliocentric transfers to inertial points on the ecliptic that lie within an assigned annular region centered in the Sun.
Similar to ESA's Comet Interceptor mission, this type of transfer concept could prove useful for intercepting a potential celestial body, such as a long-period comet or suspected interstellar object. It also provides an opportunity to test the capabilities of solar sails for future, longer-range missions into interstellar space. The heliocentric dynamics of the solar sail are described using the classical two-body model, assuming the spacecraft starts from Earth orbit (assumed circular), and an ideal force model to express the sail thrust vector. Numerical simulation results show that solar sails are an attractive option to realize these heliocentric transfers as they increase launch flexibility and avoid maneuvers requiring sharp changes in velocity.



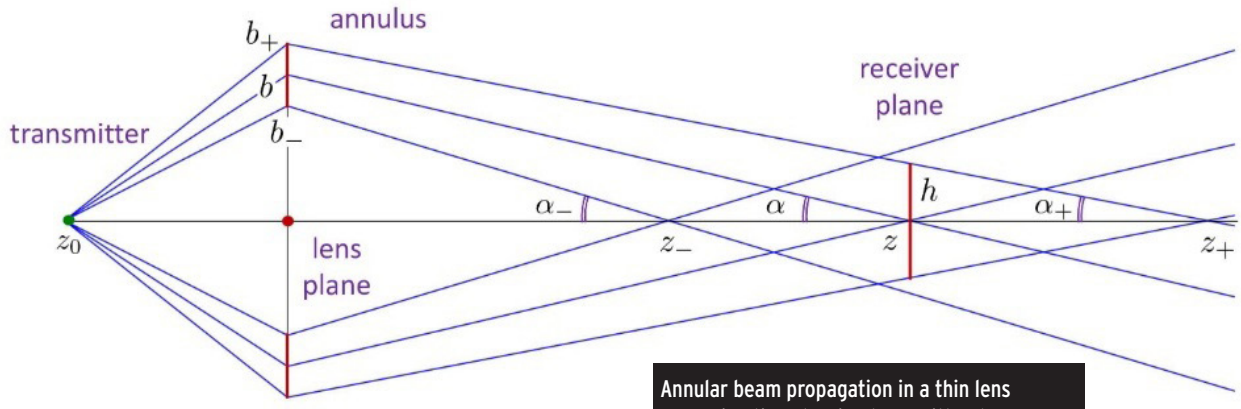
Heliocentric Solar Sail Flyby

Scheme of the reachable zone and geometric constraints on the radial distance and offset angle value.
Credit (image and caption): Mengali Figure 1.

[1] A coronal mass ejection, en.wikipedia.org/wiki/Coronal_mass_ejection and solar.physics.montana.edu/press/faq.html

The Search for Interstellar Transmissions

Recently, Slava G Turyshev of JPL published a paper titled *Search for gravitationally lensed interstellar transmissions* (arxiv.org/abs/2404.01201). As things stand today, interstellar power transmission is very challenging. Even for a collimated laser beam, the large distances involved result in very little energy received. To try and support such transmission, Turyshev explores the possibility of facilitating interstellar power transmissions with gravitational lensing. It examines axially symmetric lensing configurations where the transmitter, lens, and receiver are nearly aligned. With the transmitter positioned in the focal region of the lens, it investigates the caustic (in the optics sense) formed by a diffraction-limited beam of light emitted by the transmitter and evaluates the impact of the lens's point spread function (PSF) on the received beam.



Annular beam propagation in a thin lens approximation showing transmitter, lens, annulus, and receiver plane.
Credit: (image and caption): Turyshev Fig 1

Through this, the power delivered to a receiver at interstellar distances is estimated, the major noise sources are evaluated, and the detection sensitivity in both the noise- and signal-dominated regimes is determined. Considering realistic assumptions about the transmitter's performance, various signal detection strategies enhanced by the spatial broadening of the received beam are suggested – a result of the PSF from the transmitting lens. Turyshev finds that detection of the lensed optical signals from nearby stars may be done by relying on established optical engineering technologies. Furthermore, a network of astronomical facilities capable of observations in multiple narrow spectral bands will benefit the search. These results support the feasibility of interstellar power transmission via gravitational lensing, directly contributing to the ongoing optical SETI efforts.

Quantum Receiver for Interstellar Communications

Douglas C Youvan recently published a preprint to ResearchGate titled Development of a *Simplified Quantum Receiver for Theoretical Interstellar Communication: Design and Feasibility Study* (dx.doi.org/10.13140/RG.2.2.22662.38728). In the quest to bridge interstellar distances, the field of quantum communication offers promising new avenues. This study aims to create a practical, yet innovative quantum receiver using commercially available components. It explores the integration of fundamental quantum mechanics principles such as entanglement and superposition with standard technological hardware. The focus is on designing a receiver that is both financially feasible and technologically accessible, thereby democratizing the advanced field of quantum communication for a broader audience. Youvan details the component selection, assembly procedures, and cost analysis, providing a foundational blueprint for researchers and enthusiasts interested in the potential of interstellar quantum communication. He concludes by noting avenues for further exploration and experimentation in a field that merges theoretical physics with practical application, paving the way for future advancements in interstellar communication technologies.

An Overview of Reflective and Transmissive Solar Sails

A preprint titled *Reflective and transmissive solar sails: Dynamics, flight regimes and applications* (doi.org/10.1016/j.actaastro.2024.04.032) was recently published by Samuel M Thompson et al. Refractive and diffractive solar sails have been cited to yield benefits in both performance and utility over reflective sails, but their range of viable flight regimes and future applications have not been fully explored. In this paper, a flight model is developed to test and compare these transmissive sail designs under realistic conditions. Raw performance is translated into tangible flight characteristics within a range of flight regimes, such as rate change of orbital energy and minimum operational altitude, and used to make comparisons with reflective sails and contemporary thrusters. Additionally, the sensitivity of these flight characteristics to certain orbital parameters when operating under either a locally optimal or simplified Sun-pointing steering law is explored. The developed flight model focuses on solar radiation pressure, atmospheric drag, and the effects of eclipse and orbital precession; locally optimal steering laws are numerically generated for every flight regime using a ray tracing-derived performance sensitivity profile. Relative to an idealized reflective sail, the paper finds the sensitivity of transmissive sail performance to be lower for altitude, but higher for orbital inclination. Additionally, high-performance transmissive sail designs outperform idealized reflective ones in every flight regime.

Why X-Ray Propelled Sails Can't Work

Paul Gilster of Centauri Dreams recently reported Jim Benford on *Why X-Rays Can't Push Interstellar Sails* (www.centauri-dreams.org/2024/06/07/why-x-rays-cant-push-interstellar-sails/). Per Plank's equation, x-ray photons are much more energetic than those of visual light. However, this means that if they come in normal to the surface [ie striking the sail head-on], they ionize atoms, damaging the lattice of the material. Thus, the cross-section of the sail must be at a slight angle to the beam, not perpendicular to it, for the X-rays to reflect. That's hugely inefficient. Grazing incidence means that only the slight transverse component of the photon velocity vector is reversed, leaving the far larger axial component almost unchanged. Little energy is transferred to the inclined sail, and that drives it sideways to the beam, not antiparallel to it, as reflected photons do when they incident normally. So, the sail is accelerated very little in the direction of the X-ray beam.

Detecting Warp Drive Emissions

Recently, Erik W Lentz and Ryan C Felton published a preprint titled *Motivating Emissions from Positive Energy Warp Bubbles* (arxiv.org/abs/2405.19381). Recent research has proposed that advanced propulsion mechanisms such as warp drives are more physically feasible than previously thought, using positive energy sources potentially sourced by known classical physics. Motivated by this, the authors hypothesize that an advanced interplanetary or interstellar civilization using warp drives at sub-luminal or super-luminal speeds will broadcast detectable emissions of their travels. These technosignatures would be of significant astronomical, physical, and technological interest. This paper seeks to motivate signatures from warp drive emissions due to intrinsic and extrinsic processes across several messenger types (electromagnetic, particle, and gravitational) and proposes a research program to simulate such emissions in sufficient detail to search for their signatures through coordinated analyses across multiple observatories.

Attitude Control for Solar Sails

Recently, Toshihiro Chujo et al published a paper titled *Integrated attitude–orbit control of solar sail with single-axis gimbal mechanism* (doi.org/10.1007/s42064-023-0192-2). The authors propose a new attitude control method for solar sails using a single-axis gimbal mechanism and three-axis reaction wheels. The gimbal angle is varied to change the geometrical relationship between the force due to solar radiation pressure (SRP) and the center of mass of the spacecraft, such that the disturbance torque is minimized during attitude maintenance for orbit control. Attitude maneuver and maintenance are performed by the reaction wheels based on the quaternion feedback control method. Even if angular momentum accumulates on the reaction wheels due to modeling error, it can also be unloaded by using the gimbal to produce suitable torque due to SRP. The authors also analyze the attitude motion under the reaction wheel control by linearizing the equations of motion around the equilibrium point. Furthermore, they construct an integrated attitude–orbit control method and verify its validity in integrated attitude–orbit control simulations.

Microwave Electrothermal Propulsion

Rhea R Mulki and Efstratios L Ntantis recently published a paper titled *Study of Microwave Electrothermal Propulsion System* (www.researchgate.net/publication/378802860_Study_of_microwave_electrothermal_propulsion_system). With beam powered propulsion growing to be one of the most promising alternative propulsion mechanisms for interstellar missions, a variety of different types have emerged. Among these, electrothermal thrusters stand out, using electrical energy to heat propellant and generate thrust, with variants like resistojets and arcjets currently in use. One advanced iteration, the Microwave Electrothermal Thruster (MET), replaces electric arcs or heaters with plasma for propellant heating, addressing the limitations of older designs. MET performs better by converting a resonant cavity into a heating chamber and employing microwaves to induce plasma heating. A Bogazici University study tested a MET prototype using Helium gas, measuring chamber parameters, mass flow rate, power levels, thrust, and specific impulse (Isp). At 500 W power, they achieved an Isp of 347 seconds and 266 mN thrust – remarkable considering the newness of this technology. This experimentation showcases the potential of MET technology in achieving high-efficiency propulsion for future spacecraft.

Testing Electric Sails

Recently, a paper titled *Electric Sail Test Cube–Lunar Nanospacecraft, ESTCube-LuNa: Solar Wind Propulsion Demonstration Mission Concept* (www.mdpi.com/2226-4310/11/3/230) was published by Andris Slavinskis et al. The electric solar wind sail, or E-sail, is a propellant-less interplanetary propulsion system concept. By deflecting solar wind particles off their original course, it can generate a propulsive effect with nothing more than an electric charge. The high-voltage charge is applied to one or multiple centrifugally deployed hair-thin tethers, around which an electrostatic sheath is created. Electron emitters are required to compensate for the electron current gathered by the tether. The electric sail can also be utilized in low Earth orbit when passing through the ionosphere, where it serves as a plasma brake for deorbiting—several missions have been dedicated to LEO demonstration. The authors propose the ESTCube-LuNa mission concept and the preliminary cubesat design to be launched into the Moon's orbit, where the solar wind is uninterrupted, except for the lunar wake and when the Moon is in the Earth's magnetosphere. They introduce E-sail demonstration experiments and the preliminary payload design, along with E-sail thrust validation and environment characterization methods, a cis-lunar cubesat platform solution, and an early concept of operations. The proposed lunar nano spacecraft concept is designed without a deep space network, typically used for lunar and deep space operations. Instead, radio telescopes are being repurposed for communications and radio frequency ranging, and celestial optical navigation is developed for onboard orbit determination.

Wavefronts from Warp Drives

A paper titled *What no one has seen before: gravitational waveforms from warp drive collapse* (arxiv.org/abs/2406.02466) was recently published by Katy Clough et al. Despite originating in science fiction, warp drives have a concrete description in general relativity, with Alcubierre first proposing a spacetime metric that supported faster-than-light travel. Whilst there are numerous practical barriers to their implementation in real life, including a requirement for negative energy, computationally, one can simulate their evolution in time given an equation of state describing the matter. In this work, the signatures arising from a warp drive "containment failure" are studied, assuming a stiff equation of state for the fluid. The emitted gravitational-wave signal and the energy fluxes of the fluid are computed. Apart from its rather speculative application to the search for extraterrestrial life in gravitational-wave detector data, this work is interesting as a study of the dynamical evolution and stability of spacetimes that violate the null energy condition. It highlights the importance of exploring strange new spacetimes, to simulate what no one has seen before.

Solar Wind

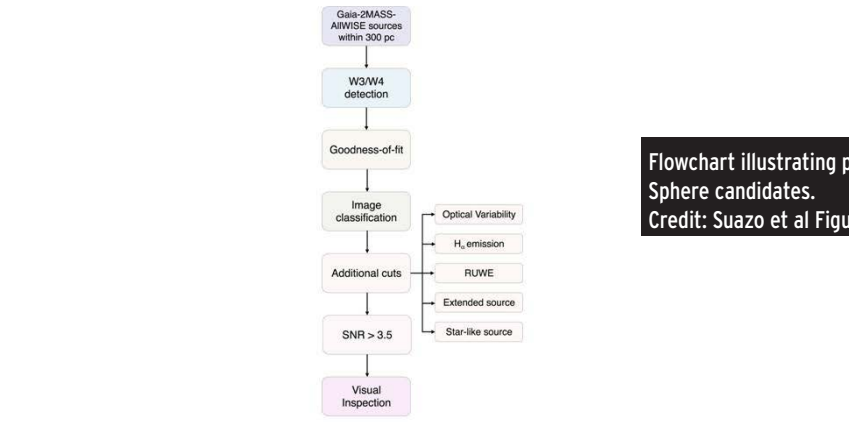
Paul Gilster of Centauri Dreams recently published an article titled *A Shifting, Seething Solar Wind* (www.centauri-dreams.org/2024/05/31/a-shifting-seething-solar-wind). In search of ever-higher velocities leaving the Solar System, solar wind provides an interesting option. This stream of charged plasma particles flowing outward from the Sun carves out the protective bubble of the heliosphere, and in doing so can generate 'winds' of more than 500 kilometers per second. This effect could be harnessed, perhaps by a magnetic sail that can create the field needed to interact with the wind, or an electric sail whose myriad tethers, held taut by rotation, create an electric field that repels protons and produces thrust. But similar to winds on Earth, solar wind is chaotic and treacherous, as likely to capsize the ship as to cause its sails to billow. It's gusty and turbulent, with velocities oscillating from well above 500 km/sec to well below this value. Exactly how it produces squalls in the form of coronal mass ejections or calmer flows is a topic under active study, which is where missions like Solar Orbiter come into play. However, if we can gain a deeper understanding of solar wind, it presents a veritable option for interstellar spacecraft.

Dyson Sphere Candidates

The search for extraterrestrial intelligence is currently being pursued using multiple techniques and in different wavelength bands. Dyson spheres, megastructures that could be constructed by advanced civilizations to harness the radiation energy of their host stars, represent a potential technosignature that in principle may be hiding in public data already collected as part of large astronomical surveys. In a recently published study by Matías Suazo et al titled *Project Hephaistos – II. Dyson sphere candidates from Gaia DR3, 2MASS, and WISE* (doi.org/10.1093/mnras/stae1186), a comprehensive search for partial Dyson spheres by analyzing optical and infrared observations from Gaia, 2MASS, and WISE is presented. The development of a pipeline that employs multiple filters to identify potential candidates and reject interlopers in a sample of five million objects is detailed, incorporating a convolutional neural network to help identify confusion in WISE data. Finally, the pipeline identifies seven candidates deserving of further analysis. These objects are all M-dwarfs, for which astrophysical phenomena cannot easily account for the observed infrared excess emission.

However, in their recently released preprint titled *Background Contamination of the Project Hephaistos Dyson Spheres Candidates* (arxiv.org/abs/2405.14921), Tongtian Ren et al argue that at least three of the seven candidates were contaminated by dust-obscured galaxies in the background. The authors suspect something similar is true for the remaining four candidates, but nothing has yet been confirmed.

Figure 1. Flowchart illustrating our pipeline to find DS candidates.



Flowchart illustrating pipeline to find Dyson Sphere candidates.
Credit: Suazo et al Figure 1.

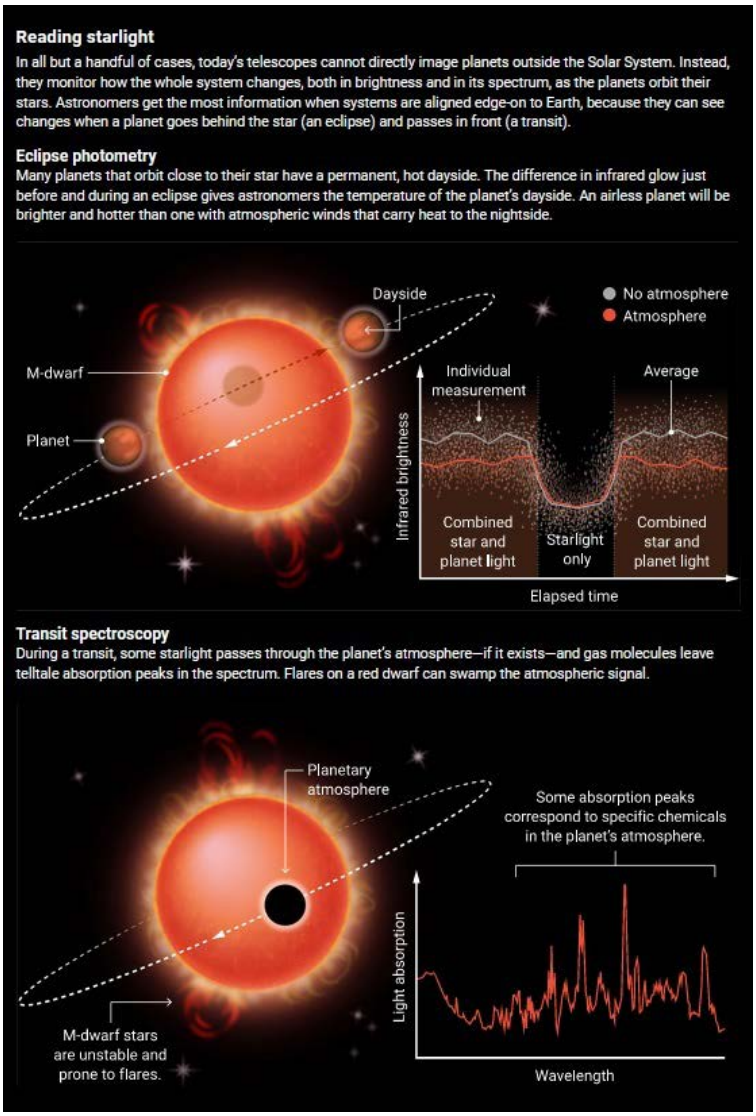
Mon Not R Astron Soc, Volume 531, Issue 1, June 2024, Pages 695–707, https://doi.org/10.1093/mnras/stae1186

Widening the search for another Earth

Science magazine reports that "The hunt for Earth-like planets has run into headwinds. Some astronomers are looking for signs of habitability on bigger worlds" see *No place like home* (www.science.org/content/article/could-super-earths-mini-neptunes-host-life-among-stars). Reporter Daniel Clery tells us –

> A working group advising NASA and the Space Telescope Science Institute (STScI), which operates JWST, is calling for a broad 500-hour study of 15 to 20 small rocky planets around various red dwarfs, to settle once and for all whether such planets can host atmospheres. "If we find nothing, it will be a disappointment, but it would feel good to have a definitive answer," says working group chair Seth Redfield of Wesleyan University.

So maybe we need to relax our criteria to include large rocky planets, Super Earths, and even mini-Neptunes with large oceans.



Credit: Science magazine, N Burgess

Clery quotes Charles Cockell, director of the Centre for Astrobiology at the University of Edinburgh "These are more speculative, and very different from the planetary body we do know has life. But any planet with the right conditions should be investigated." but points out that it's impossible to image such a planet with today's telescopes, which can directly image only the biggest, hottest planets in wide orbits that take them away from the star's dazzle but not true Earth twins—similar-size planets in Earth-like orbits around Sun-like stars.

This is a long (3,400 words) and interesting article and well worth a read for all interested in the perennial question "Are we alone?".

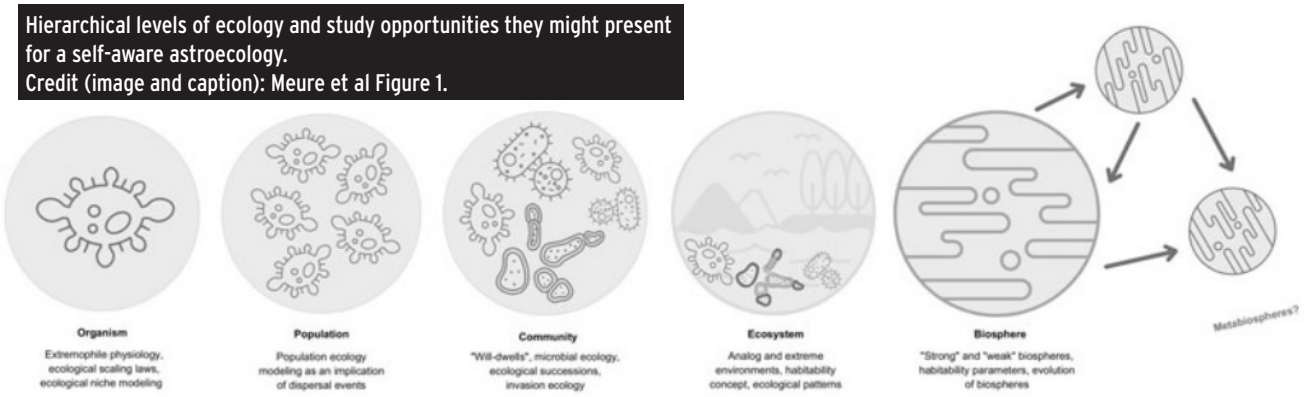
Bandwidth to the Stars

Interstellar communication by electromagnetic transmission (X-rays to VLF radio) is the only known way we we can use at the moment. In *Cosmic Channel Capacity: Extending the Shannon Limit to Universal Scales* (osf.io/preprints/osf/vjy3p) Logan Nye (Carnegie Mellon University, USA) looks at the basics of information theory, as defined by Claude Shannon in *A Mathematical Theory of Communication*, (en.wikipedia.org/wiki/A_Mathematical_Theory_of_Communication) in 1948 (elettronica.fauser.edu/shannon/shannon1948.pdf). In 44 pages of main text and 25 pages of appendices Logan Nye (www.logannye.io/) explores the Theoretical Foundations of Information Theory, Formulating a Cosmic Channel Capacity, Cosmic-Scale Information Transmission Scenarios, the implications for fundamental physics, observational and experimental prospects, cosmic-scale error correction and information preservation, the technological implications of the theory and considers where we might develop further based on the fundamentals.
This is a substantial thesis on a key subject, worthy of more detailed review possibly in a future issue of Principium.

Time for Ecology beyond Earth?

In *Astroecology: bridging the gap between ecology and astrobiology* Juliana Campos Meure, Jacob Haqq-Misra and Milton de Souza Mendonça Jr present an argument for astroecology, a merger of ecology and astrobiology. They suggest that organismal ecology provides ecological niche modelling, which can aid in evaluating the probability that Earth-like life would survive in extraterrestrial environments. They believe that understanding ecosystems by focusing on abiotic properties is also key to extrapolating from analogue environments on Earth to extraterrestrial ones. They identify a Roadmap which points to 'What Are the Processes on Other Types of Planets That Could Create Habitable Niches?'

Hierarchical levels of ecology and study opportunities they might present for a self-aware astroecology.
Credit (image and caption): Meure et al Figure 1.

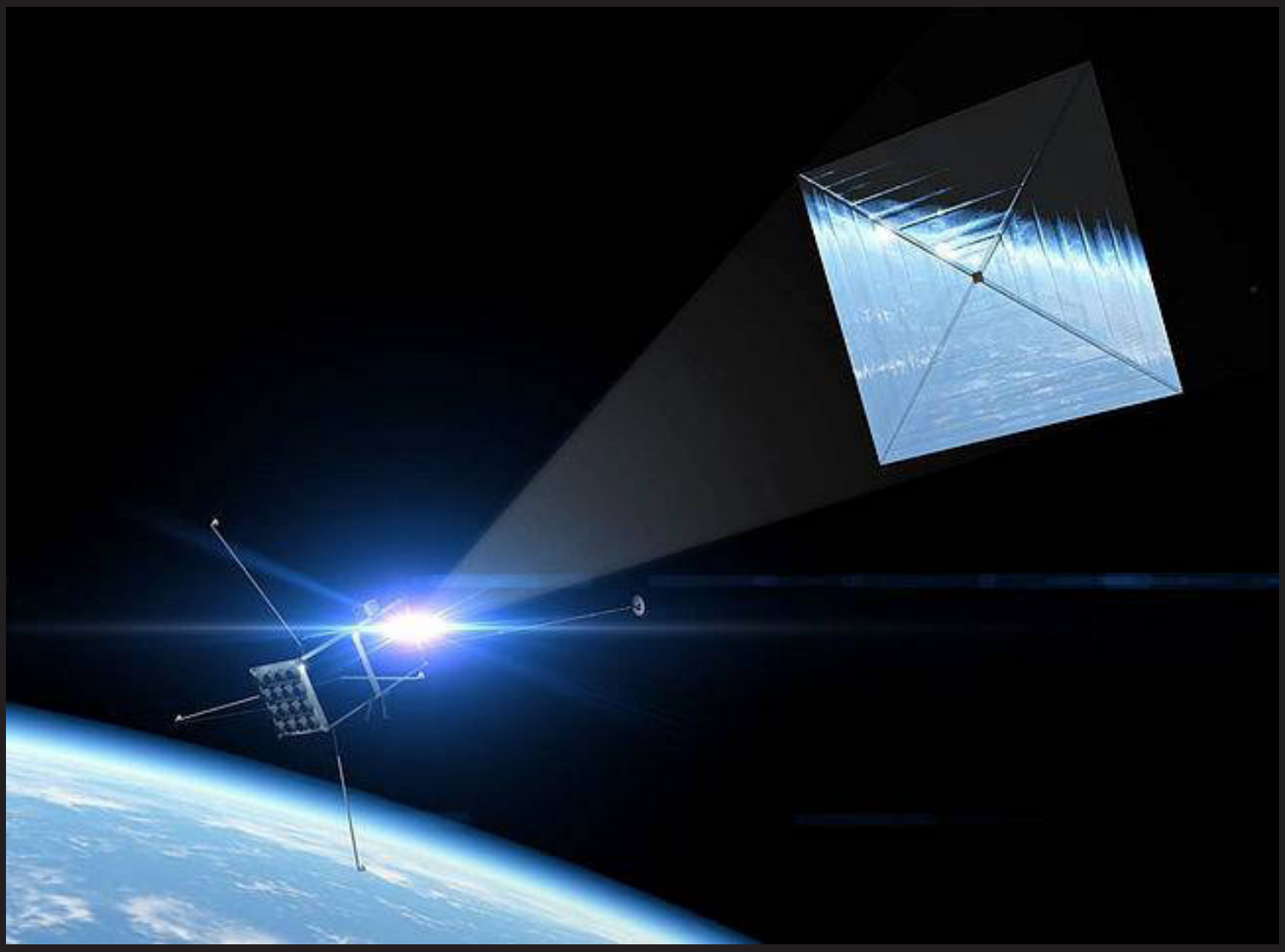


They hope their paper will encourage astrobiologists to take ecology consciously into account when studying the origin, evolution and distribution of life in the universe. New partnerships with ecologists, both in individual (astrobiologists and ecologists conducting studies together) and collective (astrobiology organizations working with ecology organisations) ways, should be established as the astrobiology community integrates one more discipline into this huge interdisciplinary field. Theoretical research in astroecology is just beginning, but they suggest it is also time to put these ideas into practice by conducting experimental astroecology in the laboratory and field campaigns – here on Earth and 'out there'.
They wonder if ecology may seem a little 'too close' for those who study planets that are light minutes to light year away but suggest we should seek new ways to look at Earth while we observe far beyond it.

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 membership scheme of the Initiative & Institute for Interstellar Studies (i4is) is building an active community of 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 to support our work and also get:

- members newsletters throughout the year
- member exclusive posts, videos and advice;
- advanced booking for special events; and
- opportunities to contribute directly to our work.

To find out more, see www.i4is.org/membership
Discounts for BIS members, seniors & full time students!

International Astronautical Congress IAC24

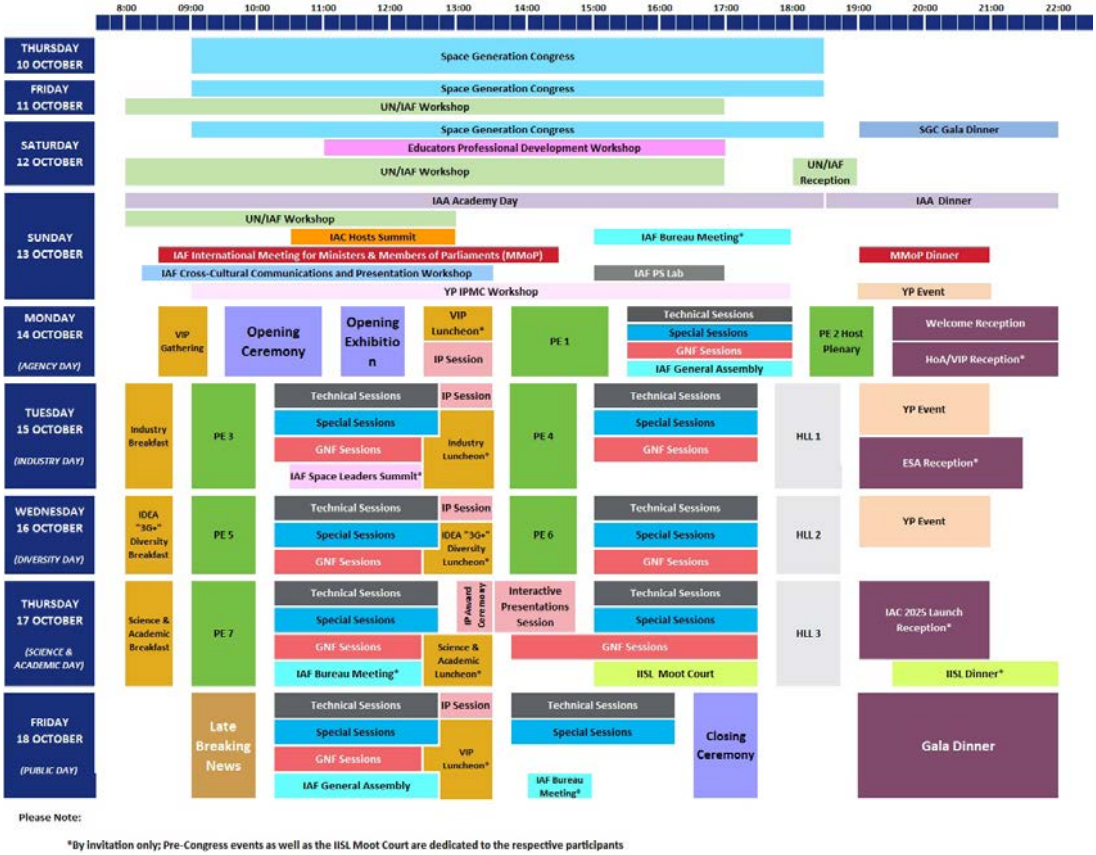
The Interstellar Presentations

This feature identifies items related to interstellar studies which are listed to appear at this year's International Astronautical Congress, IAC24.

John I Davies

Introduction

i4is is interested in all that relates to interstellar travel and communications - and to the Solar System infrastructure which must precede the extension of our species beyond it.
If you spot anything we miss then contact principium@i4is.org. We will feature it in our members' newsletter ahead of the Congress and report it in our news feature following the congress, for the November edition P47.
All of the programme items listed here are text credited to the International Astronautical Federation (IAF) and visible via the Programme: iafastro.directory/iac/browse/IAC-24/



The Programme

Here is the programme with IAF identifying codes for the symposium sessions. Shown alphabetically by IAF identifying code under session title, objective, date and time. Access them all via - iafastro.directory/iac/browse/IAC-24/

Format of programme items -

IAF identifying code	Title	Presenter	Institution	country
Abstract (and co-authors if any)				

The Interstellar Programme Items

A4,1 SETI 1: SETI Science and Technology. All scientific and technical aspects associated with the search for extraterrestrial intelligence, including current and future developments and search strategies.
2024-10-15 10:15 White Hall 1

A4,1,1,x91125	KEYNOTE: "Pesek Lecture" - Early Results from Breakthrough Listen's Automated Commensal Technosignature Survey at MeerKAT	Dr Daniel Czech	University of California, Berkeley	United States

Radio telescope arrays are increasingly built to offer commensal access, via Ethernet, to the data they produce. The MeerKAT radio telescope in South Africa provides access to a wide range of components, from each antenna's digitiser to the main F-engine. It supports a number of commensal User Supplied Equipment (USE) systems in a colocated RFI-shielded datacenter. Breakthrough Listen has built a powerful USE system (BLUSE) to conduct an automated commensal SETI survey at MeerKAT, processing the full available bandwidth for all antennas. Its primary mode of operation is to upchannelise the incoming F-engine data to ~1Hz resolution, synthesize coherent beams on objects of interest, and search the resultant data for evidence of technosignatures. Over the past two years, BLUSE has processed data from coherent beams synthesized on approximately half a million individual pointings.
In this talk, we present scientific results and analysis of two years of automated commensal observing. We discuss the technical evolution of BLUSE over this time period, examining challenges faced and addressed early on. We also describe ancillary projects and alternative SETI survey approaches conducted alongside the primary mode of operation. Finally, we discuss areas of ongoing research and development.
Co-authors
Mr David MacMahon, Berkeley SETI Research Center, United States;
Mr Matt Lebofsky, UC Berkeley, United States;
Dr Andrew Siemion, Berkeley SETI Research Center, United States;
Dr Cherry Ng, University of Toronto, Canada;

A4,1,2,x91178	Utilizing International Observatories in the Breakthrough Listen Quest for Extraterrestrial Intelligence	Dr Vishal Gajjar	SETI Institute	United States

Breakthrough Listen (BL) stands at the forefront of the quest for extraterrestrial intelligence, marking one of the most comprehensive endeavors ever embarked upon in the field. Two of the BL's goals are to meticulously survey over a million nearby stars and conduct a detailed examination of the Galactic Center, covering the entirety of the accessible electromagnetic spectrum with ground-based observatories. In this paper, I will delve into our current initiatives across a network of observatories, offering a broad perspective on the various technosignature detection efforts underway. Notably, with the Five-hundred-meter Aperture Spherical Telescope (FAST), we are exploring wideband periodic pulses—a novel class of signal that has remained unexplored until now. This venture represents a significant leap forward, introducing a new dimension to our search strategy and potentially uncovering signals that previous searches may

have overlooked. Concurrently, our wide-field survey using the Low-Frequency Array (LOFAR) international stations is surveying millions of stars cataloged by the Gaia mission, constituting the largest technosignature search ever undertaken. With the Sardinia Radio Telescope (SRT) in Italy, we are conducting the highest frequency surveys of nearby stars and a deep survey of the Galactic Center. We are also exploring innovative signal search strategies, such as the Karhunen-Loeve Transform (KLT), to look for potential signs of extraterrestrial intelligence. Furthermore, the Giant Metrewave Radio Telescope (GMRT), with its unique capabilities as an interferometer, is implementing a commensal search backend designed to produce 2,000 beams. This innovative approach enables us to conduct searches simultaneously with other observations, maximizing telescope time use and significantly expanding our search area. I will elaborate on how we plan to integrate our technosignature searches with this sophisticated system, thus enhancing our efficiency and breadth of coverage. Importantly, GMRT's focus on the 400 to 900 MHz frequency range addresses a gap in the current landscape of radio technosignature searches. This relatively underexplored range offers fresh potential for discovering signals indicative of extraterrestrial technologies. I will also discuss how we aim to leverage the flexible Allen Telescope Array (ATA) to develop and deploy various search strategies.

A4,1,3,x87543	SETI program at the Sardinia radio telescope	Dr Maura Pilia	INAF - Istituto Nazionale di AstroFisica	Italy

The Sardinia Radio Telescope (SRT) is a 64-m fully-steerable antenna, which is located in Sardinia, Italy. SRT currently observes at frequencies between 300 MHz and 26 GHz and it recently underwent a major upgrade which will extend the range of observable frequencies up to 100 GHz. Commissioning of the new receivers is now underway. SRT started a collaboration with the Breakthrough Listen (BL) Program as an auxiliary facility for Searches for ExtraTerrestrial Intelligence (SETI). Together with the regular SETI scopes, this allows us also the possibility to perform parallel piggy-back observations of astrophysical transient sources (eg pulsars and fast radio bursts). The first SETI observations at SRT were performed in 2020. They were aimed towards two groups of targets with the purpose to find evidence of artificial transmitters from putative intelligent civilizations. We observed the Galactic Center at 7 and, for the first time, 22 GHz. Moreover, SRT is one of the important partner facilities for following up potential exoplanet candidates from the TESS program in collaboration with the BL team. They were also observed at 7 and 22 GHz. A summer studentship program was activated in the framework of the collaboration starting in 2022. Both sets of observations were analysed, with an important contribution by the students, using BL open source software TurboSETI which looks for Doppler drifts in the incoming signals. The findings with TurboSETI were cross-checked with a newer software, HyperSETI, so as to also validate the different searching methods. Thirdly, a new method developed in-house, based on the Karhunen-Loeve Transform (KLT) is being tested for preliminary denoising of the data. We describe the preparatory and ongoing activities: we discuss the commissioning of the system and the scientific validation, we present the first results of the SETI searches and, finally, we outline the future perspectives of the collaboration in Italy.

Co-authors

Dr Andrea Melis, INAF - Istituto Nazionale di AstroFisica, Italy.

Sardinia radio telescope, a facility operated by Istituto Nazionale di Astrofisica (INAF) Credit: INAF

A4,1,4,x81909	Highest radio frequency technosignature searches with the Sardinia Radio Telescope	Mr Lorenzo Manunza	Berkeley SETI Research Center	Italy

The quest for radio signals from technologically-advanced extraterrestrial intelligence has traditionally concentrated on the vicinity of 1.4 GHz. In this paper, we extend the search to unprecedented territories, detailing our extensive observations at 6 GHz and initiating the first-ever survey at 18 GHz with the Sardinia Radio Telescope (SRT). Our strategy entailed rigorous observation sessions, totaling 36 hours, directed towards the Galactic Center and 72 selected TESS targets—making this the most comprehensive high-frequency technosignature search to date. Despite encountering numerous false positives, predominantly from human-made interference, our narrowband signal search found no definitive evidence of drifting signals that could suggest an extraterrestrial origin from the surveyed regions. Nevertheless, our efforts have enabled us to set new constraints on the presence of radio emissions from approximately $5 \cdot 10^5$ stars, establishing an isotropic radiated power limit of $1.8 \cdot 10^{19}$. We also provide a comparative analysis of the 'hits' recorded across both frequencies and underscore the significance of pursuing technosignature searches at higher frequencies, where the spectral landscape is less congested and more conducive to detection.

Co-authors

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Dr Vishal Gajjar, SETI Institute, United States;
Ms Karen Perez, Columbia University, United States.

A4,1,5,x86675	Searching for ETI with FAST: The Current Status and the Future	Prof Tongjie Zhang	Beijing Normal University	China

The Five-hundred-meter Aperture Spherical radio Telescope (FAST)
Credit: National Astronomical Observatories, Chinese Academy of Sciences

The Five-hundred-meter Aperture Spherical Radio Telescope (FAST), as one of the world's most advanced radio telescopes, is particularly suited for the Search for Extraterrestrial Intelligence (SETI) research and experiments due to its exceptional sensitivity. In 2019, we conducted our initial experimental observations with FAST, subsequently collaborating with the SETI@home and Breakthrough Listen teams for joint observations and data analysis. This included re-observing candidate sky regions identified by the SETI@home project through 14 years of commensal observations with the Arecibo telescope, and observing new wide-band periodic signals in collaboration with the Breakthrough Listen initiative. We have made continuous progress in exploring new observational modes with FAST and expanding the search for different signal categories. Utilizing FAST's multibeam receiver, we first replaced the traditional ON-OFF observation mode with the Multibeam coincidence matching (MBCM) method, significantly enhancing observational efficiency in SETI research. This advancement allowed us to monitor more targets in a shorter time frame. Furthermore, we developed a Multibeam point-source scanning (MBPS) observation mode specifically for SETI, enabling more precise differentiation of signals from interference in a novel multi-parameter space. This method has almost entirely eliminated continuous Radio Frequency Interference (RFI), markedly reducing the false positive rate. Through the series of surveys that we have conducted, we have found no signals capable of passing our signal identification pipeline; therefore, we have eliminated the possibility that these signals were transmitted by extraterrestrial intelligence (ETI). In the summer of 2023, we officially launched the Far Neighbor Project, aimed at conducting systematic

and comprehensive SETI research within an integrated framework. This initiative seeks to update our understanding of the distribution of ETI and to attempt receiving messages from such civilizations. The project emphasizes leveraging the latest scientific discoveries and theories to guide our regular observations of high-potential sky regions and to expand our search areas, thereby enhancing our prospects of detecting signals from extraterrestrial intelligence.
Co-author:
Mr Bolun Huang, Beijing Normal University, China.

A4,1,6,x91186	The upgraded Allen Telescope Array: a dedicated radio SETI facility	Dr Wael Farah	SETI Institute	United States

Radio SETI stands out as a highly promising technique for the identification of extraterrestrial technology. Recent enhancements to the Allen Telescope Array include the integration of sensitive feeds, a cutting-edge real-time correlator, and a beamformer, collectively enabling an advanced search capability. The telescope is currently engaged in SETI endeavors utilizing the innovative "SETI ellipsoid" technique, which is the search for coordinated ET beacons responding to an astrophysical event like a bright supernova. The investigation extends to observing multi-planetary systems during predicted planet-planet occultations, specifically targeting leakage radiation that may emanate from hypothetical interplanetary communication. Moreover, the ATA is also actively scanning nearby stars for potential indicators. This presentation will delve into the specifics of these endeavors and their significance in the broader context of our quest for finding extraterrestrial intelligence

A4,1,7,x84317	BLADE: Allen telescope array GPU accelerated real-time beamformer	Mr Luigi Cruz	SETI Institute	United States

The Allen Telescope Array (ATA) is a radio interferometer currently composed of 42 antennas optimized for the Search for Extraterrestrial Intelligence (SETI). The array is made up of 6.1-meter diameter offset Gregorian telescope elements distributed randomly with a maximum baseline of 300 meters. The recently upgraded cryo-cooled log-periodic antenna feed (known as Antonio Feed) is sensitive to a wide and continuous range of frequencies ranging from 300 MHz to 12 GHz. The Breakthrough Listen Accelerated DSP Engine (BLADE) is a C++20 GPU-based computer software developed in-house to process data produced by the ATA. It is being used in production at the Allen Telescope Array to combine signals received by individual antennas steering the sensitivity towards a target, a technique known as "beamforming". BLADE is also capable of post-channelize the beam-formed data into high-resolution (1.0 Hz/bin) spectrogram in real-time for SETI search. Currently, a twenty- antenna multi-beam observation routine at the Allen Telescope Array produces a 60 GHz of complex 8-bit integer stream of aggregated data that is processed (beamformed and channelized) in real-time by BLADE. Compute kernels are written in CUDA and leverage the power of NVIDIA GPUs. In this talk, we are going to discuss how a software-defined telescope that processes observational data in real-time can enable new scientific capabilities. As well as how the modular architecture of BLADE can handle the required data throughput at the same time as being easily extensible

A4,1,8,x81880	Image Plane SETI with Modern Interferometers	Dr Joe Bright	University of Oxford	United Kingdom

Interferometric SETI observations offer a number of advantages over the single dish searches that have traditionally dominated technosignature research, including the ability to form multiple beams with high spatial resolution, and to more confidently reject radio frequency interference (RFI). This transition has been driven primarily by an increase in our ability to process the vast data rates produced by large antenna arrays, and has enabled innovate commensal observing systems such as COSMIC on the VLA and BLUSE on MeerKAT, as well as dedicated SETI instruments such as the Allen Telescope Array. These systems are capable of recording raw antenna voltages to disk around signals of interest (found by Doppler drifting signal search algorithms), allowing for arbitrary signal analysis (including correlation) to be performed offline. While it is currently infeasible to perform high time and frequency resolution image searches across the entire observing bandwidth, offline correlation and imaging of the raw data corresponding to signals of interest opens a new avenue for signal validation and RFI rejection. I will demonstrate early results from efforts to image offline correlated data from the ATA, COSMIC, and MeerKAT, and discuss the benefits for SETI science as well as in the broader field of radio transients.

A4,1,9,x84353	Lindy's technosignatures	Mr Claudio Grimaldi	Ecole Polytechnique Fédérale de Lausanne (EPFL)	Switzerland

The probability of detecting technosignatures - evidences of technological activity beyond Earth - increases with their longevity, or the time interval over which they manifest. Therefore, the assumed distribution of longevities significantly influences the chances of success of technosignature searches, as well as the inferred age of technosignatures following a first contact. Here, we argue that the longevity of electromagnetic technosignatures (technoemissions) is limited by the energy demanded for their operation. This implies that extraterrestrial species must overcome significant technological challenges to create long-lasting technoemissions, and those that have managed to generate technoemissions for a long time are likely to produce them for a long time in the future as well. This suggests that the longevity of technoemissions adheres to the so-called Lindy's law, whereby, at any time, their remaining life expectancy is roughly proportional to their age. We show that if Lindy's law [1] holds, the general assumption that the first detected technosignature must be exceptionally long-lived may be challenged. We conclude by discussing the number of emitters that had to appear, over the history of the Galaxy, in order for one of them to be detectable today from Earth.

A4,1,12,x91290	RFI Rejection in Multi-beam Receivers Using a CNN: A Path to Identifying ETI Signals	Ms Karen Perez	Columbia University	United States

As society's reliance on technology grows, so does the prevalence of radio frequency interference (RFI), complicating the search for extraterrestrial intelligence (ETI) signals. In this study, we propose a machine learning approach to distinguish false positive narrowband ETI signals detected by multi-beam receiver telescopes and interferometric arrays. Leveraging over 1,000 hours of Galactic Plane data from the Parkes Telescope's 21 cm Multibeam receiver, obtained as part of the Breakthrough Listen program, we employ a convolutional neural network (CNN) as our final filter to identify potentially artificial narrowband transmitters from ETIs. Using the setigen tool (Brzycki et al 2022), we generate signals for our training set and inject them into background noise from real data. Training ResNet50 (He et al 2015) through transfer learning, we achieved a remarkable model validation accuracy of 98.46%. Unlike traditional RFI filtering methods, our approach analyzes each spectrogram containing a candidate signal independently, assigning a predicted signal probability. We then verify if all beams with high signal probabilities meet our coincidence rejection criteria. This significantly reduces the number of candidates requiring visual inspection to a mere 0.2%. This paper outlines our data collection process, signal generation, training data, CNN algorithm, and proposes its applicability to upcoming interferometer projects, offering an alternate, efficient solution to the daunting task of scrutinizing millions of potential ETI signals.

Co-authors

Dr Vishal Gajjar, SETI Institute, United States
Mr Sid Solaiyappan, University of Michigan, Ann Arbor, United States

A4,1,13,x82932	Fine-tuning the Narrowband SETI Signal Processing Pipeline	Mr Kenneth Houston	University of California, Berkeley	United States

A narrowband radio frequency Search for Extraterrestrial Intelligence (SETI) presumes a long-duration (~minutes), low bandwidth (~Hz) beacon or incidental transmitted signal, or technosignature, that would be unlikely to occur in the natural world. A constant-frequency signal at the transmitter will drift in frequency on reception due to relative accelerations between the transmitter and receiver. Drift rates will be proportional to center frequency, eg up to ±1 Hz/sec/GHz (Li, Sheikh et al 2023). The typical signal processing pipeline involves creation of spectrograms over a wide bandwidth (up to 1 GHz) with Hz-level frequency resolution, followed by de-Doppler integration, which integrates energy over linearly-drifting tracks in the time-frequency plane. While search capabilities have greatly expanded over recent years to include interferometric radio telescopes and aperture arrays (MeerKAT, VLA, MWA), commensal observing, and GPU-augmented server racks, the basic signal processing algorithms are largely unchanged. In this talk, updates to the algorithms and their implementation will be discussed. Topics will include:

- An updated de-Doppler algorithm (Houston 2023) and its GPU implementation
- Reducing spectrogram compression to avoid sensitivity losses
- Beamforming implementations

[1] en.wikipedia.org/wiki/Lindy_effect

• Use of "stamps", which save complex spectrograms of detections for all antennas over a limited bandwidth
• Post-detection operations in the future, such as direction-of-arrival estimation, radio-frequency interference rejection, and waveform extraction.

A4,1,15,x85533	Enhancing the Breakthrough Listen Technosignature Search with Advances in Anomaly Detection	Dr Steve Croft	University California Berkeley	United States

Breakthrough Listen, the planet's most comprehensive search for technosignatures, continues to acquire vast amounts of data from telescopes around the world and in space. Classical techniques have been applied to look for candidate technosignatures, but the enormous data volumes make this challenging, and existing approaches may miss certain types of interesting signals. The Listen program has also employed a variety of anomaly detection techniques that are complementary to existing algorithms. Some of these involve machine learning, whereas others employ novel statistical techniques to find signals missed by the standard pipelines. In other cases we can use new algorithms to vet signals found using classical approaches. I will discuss the use of these algorithms on current and future datasets at optical and radio wavelengths, how they are being used to constrain the occurrence rate of technosignatures, and synergies with anomaly detection techniques being used in other areas of astronomical observations and engineering.

A4,1,16,x81012	Strange optical pulses in starlight from HD89389 and HD217014	Dr Richard Stanton	Jet Propulsion Laboratory	United States

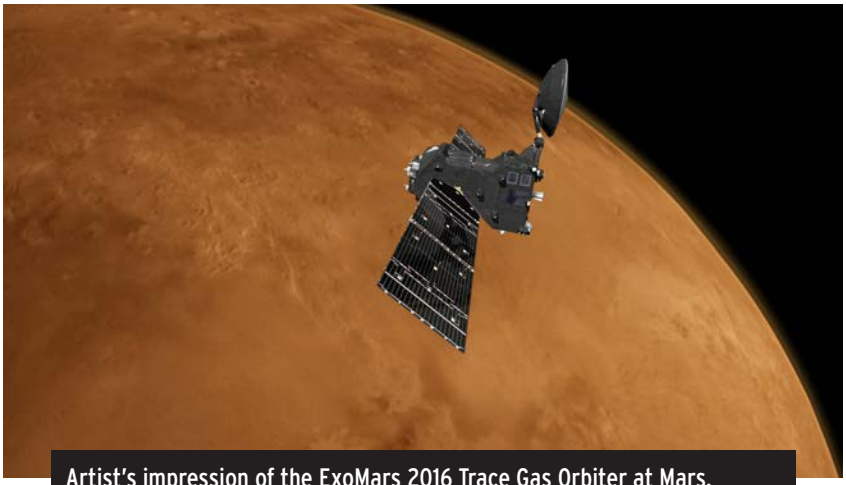
Years spent searching 1,200 sun-like stars for SETI signals in fast multi-color optical photometry have finally yielded interesting, unexpected results. A "signal" of two fast pulses, separated by 4.5 seconds and unlike anything previously seen, was discovered in light from HD89389. Close examination reveals that several unique features of the first pulse are repeated almost exactly in the second. Comparison of this pair with other known "signals" such as those produced by airplanes, satellites, meteors, lightning, atmospheric scintillation or system noise, emphasized their uniqueness. During the reexamination of historical data, another pair of similar pulses was found in an observation of HD217014 that four years earlier had been dismissed as "birds". After examining these pulses in detail and showing that they could not have been made by birds or other known source, a theory is proposed to explain them based on distant objects moving through the incoming starlight. If this theory is correct, an array of synchronized optical telescopes on the ground could provide the additional data needed to estimate the distance, velocity and possibly the size and shape of similar objects detected in the future.

A4,2 SETI 2: SETI and Society: All interdisciplinary aspects of SETI, in particular the social and societal consequences of detecting a signal, engaging with a very wide variety of human cultural pursuits - including art, language, education, science, anthropology, sociology, psychology, legal, political and institutional issues, interactions with the media, public outreach and risk communication.
2024-10-15 15:00 White Hall 1

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	-	The Netherlands

On 24 May 2023, a simulated extraterrestrial message was transmitted towards Earth by the Trace Gas Orbiter, a Mars orbiter of the European Space Agency. The signal was received by the Green Bank Telescope and the Allen Telescope Array in the USA and by the Medicina Radio Antenna in Italy. The event was part of the interdisciplinary project A Sign in Space and was streamed live by the SETI Institute, with thousands of people watching in real time. A Sign in Space started in late 2018 and was developed in collaboration with researchers at the Green Bank Observatory, the Italian National Institute for Astrophysics (INAF), the SETI Institute, and the European Space Agency over a period of four years. The project simulates one of the possible scenarios following the reception of a confirmed radio signal from an extraterrestrial civilization. In the scenario envisioned in the project, scientists release the data of the signal in the public domain, asking people from around the world to decode and interpret its content. A Sign in Space stages one of the possibly most radical events, in which humankind attempts to create meanings

around a message crafted by an extraterrestrial intelligence. Since the release of the signal data in the public domain on 25 May 2023, an international community of enthusiasts has been attempting to decode and assign meanings to the message designed for the project. Over the past months, hundreds of interpretations have been proposed and thousands of social media posts have been created in the ongoing decoding effort. The global outreach of the project has been supported by workshops facilitated by the SETI Institute, and featuring various perspectives on SETI research from around the world, including those from aboriginal communities, from the Arab countries, from China and South America. A Sign in Space reached millions of people from 175 countries, through a global media coverage and various social media channels. After one year since its public launch, Daniela de Paulis, the project's founder and director, is assessing the preliminary media and cultural impact of the work and its potential benefits for SETI research.



Artist's impression of the ExoMars 2016 Trace Gas Orbiter at Mars. Credit: ESA/ATG medialab

A4,2,3,x89071	Causal Impotence and Cosmic Messaging: A Logical Response to the Barn Door Argument	Dr Chelsea Haramia	University of Bonn	Germany

One critique of Messaging ExtraTerrestrial Intelligence (METI) involves the concern that contact could be seriously harmful to Earth or to humanity. There could be very damaging effects of our intentional cosmic messages being detected. One candidate response to this critique is what is sometimes referred to as the 'Barn Door' argument [1]. This argument is grounded in claims of causal impotence. That is, there are a myriad of ways in which we could be detected, and abstaining from intentional messaging will not affect other detectable signals and activities. If other detectable signaling is already contributing significantly to the potential outcomes the critic is worried about, abstaining from messaging will not alter our detectability in a way that causes the desired effect. If the Barn Door Argument is correct, then those who engage in messaging arguably have a moral excuse. They are permitted to continue messaging because there's no point in abstaining.

I provide a logical reconstruction of the Barn Door argument and then systematically evaluate three candidate interpretations of the appeal to causal impotence in the key premise. I show that the two interpretations that maintain the soundness of the argument are inapplicable to current messaging scenarios. While the third interpretation is applicable to messaging scenarios, this interpretation renders the key premise untrue according to our best knowledge, which entails that the Barn Door argument is unsound. I conclude that the Barn Door argument does not generate the moral excuse on which proponents of this argument rely. While this response does not challenge all arguments in favor of METI, it is demonstrable evidence that, in our current circumstances, the Barn Door argument cannot justify intentional messaging.

A4,2,5,x85743	State Responsibility for First Contact Under International Law	Prof Andrea Harrington	Institute of Air and Space Law, McGill University	Canada

It is well-recognized in international law that either acts or omissions can constitute wrongful acts by sovereign states. The sources of international law that trigger obligations for states include not only treaties, but also customary international law and general principles of law, as articulated in the Statute of the International Court of Justice. These circumstances are important when considering that there is currently no international body with legal authority to undertake first contact activities, and thus that the responsibility for the consequences of SETI

[1] David Brin, *The"Barn Door" Argument, The Precautionary Principle, and METI as "Prayer"—an Appraisal of the Top Three Rationalizations for "Active SETI"*, Theology and Science - December 2018. No open publication found.

will rest with states under international law. Active SETI, as distinguished from a passive search for radiofrequency evidence of other civilizations, creates heightened risks and opportunities for humanity in the case of contact. First contact with an extra-terrestrial intelligence would be a monumental event for humanity. The results of such contact could be minimal, if the extraterrestrial intelligence in question is located at too far a distance for reasonable communication. It is possible, however, that contact could have more substantial effects if communication and/or regular contact are possible. In that case, contact could foreseeably lead to untold scientific discoveries and opportunities or to an existential threat. Given the potential consequences, it is critical that states understand their responsibilities in relation to SETI efforts. Are SETI activities considered a space activity in the context of Article VI of the Outer Space Treaty, and thus subject to national authorization and supervision in that context? Does the Outer Space Treaty create any other responsibilities for states engaging in SETI activities, whether under the benefit principle or the due regard principle? Given the potential for transboundary harm, do states have a heightened duty of care when seeking contact with extra-terrestrial intelligence? Is there a requirement under international law for SETI activities to conform to the precautionary principle, which applies when there is serious risk that an act or omission could threaten the environment and/or human health in a manner that is grave or irreversible? Does existing SETI-related 'soft law,' such as The Declaration of Principles for Activities Following the Detection of Extraterrestrial Intelligence, create any legal responsibility or liability for states? This paper will address these questions with the aim of clarifying state responsibility for active SETI and will recommend the delegation of potential first contact to an international authority to mitigate the risks inherent in unilateral state behavior.

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

The International Academy of Astronautics has been the leading source of guiding principles to be followed in the event of a putative SETI signal detection. In 1989, the IAA formulated a set of Protocols, the "Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence" which received widespread acceptance by the international scientific community. The IAA prepared a supplemental set of draft protocols in 1995 relating to the possible reply to a confirmed communication from an ETI, which was presented to the UN Committee on the Peaceful Uses of Outer Space.

The Search for Extra-Terrestrial Intelligence takes place in a dynamic context, and the Protocols are always a "work in progress" that must adapt to and reflect constantly changing scientific and social environments. Thus, the IAA SETI Protocols were streamlined and updated in 2010 after a multi-year process. Subsequently, the IAA SETI Committee has sought to review and revise the Protocols to keep pace with the expansion of methods of searches, the increased number of facilities and personnel conducting search activities worldwide, and the rapidly evolving information environment. In 2022, a Task Group was formed for this purpose, and a preliminary report was presented during the 74th International Astronautical Congress in Baku. The relevance of this endeavor has been underscored in the past year by the deepening interest in what happens after the discovery of life beyond Earth, as evidenced by the 2024 workshops and symposia sponsored by the NASA Astrobiology Program, and the IAU/Kavli Foundation, the work of the SETI Post-Detection Hub at St Andrews, and the working group on "SETI and the Law" newly established by the International Institute of Space Law.

This report updates the activities of the Task Group following the Baku IAC, including further community consultations and proposed text, as we work towards a combination of timeless Principles reflecting the original intentions of the 1989 Protocols, and supplementary Codes of Conduct and Best Practices documents that can provide additional guidelines that can be updated regularly to respond to changing circumstances.

Co-authors
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Dr Carol Oliver, University of New South Wales, Australia
Prof Michael Albert Garrett, University of Manchester, United Kingdom.

A4,2,8,x91108	An Active and Community-Based Approach to Inclusive Debates in SETI Ethics	Ms Julia DeMarines	University of California, Berkeley	United States

SETI research has the potential to generate expansive global impacts and even to represent humanity and our planet in meaningful ways. What, then, are the obligations of SETI practitioners and researchers? Answering this question falls under the purview of multiple disciplines, but philosophical inquiry and science communication are indispensable tools for the appropriate analysis of astronomical research that carries the potential for expansive ethical impacts. We maintain that it is crucial to carry out such analyses not only in academic and scientific circles but also in pre-college classrooms and communities. We draw on our experiences in local schools and diverse communities to call for an active approach to science and ethics debates regarding astrobiology and SETI. 'Active' here means that discussants are not simply passive recipients of accepted wisdom but rather active in developing and producing knowledge surrounding important and challenging debates. For example, DeMarines has developed and administered a SETI/METI curriculum prototype. The result was that, in a small study, a large majority of students changed their attitude on the decision to send messages to potential extraterrestrials after being guided through a SETI/METI-themed curriculum. This curriculum discussed the history of METI, current transmission plans, policy considerations, and more. Haramia has developed an award-winning active philosophy course that complements this curriculum's methods and fosters an appreciation of logical argumentation and the practice of questioning beliefs and uncovering assumptions, including one's own. Looking forward, the goals of this combined curricular approach to SETI-specific issues are (i) accessible tutorials on both SETI science and ethical analysis ; (ii) recognition of the intersections between scientific inquiry and ethical inquiry; (iii) development of critical sensitivity and an attentiveness to the way that certain details can shape the content of both scientific and ethical questions; and (iv) the ability develop comfort with uncertainty while at the same time fostering the capacity to recognize philosophical and scientific progress within ongoing, unsettled debates. The overall goal is the manifestation of these skills in a community of philosophical and scientific inquiry with non-specialists whose input is nonetheless vital for inclusive discussions regarding SETI science and its ethical impacts.

Co-author

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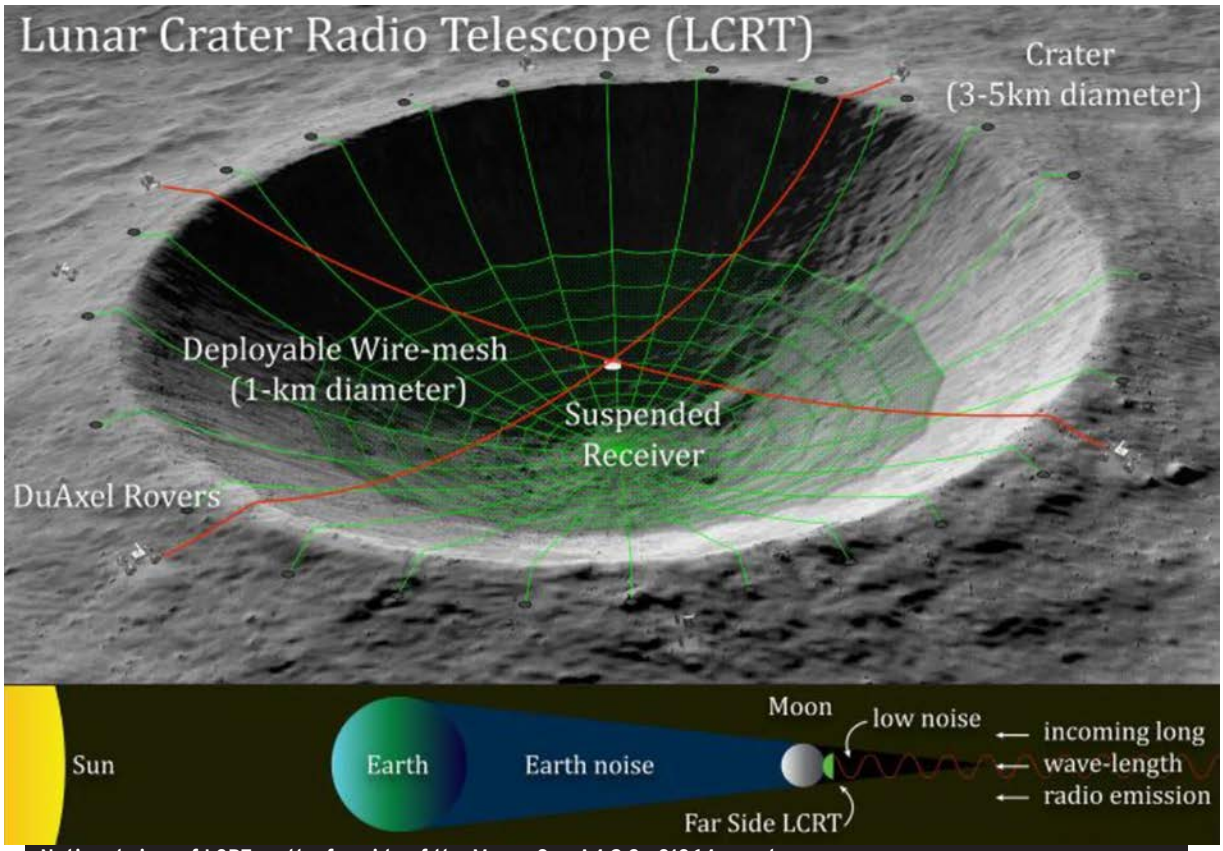

Notional view of LCRT on the far-side of the Moon. See A4,2,9,x81864 , next page.
www.nasa.gov/general/lunar-crater-radio-telescope-lcrt-on-the-far-side-of-the-moon/
Credits: Saptarshi Bandyopadhyay and NASA

A4,2,9,x81864	Moon Farside regulated by a United Nations TREATY	Prof Claudio Maccone	International Academy of Astronautics (IAA)	Italy

A new Moon Race is currently underway between the leading space-faring countries: United States, China, India, Japan, Europe, Russia and more.
But there is no International Law accepted by all stakeholders to regulate this Moon Race: both private entrepreneurs and national space agencies are free to do what they please without restrictions of any kind.
The result may well be an irreversible POLLUTION of the Moon both on the Nearside, on the South Pole (where water is) and on the Farside (still free from human-made radio noise on several frequency bands).
As for the Farside, international organizations like the International Astronomical Union (IAU), the International Telecommunications Union (ITU), and more are trying to prevent the Farside radio pollution, but it's a hard and uncertain POLITICAL and SCIENTIFIC battle.
The recent StSc Session at the United Nations COPUOS in Vienna (January 29 through February 9, 2024) abundantly proved this chaos.
Along these lines of Moon Farside Protection, the International Academy of Astronautics (IAA) organized the first IAA Symposium on Moon Farside Protection in Turin on March 21-22, 2024: please check the site www.moonfarsideprotection.org.
But that is not enough.
We need a TREATY, under the auspices of the United Nations, forcing all space-faring countries TO AVOID SPECTRUM POLLUTION on the Farside.
And that is URGENT in order to avoid the SKY POLLUTION around the Moon just as the SKY POLLUTION around the Earth is already making Optical Astronomy increasingly difficult "thanks" to thousands of Starlink-type satellites already in orbit around the Earth.
This author's Presentation at the Milan IAC will update the SETI audience about these problems as of October 14-18, 2024.
Co-authors
Dr Nicolò Antonietti, INAF - IRA, Italy;
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Prof Teófilo Vargas, Universidad Nacional Mayor de San Marcos, Peru;
Prof Victor Daniel Vera Cervantes, Universidad Nacional Mayor de San Marcos, Peru.

A4,2,11,x82901	Artificial intelligences (AIs) could potentially serve as the catalyst for the first contact between our society and an alien one.	Mr Giorgio Gaviraghi	Unispace Exponential Creativity	Italy

With recent advancements and ongoing progress in AI, it's conceivable that in the coming years, AI may surpass human intelligence and continue to evolve. Concurrently, advancements in space exploration will facilitate our expansion throughout the solar system, both manned and unmanned. Unlike biological species, artificial machines do not require life support systems, making them better suited for space exploration. They could establish bases and outposts across celestial bodies, gradually dominating space. As these intelligent artificial entities continue to evolve, they may attain consciousness and independence from human control. They could autonomously advance their own scientific knowledge and technologies. In their expansion, they might even venture into interstellar travel, seeking to conquer additional territories and resources. AI, originating from humanity, might serve as our representatives in the wider galaxy. Similarly, exosolar biological societies facing similar territorial limitations might witness their AIs assuming control and expanding into space. This scenario would lead to the first contact between our civilization and an alien one composed of artificial species. Such a development could reshape our approach to SETI research and our perceptions of exosolar alien societies. However, the prospect of machines overtaking our society presents a significant challenge that we must prepare to confront in the near future. It underscores the importance of working towards establishing a symbiotic relationship between biological and artificial species.

A4,2,12,x85455	Possible extraterrestrial Focal SETI and its implications for terrestrial SETI	Dr Nicolò Antonietti	INAF - IRA	Italy

Maybe the main problem of SETI is the low probability of receiving, at present or in the next future, an intentional message from an alien civilization: such a message, indeed, would be very easy to detect, since it would be made just for this, while unintentional messages would be very likely "invisible" to our present technology. But sending an intentional message towards the Earth would make sense to ETs only if they knew that on Earth there is a civilization capable to receive it, which, in turn, could happen only if they had already received some kind of signal from us. Unfortunately, at present our radio and television transmissions have reached only planets very close to us, which are very unlikely to host intelligent life. But what if an advanced civilization used a star as a gravitational lens to enormously magnify the power of its optical telescopes? This is not science fiction: NASA is currently planning by 2030 the first optical terrestrial mission to the focus of the gravitational lens of the Sun. This means that any advanced civilization is likely to have an entire set of telescopes exploiting the gravitational lens of its star or a nearby one. If so, ETs could have discovered the existence of our civilization long before it became able to send radio signals towards the stars. In this paper we try to calculate at what distance it would be possible to see the signs of the presence of intelligent life on another planet by using telescopes of different diameters and stars of different masses. Then we discuss the impact it could have on the probability of Earth being the target of an intentional extraterrestrial message

Co-author

Dr Paolo Musso, InCosmiCon Research Center, Italy.

A4,2,13,x86823	Cognitive Astrobiology – Mind in the Universe	Mr Pauli Laine	Finnish Astronautical Society	Finland

We don't know how unique creatures we are in the Universe. We don't even know how unique phenomenon life is in the Universe. But we know that humans are the only creatures on Earth that have created science and technology. We have languages that are capable of limitless expression and efficient communication. Although many animals clearly behave intelligently, no other animal is able to produce human linguistic utterances. Is language the enhancer of our thinking or even enabler of our abstract symbolic cognition? Why such rich languages have evolved in humans only among all possible species and during billions years of evolution? What does this mean for the possibility of creatures that are functionally equivalent of humans to exist somewhere else in the Universe? Human evolution and cultural history is not uniform, linear evolution towards modern (western) civilization. Rather modern civilization is the product of cumulative information and skills recorded and transferred extrasomatically from different cultures and traditions throughout the ages. It is said, that stone age human had already all the cognitive abilities as modern day humans. Co-evolution of cognition and language made it possible to permanently record and efficiently transfer ideas and information from human to human, from generation to generation. This led to co-evolution of brain and culture. How do human cognitive abilities then differ from other animals? Is the difference only quantitative, not qualitative? Is the ability to learn and use language the only thing that distinguishes us from other higher animals in cognitive level? Are we just the first species to achieve science and technology on Earth, or are we a product of a series of improbable coincidences?
Cognitive astrobiology is an early state research area combining two multidisciplinary research areas: cognitive science and astrobiology. One of the confluences of these two areas is the research of human specific cognitive abilities and the possibility of the emergence of similar abilities somewhere else in the Universe. The Search for Extraterrestrial Intelligence (SETI) has been searching for artificial signals for more than 50 years. During these years SETI research has assumed that (or at least is possible that) human-like intelligence and technology could evolve also somewhere else in the Milky Way. However, intelligence is a controversial and vague concept. Cognitive astrobiology can clarify the concept of intelligence by searching the features of the most general, multiple realizable rational cognition, functionally equivalent of humans.

A4,2,14,x88183	Plurality in Post Detection Scenario	Ms Kate Genevieve	University of Sussex	United Kingdom

A vital re-evaluation of SETI's post-detection protocols is underway, accompanied by calls to transform research cultures through process-oriented and culturally diverse understandings and dramatic transformations in machine learning and artificial intelligence (AI) that radically alter the scale and scope of search capabilities. This paper introduces work on scenarios and futures research conducted by the newly established SETI Post-Detection Hub at the University of St Andrews, deploying practice-based, dialogic, and creative strategies to address the complexities of post-detection in SETI. The Hub's Scenarios Working Group developed four distinct yet plausible future scenarios for the 2033 "post-detection ecosystem", drawing on participatory input from all Hub members. This scenario development process followed a participatory strategic foresight approach aligned with the "Intuitive Logics" school of thought in scenario development. These four alternative seed scenarios are developed by the Hub members as an invitation to creative groups in different countries to begin working with these alternative futures of 2033 to form their own fictional LARPs (Live Action Role Play). Structured improvisation invites trans-cultural, trans-disciplinary and trans-generational interplay, and devises ways to study community dynamics, offering unique ways to explore neglected human experiential dimensions of a post-detection event, and creative communication under pressure. These process-oriented practices offer fresh paths for SETI research to involve plural imaginaries around the uncertainties of post-detection futures. Collaborative scenario work blends SETI research with trans-national science fictions and aesthetics, weaving together different perspectives across space to expand speculation about societal response to Extraterrestrial detection. This creative methodology holds significant promise for creating novel insights into the societal impacts of confirmed detection, offering valuable contributions to the evolution of protocols. The SETI Post-Detection Hub opened at the University of St Andrews in 2022. The Hub combines emerging scientific research and varied disciplines to explore issues around the detection of extraterrestrial life, including overlooked aspects of process and maintenance beyond detection. The Hub focuses on nurturing a sustainable and ongoing effort in vibrant scientific inquiry into post-detection, in a manner that keeps pace with societal developments. The scenario work at the Hub aims to root SETI post-detection research in plural perspectives and More-than-Human approaches, towards strengthening an imaginative and engaged research culture able to listen deeply to diverse perspectives and to value a wide range of viewpoints. Research efforts emphasise the necessity of working with post-detection scenarios in a way that both seriously - and playfully - engages with decolonising research approaches.

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A4,2,15,x80945	Silent Stars, Awakening Minds: AI's Potential Role in Resolving the Fermi Paradox	Prof Mike Garrett	University of Manchester	United Kingdom

The remarkable pace in the development of AI (Artificial Intelligence), potentially accelerated through self-assisted design, may consistently lead biological civilisations to underestimate the crucial need to swiftly regulate AI advancements on a global scale. The inability of biological civilisations to effectively manage the incredibly rapid progression of AI, or any other fast-evolving technology, could instigate a global catastrophe serving as a universal resolution to the Fermi Paradox. For this crisis to effectively curtail the lifespan of a civilisation, it must manifest itself during the initial stages of a technical civilisation's growth, preceding its ability to sustainably expand beyond its native planetary system. The proposed timeframe of 100-200 years, equivalent to the longevity (L) of a technical civilisation, emphasizes the urgency to implement regulatory frameworks that govern the trajectory of future AI development. The continuity of consciousness throughout the cosmos might hinge on the effectiveness of establishing robust and all-encompassing global regulations pertaining to the progress of AI [1].

[1] Prof Garret's thinking is reported in an article in Principium 45 May 2024, *Biological intelligence vs AI - and the Fermi Paradox: Is artificial intelligence the great filter that makes advanced technical civilisations rare in the universe?* i4is.org/principium-45/

C4,9 Disruptive Propulsion Concepts for Enabling New Missions: This session will explore advanced and disruptive propulsion technologies, systems, ideas (including integration of different propulsion concepts) showing potential to enable new mission concepts, or to enhance the capabilities of current mission concepts.
2024-10-18 10:15 Blue Hall 11

C4,9,1,x86616	Development of Tri-propellant rocket engine for reusable SSTO	Dr Tadayoshi Shoyama	Innovative Space Carrier Inc	Japan

Reusable single-stage-to-orbit (SSTO) vehicles require a propulsion system that can provide both high thrust for atmospheric ascent and high specific impulse for vacuum flight. This presentation shows the development of our tri-propellant engine for SSTO performance improvement. The tri-propellant engine under development uses liquid methane, liquid hydrogen, and liquid oxygen as propellants. In mode-1 for atmospheric ascent, all three propellants are combusted to generate maximum thrust. In mode-2 for vacuum flight, only liquid hydrogen and liquid oxygen are used, resulting in lower thrust but higher specific impulse. There are ony two types of tri-propellant engines ever proposed: single-chamber and dual-chamber. The dual-chamber type, proposed by Dr Rudi Beichel, consists of an inner combustion chamber for methane combustion and an outer combustion chamber for hydrogen combustion. Furthermore, it provides altitude compensation capability by increasing the expansion ratio without changing the nozzle exit area in mode 2 by stopping the combustion of the inner combustion chamber. However, the cooling of the chamber separation wall has been a technological challenge.
This presentation shows a development roadmap beginning with a small single-chamber engine towards the dual-chamber tri-propellant engine. Thermodynamic cycle calculations and comparisons are conducted for each milestone engine. The research on transpiration cooling technology for solving the cooling issue of the chamber separation wall is reported. As a first step, a small-scale single-chamber tri-propellant engine was designed, fabricated, and tested. The engine successfully ignited, achieved stable combustion, and demonstrated mode switching by stopping methane supply during combustion. The test utilized the P4SD rocket development platform, newly constructed on Amazon Web Services (AWS), which enables integrated design, manufacturing, and testing on a single platform. This paper reports the combustion test results also as the first application of the P4SD platform.

C4,9,6,x85994	Feasibility study of a mission to Sedna - Nuclear propulsion and advanced solar sailing concepts	Ms Elena Ancona[1]	Politecnico di Bari	Italy

Exploration missions targeting the Kuiper Belt, the Oort Cloud, the gravitational focal point of the Sun, and even extending to the Alpha-Centauri system represent the next frontier in space exploration. Among potential destinations, there's a growing focus within the scientific community on the trans-Neptunian object Sedna (90377). With its highly eccentric orbit around the Sun, Sedna is currently approaching its perihelion at around 76 AU, offering an exceptional opportunity for deep space exploration. Its aphelion, situated approximately 936 AU away, makes Sedna an intriguing target for further study. Given its orbital period of 11 thousand years, scientists have been proposing missions for launch in the next few years (around 2030), including gravity assist that would allow it to reach Sedna in time for its closest approach [1]. In our study, we compare two mission scenarios that would allow to reach the Sedna: a nuclear fusion rocket engine based on a D - 3He thermonuclear fusion technology that is under development at Princeton University Plasma Physics Laboratory, the Direct Fusion Drive (DFD) [2] and a solar sail taking advantage of thermal desorption of coating [3]. The DFD is an aneutronic fusion propulsion thruster that employs a unique plasma heating system to produce nuclear fusion power in the range of 1 to 10 MW. For what concerns the solar sail, instead, it consists of a reflective membrane coated by materials that undergo thermal desorption attached to an inflatable torus-shaped rim. The sail's deployment from its stowed configuration is initiated by introducing inflation pressure into the toroidal rim with an attached circular flat membrane coated by heat sensitive materials that undergo thermal desorption at the perihelion of the heliocentric escape orbit and provide an acceleration - in addition to the conventional one due to solar electromagnetic radiation.
For the trajectories design for exploration of Sedna we considered 2 and 6 MW DFD and assumed constant thrust and specific impulse. For missions with DFD and solar sail four phases are considered: spiral departure, interplanetary acceleration, interplanetary coasting and rendezvous.

[1] Elena Ancona coordinated the first Foundations of Interstellar Studies Workshop on Interstellar Flight delivered by the Institute For Interstellar Studies and the Center for Theoretical Physics (CTP) at City Tech, New York, USA in 2017 when she was Spacecraft Controller at European Space Operations Centre (ESOC) for Telespazio-Vega GmbH. She is now working in Flight Dynamics Operations at SITAEL S.p.A.

1 V A Zubko, et al, Adv. Sp. Res., 68, 2752, (2021).
2 S A Cohen et al Phys. Rev. Lett. 85, 5114, 2000; JBIS, 72, 37, (2019).
3 E Ancona and R Ya Kezerashvili, Adv. Sp. Res. 63, 2021, (2019).
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C4,9,12,x86196	Optimization of Solar Sail Trajectories under Uncertainties via Deep Reinforcement Learning	Mr Christian Bianchi	University of Pisa	Italy

The design of solar sail trajectories is strongly affected by the presence of various sources of uncertainty due, for example, to an inaccurate modelling of the propulsive acceleration, which, in turn, mainly de- pends on the optical and physical properties of the sail membrane. Because many standard optimization methods often prove difficult or even impossible to apply in nondeterministic scenarios, other techniques for handling a stochastic dynamics have been proposed in the literature, among which the use of Rein- forcement Learning (RL) has shown promising results in recent years. In the RL approach, an agent learns the optimal way to perform a given task by interacting with the environment and gathering experience in order to maximize an appropriately modelled reward.
In this work, an RL strategy is applied to the design of interplanetary solar sail trajectories, where the agent is trained to learn the control policy that associates the optimal sail attitude with each dynamic state (eg position and velocity) during the transfer. A policy-gradient Proximal Policy Optimization (PPO) algorithm is used to train the agent due to its simplicity of implementation and good stability. The control policy is approximated by means of a feed-forward deep neural network, whose weights and biases constitute the set of parameters on which the optimization is performed.
The RL agent is first trained in a deterministic interplanetary transfer scenario, for which an optimal solution obtained with a classical indirect approach is known. Then, uncertainties that are typical of solar sailing are considered, such as an inaccurate knowledge of the film's optical coefficients, as well as the presence of wrinkles that inevitably arise due to folding and deployment of the extremely thin membrane. Both phenomena are modelled based on the latest experimental measurements available in the literature. After the training phase, Monte Carlo simulations were conducted, assuming that the sail attitude is selected according to the trained policy. The results demonstrate a good ability to achieve the mission objectives, while also showing robustness against the mentioned uncertainties. Although they require a relatively long training time compared with more conventional optimization strategies, one of the main advantages of control policies obtained through RL is that, once trained, they can be implemented aboard small spacecraft to provide real-time control with minimal computational effort.

C4,10 Joint Session on Nuclear Power and Propulsion Systems, and Propellantless Propulsion: This session, organized jointly between the Space Power and the Space Propulsion Symposia, addresses all aspects related to nuclear power and propulsion systems for space applications. The session also addresses all types of propellantless propulsion including (but not limited to) solar sails, magnetic sails, laser propulsion, tethers, etc.
2024-10-18 13:45 Blue Hall 1

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

Nuclear power is an increasingly important strategic enabler for commercial and multinational space missions. All space missions require power. With the anticipated increase in commercial missions over the coming decade, there is a growing demand for power for robotic exploration of the Solar System and the return of humans to the Moon. For missions to the outer Solar System, the effectiveness of solar power decreases quadratically with distance from the Sun, making nuclear power sources often the best or only option.
Simultaneously, nuclear propulsion addresses the need for high transfer delta-V in space exploration missions, effectively bridging the gap between high-thrust/low-specific-impulse chemical propulsion and very-low-thrust/high-specific-impulse solar electric propulsion systems. This enables reaching trajectories, pass times, and return windows that are compatible with exploration ambitions.

The UK is uniquely positioned to develop this technology and provide it to space agencies and private companies, owing to its rich industrial heritage and capabilities in both space and nuclear sectors. The strategic approach is based on three distinct pillars of activity, each with significant potential for the UK:
1. Heat and power for robotic spacecraft or rovers: Radioisotope Power Systems offer essential, reliable power, notably for the Moon's extended 'lunar nights' and missions to Mars. The UK's stockpile of nuclear waste can provide fuel for new system developments, meeting global demand. This supports ESA's exploration strategy and may enable new global partnerships.
2. Power for human exploration on the Moon: Fission power is crucial for sustaining future, extended lunar missions, powering habitats, vehicles, and drilling operations. The simplicity and modularity of fission-based microreactors present a promising solution to meet these energy needs.
3. Propulsion for deep-space missions: Nuclear Electric Propulsion (NEP) and Nuclear Thermal Propulsion (NTP) offer advanced propulsion for space exploration; NEP provides durable, low-level electric propulsion, while NTP's fission-based method delivers significantly more power, supporting larger, more frequent Solar System missions.
The UK Space Agency, in cooperation with other UK governmental authorities and sponsors, is delivering this strategy through various national grants, contributions to ESA programmes, and bilateral cooperation. The Agency is also contributing to all aspects related to the international regulation to ensure nuclear systems in space are used sustainably, safely, and peacefully.
This paper presents the technical elements of ongoing activities, provides a view on the challenges, and offers a perspective on the possible path to the full realisation of the UK's nuclear ambitions in space exploration.
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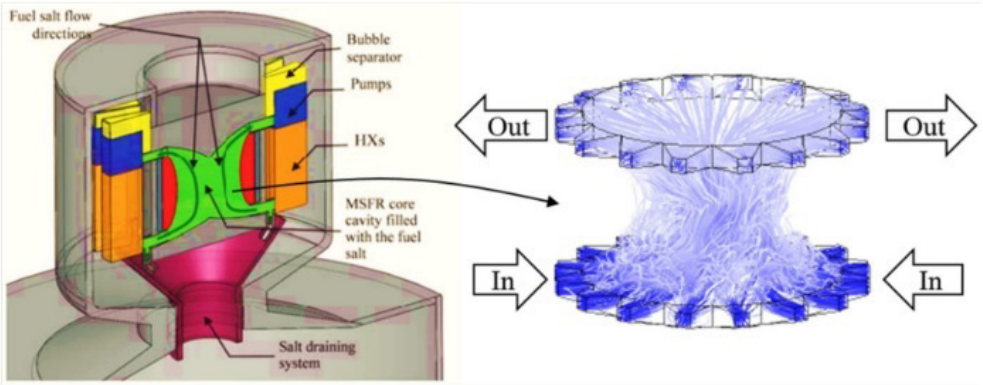
C4,10-C3.5,3,x88438	A comprehensive methodology for designing a nuclear electric propulsion (NEP) concept	Prof Pablo Rubiolo	CNRS	France

A multidisciplinary team is conducting an assessment of Nuclear Electric Propulsion technologies for the European Space Agency (ESA) within the frame of the Future Launcher Preparatory Program (FLPP). One of the key objectives of this project is to identify the more promising NEP concepts that could be developed in Europe. The starting point for this assessment are six Use-Cases (UCs) proposed by ESA, expected to cover demands for medium and long-term missions to earth, Moon, Mars orbits and exploration beyond Mars. This work presents a comprehensive methodology for designing a NEP system, beginning with the selected Use-Cases and provides preliminary results of the study. In the proposed methodology, the selected Use-Cases serve as the starting point for determining approximate mission requirements. These requirements are then refined based on an initial market assessment. The goal of the market analysis is to characterize potential markets for the Use-Case, estimate the potential payload and establish economic objectives to ensure competitiveness compared to other alternatives such as chemical and solar electric propulsion systems. The refined mission requirements derived from the original Use-Case are used to determine approximate design requirements, including the reactor power and the mission duration.
Based on these design requirements, NEP design studies were conducted, considering different thermal powers from a few kilowatts to several hundred of kilowatts to



Core cavity of the Molten Salt Fast Reactor (MSFR) and representative flow field obtained for the liquid fuel in the core cavity. From Development of Explainable Data-Driven Turbulence Models with Application to Liquid Fuel Nuclear Reactors, Mauricio E Tano and Pablo Rubiolo, 2022, www.mdpi.com/1996-1073/15/19/6861

cover various possible scenarios. Furthermore, following a review of existing NEP technologies, two main reference reactor concepts were selected for detailed design studies: a Heat Pipe Reactor (HPR) concept at low power applications and a Molten Salt Reactor (MSR) concept for moderate to high power applications (exceeding approximately 100 kW). The design studies aim to determine the approximate layouts and materials for the reactor, as well as define power conversion, radiator and electric propulsion systems. They also allowed for obtaining approximate estimates of the masses of the NEP system, propellant and payload for each Use-Case. Additionally, a preliminary safety analysis was included in the studies. Results from the design studies were then used to update the market assessment, providing a comprehensive evaluation of whether the proposed concepts are likely to meet the technical, safety and cost requirements necessary for competitiveness against other technologies.

C4,10-C3.5,4,x90913	Market study on nuclear electric propulsion for space applications	Dr Alesia Herasimenka	University of Luxembourg	Luxembourg

Nuclear Electric Propulsion (NEP) offers groundbreaking capabilities for both exploration missions and in-space logistics. In the context of the New Moon race and the aspiration to establish a Mars colony, NEP holds potential application for space transportation, when other propulsion means can be inefficient. Compared to chemical propulsion, the main advantage of nuclear electric propulsion is its engine efficiency. Additionally, when compared to solar electric propulsion, NEP's ability to provide significantly more power enables the transportation of heavy cargo while remaining independent from the sunlight.
This paper proposes a market study to assess the potential applications of NEP. By comparing costs and the time efficiency with existing propulsion methods, our analysis aims to identify the demand and future opportunities for the NEP. The performed analysis serves as a basis for defining the design parameters for the future nuclear electric propulsion system. The paper analyses various use-cases (LEO-GEO transfer, lunar orbit), enabling the identification of gaps in existing technologies that nuclear electric propulsion can address. This analysis is performed as a part of ESA's RocketRoll project, or "pReliminary eurOpean reCKon on nuclEar elecTric pROpuLsion for space appLications".
Co-author: Prof Andreas Makoto Hein, University of Luxembourg, Luxembourg [1]

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	United States

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. If the concept can be successfully realized, the CNTR would have a high specific impulse (1,800 s) at high thrust, which may enable (i) viable near-term human Mars exploration by reducing round-trip times to 420 days and (ii) direct injection orbits for scientific rendezvous missions to the Solar System outer planets and Kuiper Belt objects. The CNTR could also use storable propellants such as ammonia, methane, propane, or hydrazine at an Isp of [2], enabling long-term in-space storage of a dormant system. Research is presently underway to determine resolutions for the significant engineering challenges that the CNTR concept presents. Papers were presented at the 2021, 2022, and 2023 IACs which described these challenges, the study plan to address them, and progress to date. In particular, the 2023 paper described progress to level the heat generation gradient in the liquid uranium annulus, which allows higher operating temperature and achieves engine performance approaching the target of 1,800 s. This paper provides a follow-on update which summarizes progress of the overall research effort, including strategies and key results to date on establishment of a reference configuration, definition of key parameters which allows integration of the results of various analyses, and reviews strategies to mitigate the problem of Uranium vapor saturating the propellant exhaust and significantly impacting the CNTR's specific impulse. Finally, updated estimates of engine key performance parameters including specific impulse, thrust and thrust to weight ratio will be given along with the identification of selected design margins within the engine itself - all toward the goal of enabling plans for a laboratory demonstration of a single Centrifugal Fuel Element.

[1] Executive Director, i4is.org

[2] The abstract in the IAF page says " at an Isp of , enabling ". No value of the Isp is given.

C4,10-C3.5,11,x91409	A Comprehensive Study of Solar and Nuclear Hybrid Power Systems in Spacecraft Design for Deep Space Missions	Ms Ivy Mayor	-	Sweden

Deep space exploration missions demand robust power systems capable of adapting to diverse and challenging environments. Therefore, it is crucial to consider the target celestial body's location when designing a spacecraft's power system. In this article we propose that combining the strengths of solar and nuclear into a hybrid power system, would enable spacecraft to benefit from both the proven reliability of solar panels and the endurance power output of a compact nuclear reactor, offering a versatile and sustainable solution for missions spanning the inner to outer solar system and beyond. By bridging theoretical modelling with empirical evidence, this study endeavours to assess the potential applications, feasibility and limitations of the proposed spacecraft energy systems for upcoming deep space missions. Furthermore, this paper offers an extensive survey of contemporary spacecraft power technologies from decades of space exploration experience, as well as provides actionable insights and recommendations for seamlessly integrating hybrid power systems into spacecraft designs. As deep space exploration becomes an integral facet of humanity's scientific ambitions, this research seeks to provide insights into the strategic deployment of solar and hybrid technologies, to pave the way for missions ultimately expanding our understanding of the universe's frontiers. This research project is part of the Andromeda research program of the Deep Space Initiative, a non-profit space research organisation based in Colorado, USA.

C4,10-C3.5,13,x88393	Nuclear Power and Propulsion International Gap Assessment	Mr Rinat Rashapov	Canadian Space Agency	Canada

Space exploration within our Solar System requires a robust, clean, and high-performance energy source. Traditional systems, reliant on chemical propellants, batteries, or solar arrays, face limitations in power and energy density. This paper delves into the potential of nuclear technology as a solution, presenting a summary of a report by the International Space Exploration Coordination Group (ISECG) that assessed gaps in nuclear power and propulsion technology. The assessment categorizes space nuclear technologies based on power levels, encompassing radioisotope power systems (RPS), fission reactors, and nuclear propulsion. Initiated in 2020, the ISECG Technology Working Group (TWG) formed a dedicated gap assessment team involving representatives from 13 international space agencies and non-space organizations. The team aimed to identify new capabilities, understand the global state of the art, pinpoint gaps, and facilitate partnerships. Agencies, depending on their resources, focus on different aspects of nuclear technology, ranging from conceptualization to the development of space nuclear systems for harsh space environments. Challenges and opportunities in space nuclear technology highlight safety and security concerns. Further, the absence of consistent international nuclear safety standards and a regulatory framework for Nuclear Power and Propulsion (NPP) systems in space is recognized as a challenge. Identified technological and programmatic gaps in the development of space nuclear technology are discussed, emphasizing the current shortage of radioisotope and reactor fuel supply for space applications. Key findings and recommendations stress leveraging unique capabilities among member agencies, recognizing substantial mission demand for nuclear systems, and addressing technical and geopolitical challenges through international collaboration. The absence of an internationally governing regulatory framework for space nuclear systems and the importance of nuclear launch safety highlight areas for cross-agency cooperation. The paper concludes by emphasizing the large potential of space nuclear systems to leverage advances in terrestrial nuclear technologies while addressing climate change and providing socio-economic benefits.

Co-authors

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C4,10-C3.5,1,x90230	Optimizing Solar Sail Hybrid Systems for Interstellar Exploration	Mr Swapnil Singh	-	India

Solar Sail Hybrid Systems stand at the forefront of revolutionizing sustainable space operations and propelling ambitious interstellar exploration endeavors through the integration of advanced propulsion mechanisms. The optimization efforts prioritize practical and implementable solutions to strengthen the propulsion capabilities of these systems for interstellar missions. Advanced solar sail designs, featuring modular structures embedded with photonic sensors for real-time adjustment, optimize surface area exposure to incident solar radiation, ensuring efficient conversion of solar energy into electrical signals for precise control over sail orientation. Additionally, trajectory optimization algorithms such as Sequential Quadratic Programming (SNOPT) and Genetic algorithms enhance the system's capabilities. SNOPT iteratively refines trajectory parameters to minimize a cost function, ensuring optimal utilization of available propulsion resources. Genetic algorithms leverage evolutionary principles to search for optimal trajectories, considering complex mission constraints and uncertainties. Furthermore, charge induction mechanisms with plasma contactors play a crucial role in optimizing propulsion efficiency. Compact plasma contactors, utilizing Field Emission Electric Propulsion (FEEP) technology, emit streams of charged particles to neutralize spacecraft charge buildup and induce surface charges on the solar sail. The induced charges interact with incident solar charged ions, generating electrostatic repulsion forces that propel the spacecraft forward. Moreover, the integration of deployable electrostatic tethers, featuring smart tether systems with AI algorithms for adaptive length adjustment and charge distribution, enables versatile propulsion control and debris management. Utilizing carbon nanotube-based conductive materials, these tethers dynamically adjust length and charge distribution based on environmental conditions and mission objectives, optimizing propulsion efficiency and debris capture capabilities. Dynamic Solar Sail Angle Adjustment mechanisms further enhance maneuverability and propulsion efficiency. AI-driven actuators autonomously adjust the sail angle based on real-time solar radiation data, ensuring optimal orientation for maximum propulsion efficiency in dynamic mission scenarios. Material advancements also play a pivotal role in optimizing Solar Sail Hybrid Systems. Employing self-healing, nanomaterial-based membranes composed of meta-materials maximizes solar radiation capture and thrust generation. Embedded nanocomposite sensors and actuators enable autonomous repair and optimization of sail integrity, ensuring mission success in harsh space environments. In conclusion, the practical implementation of advanced propulsion mechanisms, trajectory optimization algorithms, and material advancements in Solar Sail Hybrid Systems signifies a profound advancement in space technology. These developments herald an era of enhanced exploration and discovery in the vast expanse of space, positioning these systems as pivotal enablers for future space mission.

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C4,10-C3.5,5,x85744	A Field Reversed Configuration Fusion System Applied to Space Propulsion	Mr Charles Henrique M F Fernandes	Instituto Tecnológico de Aeronáutica (ITA)	Brazil

At the Instituto Tecnológico de Aeronáutica (ITA), in Brazil, the research segment on computational analysis of fusion systems for space propulsion began, and for this purpose a mathematical model of a fusion rocket engine with a compact geometry that uses a Field Reversed Configuration (FRC) magnetic confinement was developed, which allows a high plasma beta. The FRC employs a set of linear solenoidal magnetic coils for confinement, operates at higher fusion power density for a given magnetic field strength than other magnetic confinement plasma devices and consists of two distinct regions: a closed-field-line torus inside the separatrix and an open-field-line region outside the separatrix. The fuels explored are Helium-3 and Deuterium, as they present an aneutronic primary reaction, and a magnetic nozzle exhaust the charged reaction products. This paper presents the model developed, as well as the results of the estimated performance calculations of such a system, which, due to its high exhaust velocity, allows it to reach destinations in the solar system with a larger payload more quickly, and transmit more delta-v than traditional propulsion methods.

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C4,10-C3.5,6,x82163	Sub-Scale Demonstration of a Pulsed Fusion Axial Magnetic Nozzle with a Target-Type Thrust Stand	Dr Nathan Schilling	self	United States

Currently, crewed missions to Mars and robotic missions to the outer planets are hampered by long trip times. Using state of the art technology, it will take 1-2 years for a crew to get to Mars, and 10-20 years for a robotic mission to rendezvous at an outer planet. These long trip times represent increased risk of mortality from galactic cosmic rays and microgravity for crewed missions, and increased programmatic risk for robotic missions. It has been known since the 1960s that using pulsed nuclear fusion propulsion reduces these trip times by up to 88%; 0.25-0.5 yrs for crewed Mars and 1-5 years for the robotic outer planet mission. However, pulsed fusion propulsion is currently hampered by numerous technological challenges, one of which is efficient conversion of exhaust to directed thrust. The leading technology to solve this problem is the magnetic nozzle, but authors disagree as to the most efficient configuration. Previous works have postulated that the solenoidal configuration, with solenoidally-wound coils, is ideal, but recent authors have proposed an alternative most-efficient configuration: the axial configuration, with axially-wound coils. Previously, this research team has tested a smaller, sub-scale version of the axial configuration, showing net thrust via a set of charge collector measurements. However, it is difficult to determine the efficacy of these results due to deficiencies in the charge collector thrust measurement method; for example, at certain points in the experiment the charge collectors show negative thrust, which is non-physical. Therefore, in this work we set out to measure thrust using a more traditional method: a target-type thrust stand which should not have the same deficiencies. We hope to verify the efficacy of the axial nozzle configuration via this new method, showing net thrust. If this can be done, pulsed fusion propulsion will be more feasible, making the solar system more accessible to all humanity.

Co-authors

Dr Hideki Nakashima, Kyushu University, Japan;
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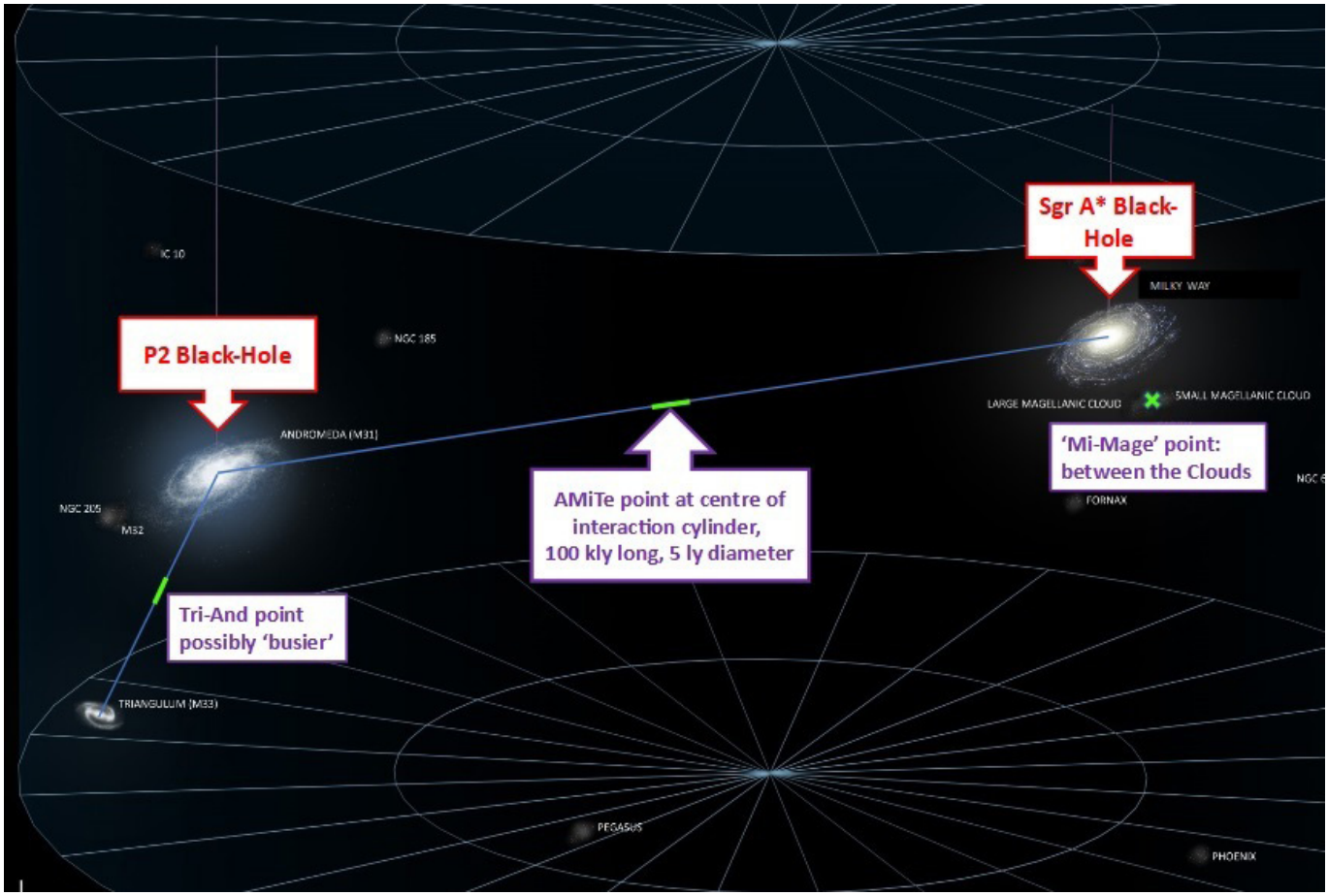
D1,1 Innovative Systems toward Future Architectures: This session explores innovative system concepts, technical capabilities that enable future architectures, new applications, new business models and evolution of the global ecosystem. It also analyses how new challenges such as reduction of environmental impact (space debris, CO2 footprint reduction) can induce new space system architectures, applications, eventually proposing solutions to reduce global warming and debris mitigation. As examples: Could Space based Solar Power contribute to reduction of CO2 emission and make an economically and technically feasible option to meet the energy needs? Will in-space transportation and logistics develop in association with reusable launchers? Which new applications could be enabled ie, Active Debri Removal (ADR), In-orbit Service and Manufacturing (IOSM) or recycling? How would these changes affect the ecosystems? This session objective is to connect innovators and researchers in building a vision of transformation of space systems architecture. In this perspective, the dreams of yesterday are the hope of today and the reality of tomorrow.
2024-10-14 15:15 Orange Hall 3

D1,1,14,x81188	Design and Analysis of the Technical Infrastructure for a Self-Sufficient and Sustainable Intergalactic Hub	Mr Daniel Akinwumi	In-Space Missions Ltd	United Kingdom

This research examines the design and technical challenges of creating a viable and sustainable long-term space habitat, specifically focusing on a conceptual design, the Intergalactic Hub (I-HUB). As humanity stands on the precipice of a new era of space exploration, a comprehensive understanding of the complexities of prolonged human habitation in outer space is pivotal. The study conducts an in-depth analysis of the key design parameters of I-HUB, including advanced life support systems, artificial gravity, food production, habitat structural design, and autonomous operations. It illuminates the critical aspects of these parameters and elucidates the challenges each presents, such as efficient resource recycling, sustainable energy provision, radiation protection, psychological well-being, and habitat resilience. The research further identifies potential areas for future exploration and investigation essential to advancing space habitat design.

Emphasizing multidisciplinary design optimization, the study proposes synergies across multiple disciplines to address these challenges, including bioengineering, environmental science, nanotechnology, astrophysics, sociology, and more. Moreover, it offers impeccable recommendations to overcome these identified challenges, integrating state-of-the-art technologies and innovative design principles. By integrating forward technologies, leveraging AI-driven power management, harnessing artificial gravity, and incorporating a human-centered design approach, this study provides a blueprint for effectively addressing the critical needs of a self-sufficient and sustainable space habitat. Through this detailed investigation, the thesis underscores the significance and potential impact of pursuing research in these areas and their implications for sustainable human spaceflight. It offers valuable insights into the broader objectives of space exploration and the vision of transitioning humanity from mere space explorers to established denizens of the cosmos.



An earlier related idea from *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations*, David F Gahan, in Principium 32 February 2021 i4is.org/principium-32/

D2,4 Future Space Transportation Systems: Discussion of future overall transportation system designs and operational concepts for both expendable and reusable systems for Earth-to orbit transportation and exploration missions considering also emerging space ventures and deep space transportation. 2024-10-16 10:15 White Hall 2

D2,4,11,x87542	Prospects of Space Tugs in Interstellar Development and Their Solutions	Mr Kaizhou Xie	Beihang University (BUAA)	China

Over the years, the application of high-performance upper stages has been a crucial means for launching deep space exploration spacecraft. However, the current upper stages have inherent limitations in their capabilities, with restrictions on the mass that can transport. Typically, the ΔV provided by hydrazine-based fuels is limited, and the available coasting time with LH2 upper stages remains insufficient. By improving existing technological levels in energy supply, propulsion methods, and orbital design, a novel class of spacecraft, known as space tugs, has been developed to address the transportation challenges. This approach leverages a temperature difference of up to 200 C on the spacecraft surface and employs higher energy density nuclear fusion to extend on-orbit operational time. Recent research has explored various propulsion methods, including solar sails, beam propulsion, and nuclear saltwater propulsion, offering high specific impulse (Isp). For instance, under nuclear saltwater propulsion conditions, the total engine exhaust power can reach 427,000 MW, with an Isp of 6,730s. Dynamics effects of solar radiation have been analyzed to obtain thrust density data for solar sails under operational conditions. Functional methods have been employed to derive the neutron flux formula along the longitudinal direction in the nuclear reaction chamber, enabling the determination of the required fuel flow rate to prevent thermal neutron reflux. In these operational modes, the transportation time between Earth and gas giants is significantly reduced. Appropriate trade-offs between time and fuel consumption can be achieved through suitable orbital design. The advancement in computational capabilities in recent years has facilitated the emergence of nonlinear orbits accommodating multiple body gravitational calculations, such as the dual lunar flyby trajectory. Cycler orbits demonstrate exceptional potential, allowing for the permanent presence of large spacecraft and enabling normalized and routine space tug transportation. This work aims to propose potential concepts for future space tugs through computational analysis, focusing on energy, propulsion, and orbital aspects. Various workload magnitudes with valuable utilization methods are analyzed and evaluated. A brief overview is provided, envisioning performance data for an independent space tug working model within a specific workload magnitude and task scope.

Co-authors

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Prof Ming Xu, School of Astronautics, Beihang University, China.

D4,1 Innovative Concepts and Technologies: 1) In order to realize future, programs of space exploration and resource utilization, a focused suite of transformational new system concepts and enabling technologies must be developed during the coming decades. The technical objectives to be pursued should be drawn from a broad, forward-looking view of the technologies and system needed, but must be sufficiently focused, to allow tangible progression and dramatic improvements over current capabilities. 2) Ideally, the concepts should be presented in three categories: 1. Concepts which represent a significant advance, but require laboratory advancement, and 2. Concepts which have been demonstrated to some level in the laboratory, but require demonstration to validate their utility, and 3. Concepts which identify cross-cutting advances which, when combined can be successfully developed to support transformational new system concept. Papers are solicited in these and related areas 2024-10-14 15:15 Turquoise Hall 1

D4,1,3,x83992	Artificial Magnetic Field as Active Shield against Cosmic Radiation	Dr Alessandro Bartoloni	National Insitute of Nuclear Physics - INFN	Italy

The prospect of establishing a permanent human presence on the Moon and eventually on Mars has gained significant momentum, particularly with the involvement of private entities in space exploration and its economic implications. However, residing beyond our planet Earth brings forth a set of challenges, including temperature fluctuations, vacuum conditions, and constant exposure to cosmic and other radiation types. Addressing these issues not only shapes the structure of extraterrestrial habitats but also has psychological and physiological implications. On Earth, our protection against cosmic radiation comes from the atmosphere and, crucially, the natural terrestrial magnetic field, which deflects these radiations within its magnetic bands. Ionizing cosmic radiation poses a significant threat, as prolonged exposure can seriously

compromise human and animal health by altering DNA chains, increasing the risk of cancer, and damaging eye lenses. This fundamental research aims to address the challenge of ionizing cosmic radiation exposure. Current state-of-the-art solutions involve creating habitats beneath thick layers of lunar or Martian regolith to passively shield the inhabited space from external radiation. However, this approach results in living essentially underground, raising serious psychological issues, especially for extended stays such as those envisaged for Mars colonization. The innovative solution proposed in this research is to construct an artificial magnetic shield using a series of electric cables strategically arranged to deflect particles away from the habitat. This design prevents cosmic particles from entering the inhabited zone, allowing for the construction of habitats with large windows, offering panoramic views and reducing psychological stress during the stay. The project envisions the use of an artificial magnetic field generated by an underground toroidal structure composed of superconducting wires (potentially experimenting with magnesium diboride). The magnetic field lines generated will envelop the settlement, located inside the toroid on the lunar surface, effectively repelling cosmic rays. This approach necessitates a highly interdisciplinary investigation from the outset, involving expertise in cosmic rays, space radiobiology, superconducting wires, electromagnetic field generation, and characterization, as well as architectural and civil engineering considerations associated with its implementation. This comprehensive approach underscores the complexity of developing active shielding technologies and highlights the need for collaborative efforts across diverse scientific and engineering domains.

Co-authors
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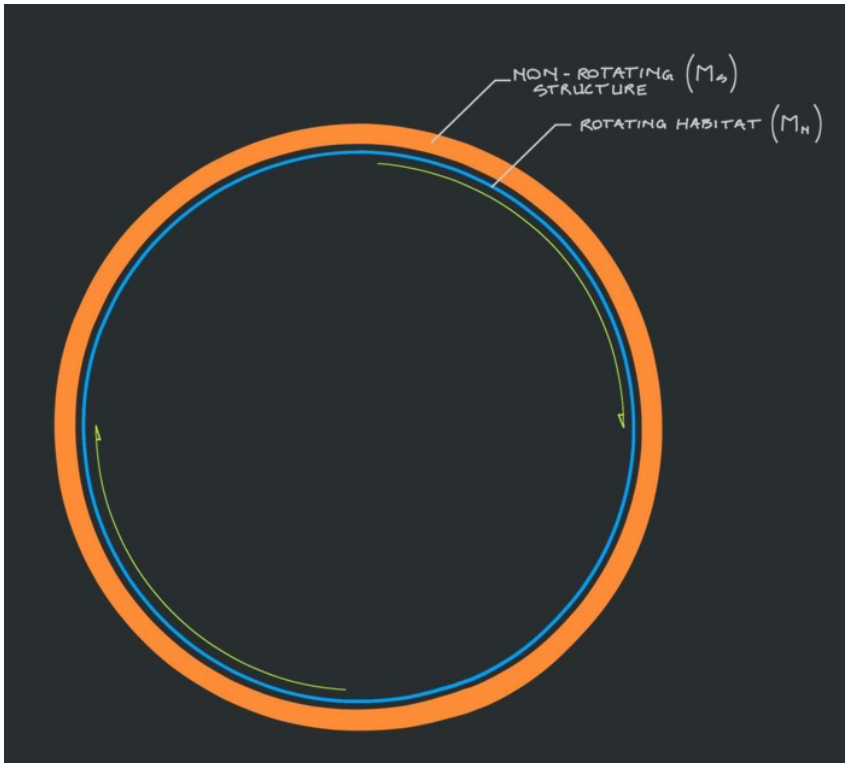
D4,1,9,x80842	Self-Replication Technology for Ubiquitous Space Exploration	Prof Alex Ellery	Carleton University, Space Exploration and Engineering Group	Canada

Self-replication technology offers a radical approach to space exploration that effectively circumvents high launch costs by exploiting extraterrestrial resources. It offers an efficient, rapid yet low-cost approach to lunar industrialisation. The capital cost of launch of a single "cellular" unit is amortised over the subsequent exponential growth in population afforded by self-replication. Indeed, the capital cost may be minimised by launching a "seed" unit (10 tonnes) that initially grows to maturity (100 tonnes) before undergoing self-replication. The concept is not new – it was the central theme of NASA's "Advanced Automation for Space Missions" (1980) that suggested that the approach was highly desirable but required significant technological development. Since then, significant technological advances have occurred which render the self-replicating machine more plausible today. There are several key features that are crucial to self-replication technology. In-situ resource utilisation has migrated from being a minor space research activity to a mainstream one. Although most effort has been focussed on mining water for propellant and 3D printing regolith for outer structures, in-situ resource utilisation may be extended to utilise all the Moon's resources to build a lunar infrastructure. This is the rationale behind the lunar industrial ecology inspired by the constraint of sustainability through recycling. The sustainability constraint is enforced by the necessity for material, energy and information closure. The central spine of the industrial ecology is aluminium processing – we have shown experimentally that lunar highland simulant representing anorthite-rich lunar regolith yields silica and alumina, the latter of which may be reduced to aluminium metal with high purity using the efficient FFC process. Furthermore, aluminium may be supplemented with other lunar-derived additives to yield a suite of alloys for multifunctional applications. We have been characterising the properties of these lunar-derivable aluminium alloys. We expand this resource suite to include iron from lunar ilmenite and nickel-cobalt from buried M-type asteroid material. This generates a demandite list of functional materials that maps to specific applications that include mechatronic components. Manufacture of components may be accomplished by 3D printing, a rapidly evolving technique that minimises material waste. We have demonstrated that DC electric motors may be 3D printed, a major step towards demonstrating 3D printing as a universal construction mechanism. Universal construction is a sufficient condition for self-replication. Mastery of this technology offers exponential industrialisation of the Moon at minimum cost. Self-replication technology represents a revolutionary approach to space exploration whose time has come.

D4,1,17,x86336	Beyond the Limits - Arbitrarily Large Rotating Space Habitats through Structural Decoupling	Mr Elliott Ruzicka	-	United States

Rotating space habitats have been a staple of space habitat design language since Tsiolkovsky's writings dating back to 1903. The notional conception of a rotating space habitat has a maximum theoretical size, which is due to the breaking length of the structural material. While this notional rotating space habitat concept has been universally assumed, it has a glaring design flaw: the structural mass contributes to the centrifugal weight. This flaw inherently limits the structural mass efficiency of the habitat and is solely responsible for the oft-cited maximum theoretical size. Although it might seem unavoidable, the limitations associated with this flaw are not intrinsic to the concept of rotating habitats and can be overcome. This study proposes a novel design solution: decouple the habitat and structure, enabling the habitat to function as a rotating inner ring encased within a static structural ring. By keeping the structural ring static, it need not resist the centrifugal force generated by its own mass, ensuring that the structural mass does not contribute to additional hoop stress. This research focuses on the application of superconducting magnetic levitation of the inner, rotating ring against the outer, static ring, thereby substantially diminishing the hoop stress on the outer ring. The core objective of this research is to validate the hypothesis that decoupling the rotating portion of the habitat from the support structure eliminates size constraints associated with rotating habitats and decreases the amount of structural material required. This validation is achieved through theoretical proofs as well as scale model demonstrations, which illustrate the fundamental principles. Consequently, this allows for the construction of extremely large habitats using rudimentary materials, challenging the predominant view that advanced materials are necessary for such structures. Such a habitat would maintain additional benefits, such as kinetic energy storage and straightforward docking/berthing. The results of this research have immediate implications for reducing the structural mass of prospective rotating space habitat designs and opens possibilities for using common materials in large-scale habitat construction. Given these outcomes, the findings not only pave the way for more efficient and sustainable space habitat construction but also signal a pivotal shift in the field. This research lays the groundwork for a comprehensive re-evaluation of rotating habitat design, underscoring the need for further exploration in areas such as the development of orbital test beds for magnetic levitation, biological testing across different gravity levels, and comparative analyses of structural materials.



The "vicious circle" for rotating habitats designed to provide simulated gravity for human inhabitants is illustrated here in an earlier publication by Elliott Ruzicka - www.orbital.design/blog/the-decoupled-orbital. If the support structure of the wheel rotates with the inhabitants then it contributes to the hoop stress as the structure rotates. This leads to an increasing demand for tensile strength reminiscent of the tether stress problem for a space elevator. But in the case of a habitat the mass which must rotate is only the human habitat and, given a very low friction interface between the hoop and the habitat both need not rotate.

D4,4 Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond: Knowledge about space beyond our solar system and between the stars – that is interstellar space – is lacking data. Even as IBEX, NASA's Interstellar Background Explorer, studies the edge of our solar system, it still is confined to earth orbit. Arguably, some of the most compelling data to understand the universe we live in will come from sampling the actual environment beyond our solar system as Voyager 1 and Voyager 2 spacecraft are on the threshold of doing. In the 36 years since the Voyager probes' launches, significant advances in materials science, analytical chemistry, information technologies, imaging capabilities, communications and propulsion systems have been made. The recently released IAA study: "Key Technologies to Enable Near-Term Interstellar Scientific Precursor Missions" along with significant initiatives like the DARPA seed-funded 100 Year Starship and the Breakthrough Starshot project, signal the need, readiness and benefits to aggressively undertaking interstellar space missions. This session seeks to define specific strategies and key enabling steps to implement interstellar precursor missions within the next 10-15 years. Suggestions for defined projects, payloads, teams, spacecraft and mission profiles that leverage existing technological capacities, yet will yield probes that generate new information about deep space, rapidly exit the solar system and which can be launched before 2040 are sought.
2024-10-17 10:15 Turquoise Hall 1

D4,4,1,x89587	Advanced Propulsion Technologies for Rapid Implementation of Interstellar Precursor Missions	Mr Angelo Genovese [1]	Thales Electron Devices GmbH	Germany

Today, Voyager 1 has travelled farther from Earth than any other manmade object, collecting data just beyond the heliopause in the Very Local Interstellar Medium (VLISM), 47 years after its launch. This first interstellar mission is however strongly limited by a final speed of 3.6 AU/year. To go beyond this achievement, two challenging missions are currently being designed: the Johns Hopkins Applied Physics Laboratory's Interstellar Probe (ISP) and the Jet Propulsion Laboratory's Solar Gravity Lens (SGL) mission. In order to design a technically feasible mission with minimum development risk, the ISP uses traditional chemical propulsion technology; the baseline launch would be in 2036 using the SLS launcher with additional Centaur and Star 48BV boosters. This launch would put the probe on a direct trajectory to Jupiter, and after a passive gravity assist it would speed out at about 7AU/year, two times the speed of Voyager 1. The SGL mission is far more ambitious than ISP; it begins its primary science mission at the Sun's gravitational lens distance of 650 AU. Reaching the SGL focal region at 650 AU in less than 30 years implies a hyperbolic escape velocity in excess of 20 AU/year. Currently, solar sailing in combination with a very close (0.1 AU) perihelion represents the only method of propulsion for a realistic mission to reach solar system exit velocities of 20+ AU/year. However, this propulsion technology needs to be matured and is probably not compatible with a launch before 2050. However, there are other propulsion technologies which could enable challenging near-term interstellar precursor missions by either increasing the achievable delta V, or reducing the required flight time, or mitigating the necessity of very expensive launches, or allowing for higher payload mass ratios, or a combination of these improvements. Of particular interest are electric propulsion systems powered by solar (SEP), nuclear (NEP) or laser (LEP) power sources, nuclear and laser thermal propulsion, solar and electric sails. This paper gives an update on the status of these advanced propulsion concepts and compares them with the ISP and SGL propulsive approaches. Furthermore, it provides examples of other interstellar precursor missions which could be launched before 2050.

Co-authors
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[1] Angelo Genovese is a member of the board of the Initiative for Interstellar Studies

D4,4,2,x89414	Advanced Capabilities for Nuclear Electric Powerplants for Interstellar Precursors [1]	Mr Roger X Lenard	LPS	United States

In recent years there has been a number of advances in fields tangential to, but including nuclear reactors that gives promise to space nuclear electric power systems whose specific mass, kg/kWe, achieving values 20 kg/kWe. Historically, the concept was to have very high temperature reactors, 1,300 Kelvin, driving relatively inefficient thermoelectric system with high temperature radiators. The concept was that since radiators comprised a relatively large fraction of the systems mass, the radiators should be made as small as possible. The advent of composite materials has ushered in the potential for large, lightweight radiators, which can enable highly efficient systems, generating moderate quantities of electrical power, with low values of power system . Little Prairie Services, LLC has pioneered work in several areas leading to an integrated system with a power system 20 kg/kWe at electrical power levels 375 kWe. The power systems themselves are presently design to operate for 5 full power years, however, we discovered that given the correct conditions, velocity additions 100 km/s were feasible with approximately 1-2 full power years of thrusting, followed by 20 years operations at 10 km/s.
In this paper the author discusses the advances made by LPS in concert with research from other organizations to improve efficiency, power levels, and to minimize system mass with a few examples of potential implications of these advances. The technologies are all quite advanced in development status, but have not been integrated in this fashion before.

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

Reaching "nearby" interstellar space has always been challenging due to the long distances and associated long travel times. Combinations of near-term, planned, large chemical rockets with multiple stages and planetary gravity assists can potentially double the solar system escape speed of Voyager 1 of 3.6 au/yr. The addition of orbital propellant "depots" and super heavy-lift launch vehicles (SHLLV) in the class of the Starship Super Heavy vehicle could potentially enable a Voyager-class scientific satellite to leave the solar system at an escape speed of up to 10 au/yr, but even that speed (47 km/s) falls short of some of the older notional goals of 20 au/yr. The latter was envisioned for, eg, the Thousand AU (TAU) mission, with a goal of reaching a distance of 1,000 au from the Sun during a flight time of 50 years. Of the 20 Interstellar Probe studies and concepts articulated from 1960 through 2022, three have been based upon nuclear electric propulsion (NEP). Of these, only 2 "promised" flyout speeds 20 au/yr or greater, with the third providing an average speed of 13 au/yr to a distance of 200 au. The reactors considered in the two faster NEP-enabled studies ranged from power outputs of 500 kWe to 1 MWe with electric thruster operational times of 8 to 12 years with specific mass of the propulsion systems of 12 to 17 kg/kWe. These detailed NEP concepts were last considered over 35 years ago. Since that time many advances have been made in both gridded ion thrusters and Hall thrusters, as well as in more advanced deep-space electric propulsion systems. The latter include the solar electric propulsion (SEP) systems used on the Deep Space 1, Dawn, and ongoing Psyche missions, all using xenon for propellant. Masses and reliabilities for constituent parts for such SEP missions are now well known. Similar required advances in space nuclear reactors for NEP missions have, however, continued to lag. Questions of durability, autonomous operation, and decade-long reactor lifetime and associated reactor and waste-heat rejection masses continue to remain a problem, although these problems were better defined in the course of the Project Prometheus pre-phase A study conducted by NASA almost 20 years ago. We re-examine the state of the art in enabling long-term NEP operation required for a rapid interstellar precursor mission as compared against more recent nuclear technologies and more recent implementation of such missions using chemical means.
Co-authors
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[1] Some curious typography in this abstract has been adjusted from the PDF at iafastro.directory/iac/paper/id/89414/summary/

D4,4,7,x91195	Interstellar Systems at the Edge of Chaos	Dr Angelo C J Vermeulen	Delft University of Technology (TU Delft)	The Netherlands

Human interstellar exploration involves navigating through a realm of significant uncertainty. Assessing the exact impact and consequences of moving at high velocities through the interstellar medium is challenging. Interstellar space is home to considerable amounts of cosmic dust, comprising microscopic particles with a wide range of sizes and compositions. At high speeds, spacecraft face significant risks from accumulating collisions with these particles. However, the expansive nature of interstellar space currently makes it impossible to accurately measure and chart the spread of this dust along specific trajectories. Interstellar space is also filled with high-energy cosmic rays, emitted by distant stars and other cosmic bodies. Dominated by protons and atomic nuclei, these cosmic rays travel nearly at the speed of light. The enduring effects of exposure to such radiation on the spacecraft, its crew, and the life support systems that sustain them remain unknown. The question then arises how to design an interstellar spacecraft capable of withstanding such inherent uncertainties. The solution requires a system robust enough to remain functional across diverse conditions. To try to cover for all possibilities in a top-down approach quickly becomes unfeasible. A promising direction is a bio-inspired adaptative approach. The Evolving Asteroid Starships (E|A|S) project integrates the utilization and recycling of local resources, self-organization, and bioregenerative principles to create a resilient spacecraft design. This aligns with the top priorities from NASEM's 2023 decadal survey, emphasizing space research on circular materials and bioregenerative life support. Within the framework of the E|A|S project, two distinct computer models have been developed, aiming for their eventual integration into a unified multi-model system. The inspiration for these models came in part from ESA's MELiSSA program and a visionary 1982 NASA study on a self-replicating lunar factory. Once living artificial ecosystems and self-organizing architectures are deployed, one is confronted with potential chaotic behavior characteristic of complex systems. Sets of critical conditions that can push an otherwise stable self-sustaining system into collapse and failure were identified. It's crucial to gain a deeper understanding of how these systems function over extended periods, both under ideal environmental conditions and within the unpredictable exacting context of the interstellar medium. To address these challenges, the key drivers of systemic resilience (or lack thereof) were identified through an exploration of the characteristics of the individual components of each system. Moreover, potential mitigation strategies were also explored. These include enlarging buffer capacities, integrating redundancy, and enhancing system adaptability.

Co-authors

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D4,4,8,x90437	Technology Development Pace Coefficient for Reliable Interstellar Travel Timeline	Mr Antoine Faddoul	Tony Sky Designs Group	United States

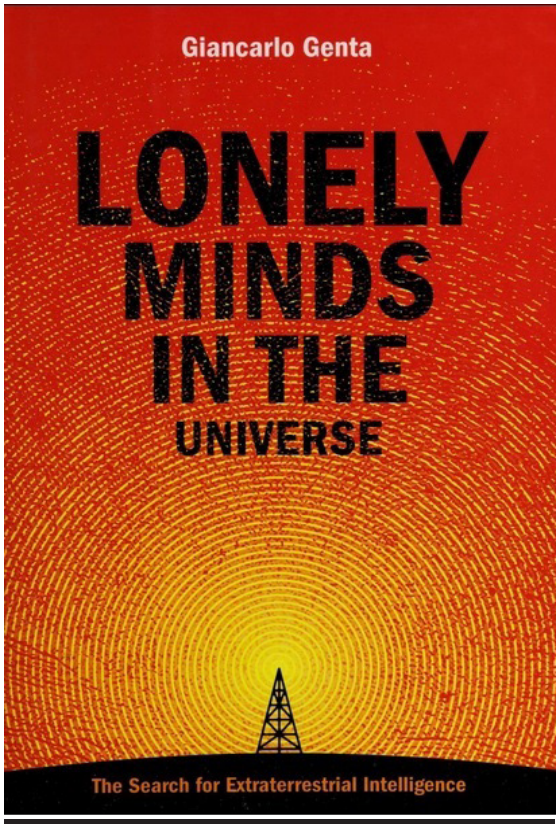
Establishing a timetable for interstellar travel requires assessing the elements of a sequence of inter-dependent missions from LEO to Lunar, interplanetary, all the way to interstellar. Such evaluation must account for a grid of interconnecting components and milestones including the current and anticipated advancements in space travel technology. Space travel projects belongs to an extraordinary projects category of relatively novel and complex projects that usually run behind schedule. Furthermore, the interstellar timeline extends over a century exposing it to more influence from elements of rare occurrence with projects of shorter duration. Thus, there is more possibility for scientific breakthroughs, technology developments, political and funding variations, inconsistent public and sociopolitical interest, wars, and pandemics among others. This study investigates quantifying the space technology development pace based on the parameters involved, and developing a coefficient that could be applied to make interstellar travel schedules more realistic.

The Integrated Space Plan (ISP) and the Roadmap to the Stars (RMTS) utilized comprehensive plans with incremental progress to assemble decades-long schedules. The large number of unknowns involved in the assessments require constant revisions to the timeline. In the past few decades there was a pattern of delays in space technology and space travel development while some telecommunication evolutions were relatively rapid. RMTS applied a technology development pace coefficient (TDP) in 2022 among measures to improve projection of

technology advancement in space travel. This study itemizes the coefficient factors' quantification, expands the static model equation, and runs 50 iterations of Monte Carlo simulation to compare results.
The factors utilized in the technology development pace coefficient include the (i) scientific breakthrough occurrence, (ii) lag time in rebuilding a technology, (iii) political events and funding fluctuation, (iv) specific technology connexion with common technology, (v) interstellar roadmap progress, (vi) private space travel progress, (vii) sociopolitical affairs and public interest, and (viii) global events including pandemics, natural disaster among others. The ratio of the elements is based on their occurrence, duration, and effects. While such elements are not easy to quantify, it was possible to assign numeric figures and derive equations for the coefficient based on the number of years they delayed/saved. The basis for the quantification of the elements will change with time requiring revisions and adjustments. Applying the TDP coefficient to interstellar travel which has a relatively longer interval allows to factor in events that are rare enough to be considered for shorter term projects.

D4,4,9,x81405	Space Arks for the Nearest Stars: a Feasibility Evaluation	Prof Giancarlo Genta	Politecnico di Torino	Italy

Since the first discovery of an exoplanet we realized that a large number of stars have a planetary system, and now that we are able to discover planets smaller than Jupiter size, we know for sure what before we just expected (and what science fiction writers are saying since almost one century): terrestrial planets are common and a number of them lie in the habitable zone of their star. We discovered that even our closest star has a terrestrial planet. In the next years we expect to start the process leading us to become a multiplanetary species, by first exploring and then colonizing the Moon and Mars and other bodies of the solar system. Plans to launch precursor interstellar probes are also being studied and also true interstellar robotic spacecraft are being designed, even if for now we speak of microprobes performing a fast flyby mission like that of the Starshot Project. Microprobes, performing a flyby and later remaining in the destination planetary system require just moderate and predictable advances in technology and are a required step toward human interstellar exploration and colonization. The aim of the present paper is to study the possibility of performing true interstellar human missions of the simplest type in a predictable timeframe. Such simple interstellar missions are based either on space arks (or generation ships) or slow interstellar ships carrying a hibernated crew. In both cases a nuclear propulsion system – either an advanced fission or a fusion thruster is assumed – which does not require advances in basic science, but only the development of technologies which are already under study, can be used. Since fusion thrusters must be considered low thrust engines, both cases of constant ejection velocity and limited variable ejection velocity are considered and the optimal specific impulse is sought for. The study concentrates on the design of what is usually referred to as a 'slow boat', ie an ark of small size travelling at a small percentage of the speed of light, to reach the extrasolar planet Proxima Centauri b in less than 450 years. The habitat – assumed to be similar to a space settlement of a relatively small size – and of the thruster are mainly considered, since these elements are assumed to be the most critical ones to assess the feasibility of such an interstellar exploration and colonization mission.



Lonely minds in the universe, Giancarlo Genta, Copernicus Books in association with Praxis, 2007

Project Lyra Update

Starships and Swarms

Project Lyra, the continuing mission of i4is to explore strange new interstellar objects (ISOs), began in 2017 soon after the discovery of the first ISO 1I/'Oumuamua [1]. In this article Adam Hibberd, our lead astrodynamicist and key member of the Project Lyra team, considers how a mission to Oumuamua could locate this small, dark object in deep space, given the positional uncertainties, and looks at the potential value of using Nuclear Thermal Propulsion for part of the mission.

Adam Hibberd

As a contributor to Project Lyra, the investigation of spacecraft missions to the first interstellar object to be discovered in our Solar System, designated 'Oumuamua, I was responsible for the development of a powerful software tool called 'Optimum Interplanetary Trajectory Software' (OITS). It is through exploiting OITS to investigate 'Oumuamua as a target that I introduced myself to the Project Lyra team, who had already conducted some investigations of their own on the subject by this time.

For an overview of the results of this research, spanning several peer-reviewed papers and preprints it turns out there are several different routes a chemical-rocket-propelled spacecraft could exploit to catch-up with 'Oumuamua. The emphasis is on chemical propulsion due to its high 'Technical Readiness Level' (TRL) and, conveniently, it is a high thrust option rendering the results of OITS both valid and pertinent.

The following are the feasible trajectory options for Project Lyra with chemical propulsion:

1) A Solar 'Slingshot' or Solar Oberth Manoeuvre (SOM)
2) A Jupiter Oberth Manoeuvre (JOM)
3) A Passive Jupiter Gravitational Assist (PJGA)
4) A Double Jupiter Gravitational Assist (DJGA)

Note that a direct route is not listed above as it requires too high a mission ΔV, an important finding highlighted in the first Project Lyra paper. But it doesn't end there, it turns out there are plenty of further problems in the realisation of a mission to 'Oumuamua.

The main issue is simply one of uncertainty as to where 'Oumuamua will be in ~30 years or so time, which would be around the time the putative Lyra craft would catch the target.

There are two contributing factors to this positional uncertainty, both associated with the calculation of 'Oumuamua's trajectory as it encountered the inner solar system. The first is the short time span over which 'Oumuamua ephemerides were measured, to wit, the overall observation cadence started from 14th October 2017 (prediscovery by the Catalina Sky Survey), continued through to the 19th October initial detection by Pan-STARRS 1, and finally ended at the last date the Hubble Space Telescope observed 'Oumuamua before it became too dim on 2nd January 2018.

The second factor was the presence of a non-gravitational acceleration clearly and unambiguously identified by performing a fit to 'Oumuamua's trajectory as it receded from the Sun. There is a lot of debate and even controversy over the cause of this anomalous acceleration which we shan't delve into here, though no one disputes its presence and although the error bar on this is more than would be desired, nevertheless the magnitude of this acceleration compared to its standard deviation, makes it a significant discovery.

[1] More details of this pioneering work in Paul Gilster's Centauri Dreams *Project Lyra: Sending a Spacecraft to 1I/'Oumuamua (formerly A/2017 U1), the Interstellar Asteroid* (www.centauri-dreams.org/2017/11/10/project-lyra-sending-a-spacecraft-to-1ioumuamua-formerly-a2017-u1-the-interstellar-asteroid/) and our first academic paper on arXiv with the same title (arxiv.org/abs/1711.03155).

When we consider both influences on uncertainty, we find that in 30 years hence, the lateral position error of 'Oumuamua is on the order of one or two Moon distances. This would appear to render a mission (which would naturally have to return useful data on 'Oumuamua back to Earth) an impossibility, especially when one considers the encounter distance from the Sun would be ~ 200 au, and thus 'Oumuamua would be exceedingly dim. But let's now look at the LORRI telescope.

If we examine the performance of the Long-Range Reconnaissance Imager (LORRI) telescope on board New Horizons (the NASA mission destined for Pluto in 2015), it managed to detect Pluto at a maximum distance of d ~ 170 million km. Clearly with sufficient exposure time, New Horizons could image Pluto at this huge distance. Project Lyra has conducted a detailed analysis of this and has discovered with a significantly longer exposure time (~ 11 hours), the LORRI should also be able to observe 'Oumuamua at the low brightness levels previously mentioned (even lower than Pluto).

Investigations reveal that for the nominal Project Lyra mission with a Solar Oberth at 6 SR (Solar Radii) and journey time of 22 years, first detection would occur 43 hours in advance of closest approach. ie ~5 million km before reaching 'Oumuamua. (As a sanity check, assuming an inverse square drop-off with Sun-distance, this scales up nicely, ie to easily within an order of magnitude of the previously quoted 170 million km for New Horizons.) Note also that the LORRI telescope has a resolution of 5 microradians, and at a distance of 5 million km, this translates to a pixel size of 25 km, which is ~100 times 'Oumuamua's diameter. (Do read on as this apparent obstacle will be resolved further down.)

At any rate, putting aside this difficulty and assuming an Earth-Moon distance uncertainty in 'Oumuamua's lateral displacement of ~500,000 km, with detection 43 hours out, we would need therefore a ΔV from the approaching spacecraft of 3.2 km/s. It turns out that this would be practically speaking beyond a chemical rocket, especially after a journey time of 22 years or so in deep space. But there is a possible alternative solution to a New Horizons LORRI telescope onboard the Lyra craft.

Alongside i4is's colleagues at Space Initiatives Inc, i4is is currently working on a NIAC, which stands for 'NASA Innovative and Advanced Concepts'. This work is currently in Phase 1, and is to do with optical communications of a swarm of interstellar probes and Earth. We have also submitted a NIAC proposal concerned with the realisation of a technology known as 'flat or folded optics'. This has already been mentioned briefly in our previously published preprint about swarming our Sun's nearest neighbouring star, Proxima Centauri with interstellar laser sails, this paper can be found in Eubanks et al, *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* (arxiv.org/abs/2309.07061), and the relevant section is 3.2.

A flat optical device would be 1,000th the mass of a LORRI, and around one 10th of the LORRI area, but would be able to achieve the same resolution. This introduces the possibility of using a small probe instead of a large one. We can calculate the distance this probe would have to be from 'Oumuamua to resolve the object if it had the flat optics technology (ie 1 pixel < 250 m) and it turns out to be ~ 50,000 km. But even so, on its own it could never get that close since we have seen that a ΔV above 3.2 km/s would probably be unrealistic.

But now what happens exactly when we contemplate the possibility of more than one, or even a swarm of spacecraft for Project Lyra?

For the moment let us consider the possibility of just two spacecraft, both chemically propelled. Furthermore, we shall discard the SOM route to 'Oumuamua, identified in (1) above, since it is simply too complex and technologically demanding. Which of the remaining trajectory options would be optimal?

I have done a lot of research on this problem and have discovered that for chemical missions, we should reject both the single JOM (alternatively called a 'powered' Jupiter gravitational assist - GA) and the double (ie the DJGA). As far as the latter is concerned it turns out that the extra 6-year delay in returning to Jupiter for a second GA, after already having conducted the first, renders this a significantly suboptimal route. It is also deficient in that it is a far more complex alternative to the straight-forward single GA. However why should we reject the JOM option, surely one would expect this to be more effective than the PJGA option as it delivers more kick at perijove?

Surprisingly enough, and I reiterate I have investigated this extensively, it is nonetheless more efficient to fire any extra rocket boosters the Lyra craft might have immediately on the Earth-escape leg of the journey and none at Jupiter, than delay the booster's thrust until Jupiter is reached – this is the optimal solution based purely on the mechanics of the system. But there is no surprise here, this is precisely the solution preferred by the Interstellar Probe study which was conducted by the Johns Hopkins University (JHU), into a chemical mission beyond the heliopause and into the Interstellar Medium (ISM).

But there are other issues with the Jupiter Oberth option which would also make the JOM challenging. First of all, in the case of a liquid cryogenic Centaur stage, there would be leakage and boil-off of LH_2/LOX during the lengthy Earth-to-Jupiter transfer; and second, there would also potentially be significant degradation of solid stage performance from prolonged exposure to space. Moreover the use of the Centaur stage only becomes tenable when it is exploited as soon as possible after lift-off, waiting until Jupiter would clearly not be plausible.

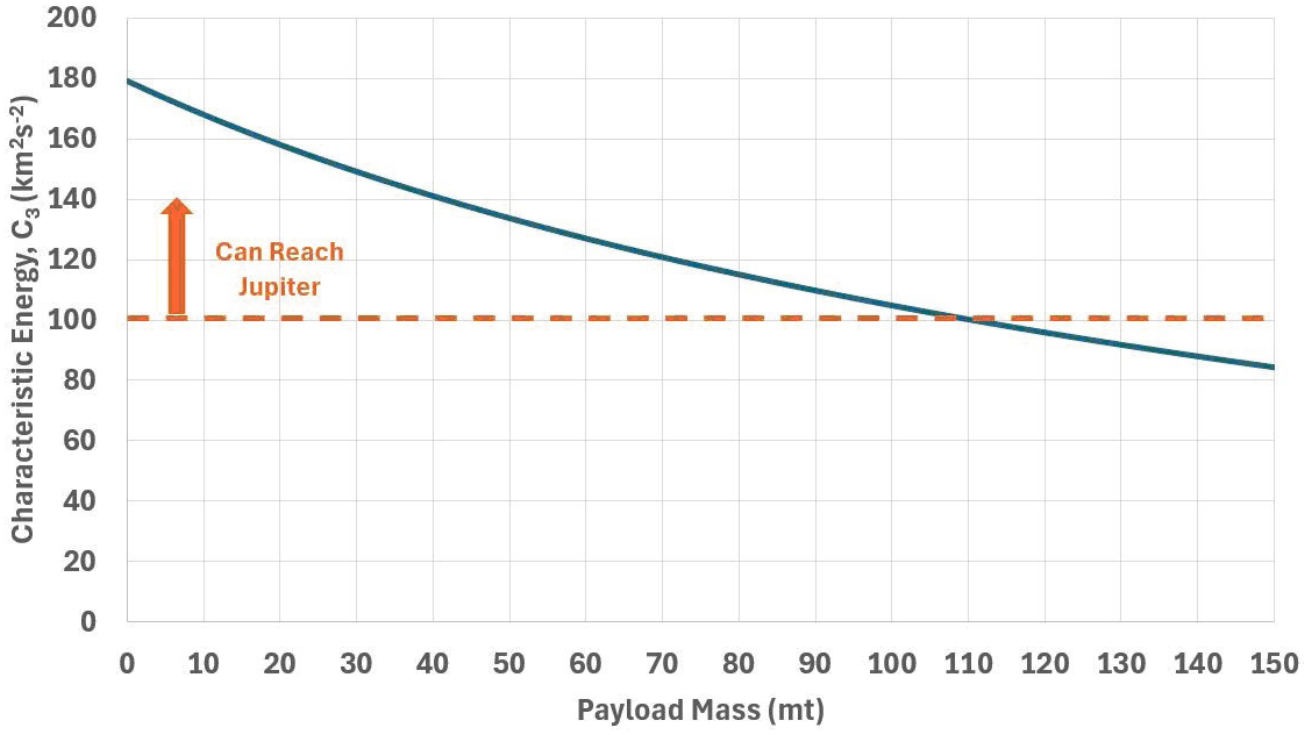
With all this preamble over, let us now come to the knub of this article, and that is using a SpaceX Starship to reach 'Oumuamua.

Many papers have been written on the possibility of exploiting the NASA Space Launch System (SLS) for Project Lyra, but the question is: 'will this be at all likely?' The quick and most likely answer is 'no'. The SLS is booked up to ARTEMIS 5 in 2030, and in my opinion, with a PJGA launch year in either 2031 or 2032, it would be difficult to persuade NASA to dedicate a full SLS to Project Lyra. The easier and more sensible strategy is to concentrate on the SpaceX Starship, a far more likely prospect, especially with Elon Musk's plans to ramp up production of this powerful launch vehicle to support his lunar and interplanetary ambitions.

Furthermore, he intends to introduce the infrastructure necessary for LEO refuelling of a Starship, and the current planned transfer of 1,000 metric tons (mt) of propellant opens the possibility of Earth-escape missions, unattainable by a single un-refuelled Starship. I decided to derive the Earth Characteristic Energy, C_3, achievable by a Starship in LEO refuelled with 1,000 mt of propellant. Refer to Figure 1.

Figure 1

Characteristic Energy, C_3, of a SpaceX Starship in LEO Refuelled with 1000 mt Propellant against Mass of Payload

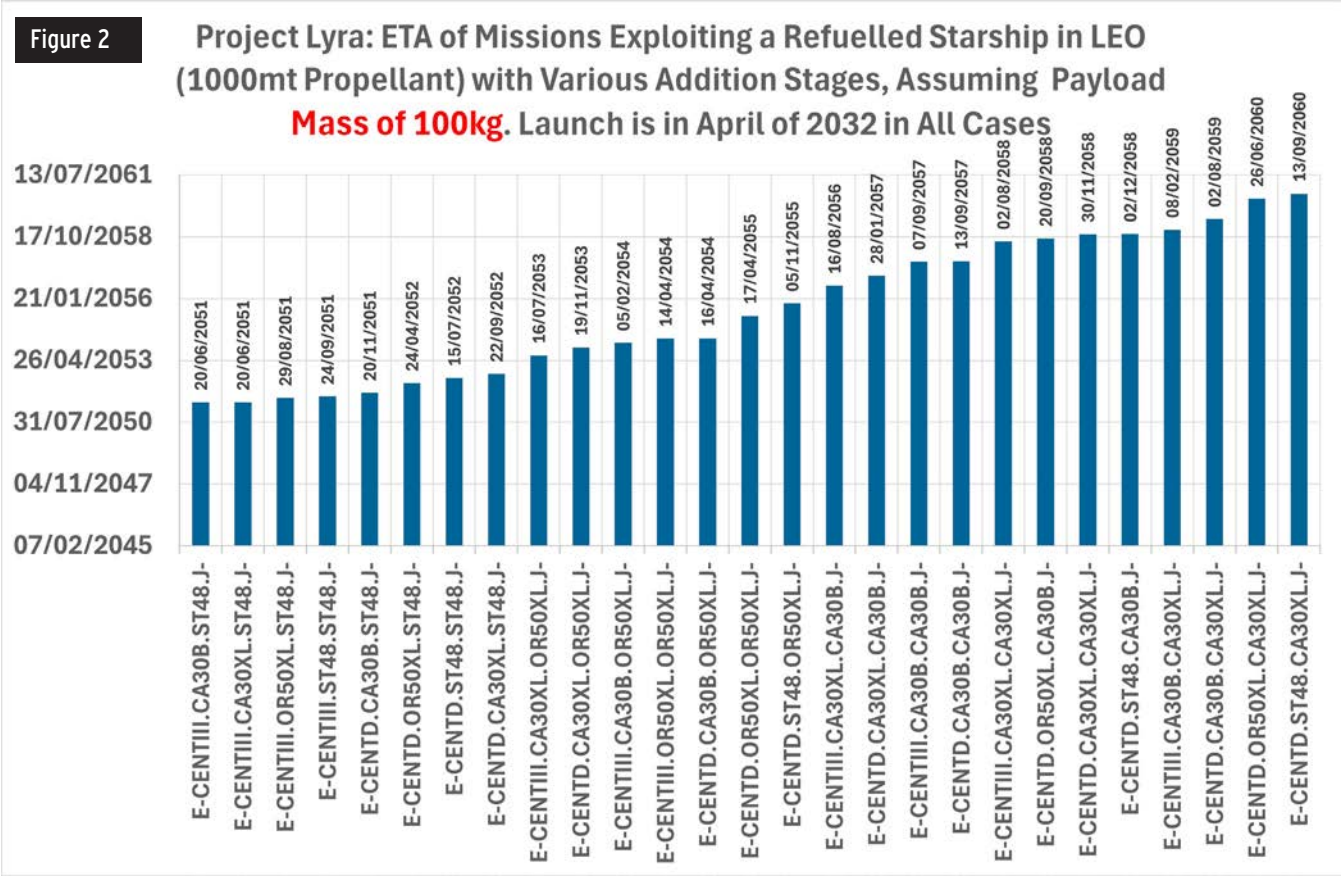


We can see that a refuelled Starship can carry up to 110 mt of mass payload to Jupiter. Moreover a Starship payload bay is 17 m x 8 m, which is quite a capacity, so what about adding some stages onto the Project Lyra payload to give an extra kick where the Starship has finished off? I tried up to three extra stages and a range of different rocket stages, summarised in the Table below.

Booster Stage	Exhaust Velocity (km/s)	Total Mass (kg)	Dry Mass (kg)	Propellant Mass (kg)	Length (m)
STAR 48B	2.8028	2137	124	2013	2.03
ORION 50XL	2.8647	4306	367	3939	3.07
CASTOR 30B	2.9649	13971	1000	12971	3.5
CASTOR 30XL	2.8866	26406	1392	25014	6.0
CENTAUR D	4.3512	16458	2631	13827	9.6
CENTAUR III	4.009	20830	2247	18583	12.68

In order to translate these spacecraft and rocket combinations into optimal trajectories to 'Oumuamua, we must apply my software known as OITS (Optimum Interplanetary Trajectory Software), NOT in minimum 'ΔV' mode, but instead in minimum 'total flight duration' mode, since we KNOW the precise ΔVs at Earth and Jupiter – the former is simply a question of applying the famous rocket equation of Tsiolkovsky, and the latter is naturally set to zero or a negligibly small upper bound - as articulated already, we need to follow a PJGA trajectory, as this is the optimal route.

Figure 2



I did precisely this investigation with three Project Lyra masses, 100 kg, 500 kg and 860 kg (refer Figures 2 to 4) . The logic behind the selection of 500 kg (Figure 3) is that is about the same as the New Horizons spacecraft to Pluto and further the reason for 860 kg (Figure 4) is that this is about the mass of the proposed interstellar probe. The 100 kg value (Figure 2) is so that we have a handy theoretical baseline as to what is achievable by a refuelled Starship.

Figure 3

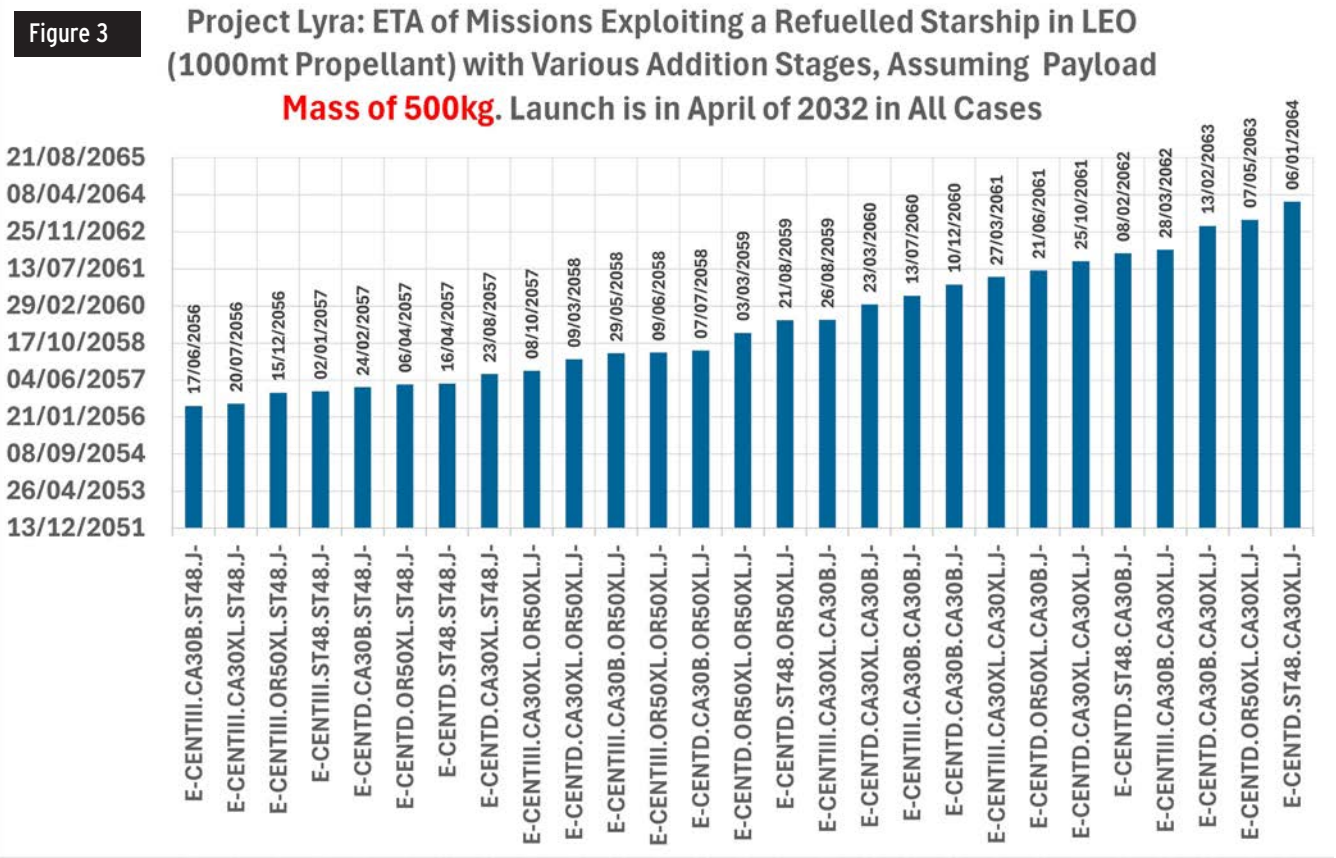
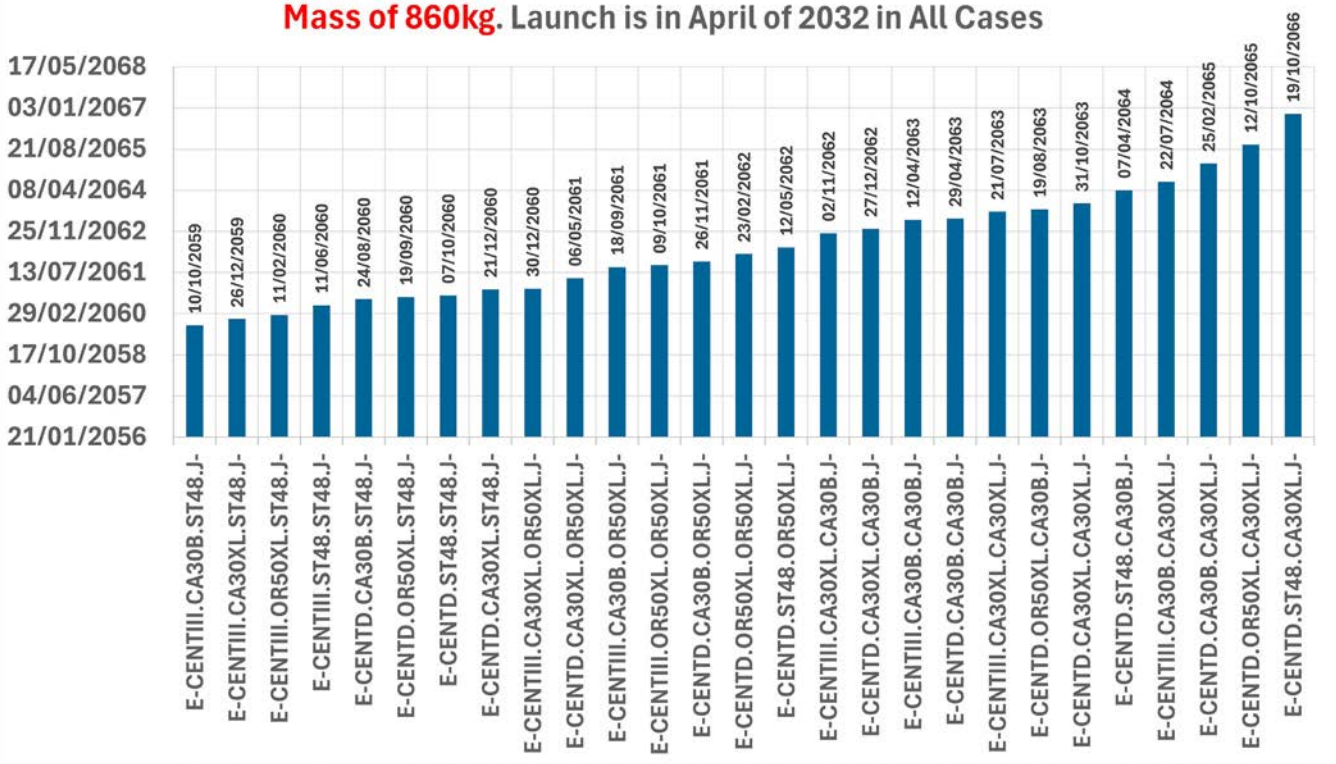


Figure 4



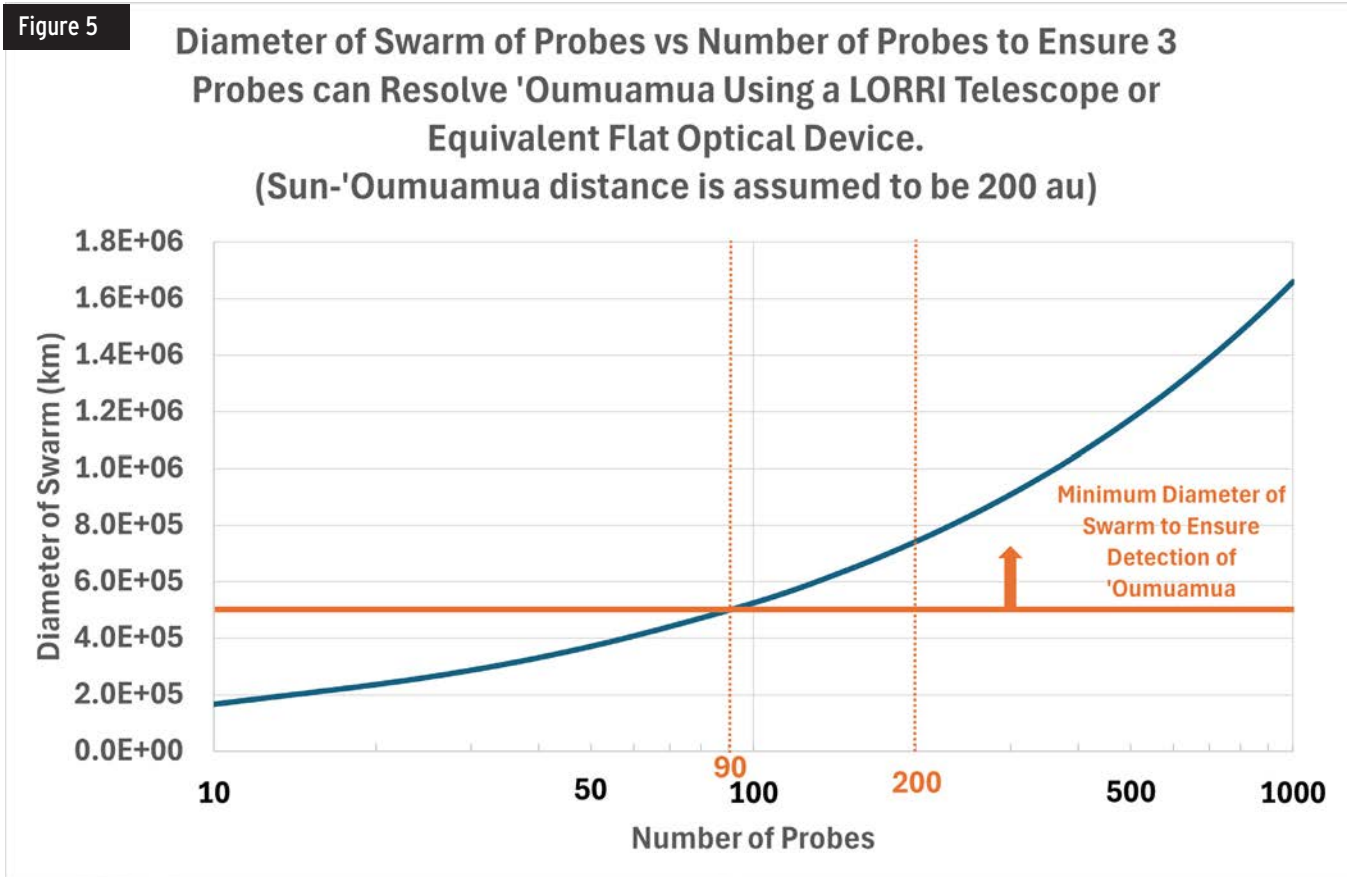
To this end we find that in principle, with a PJGA and a Starship, we can achieve arrival times at 'Oumuamua as early as 2051, which is one year sooner than the nominal Project Lyra SOM mission which assumes 6SR perihelion. The 500 kg and 860 kg missions have slightly later ETAs in 2056 and 2059 respectively. In all cases the Centaur III is only slightly preferred over the Centaur D, though the requirement to fit inside the cargo bay (length ~17m) with any additional stages attached lengthwise, would seem to make the latter stage preferable as it is quite considerably shorter.

But what, in practice would the mass of the Lyra craft be? The following analysis endeavours to investigate this.
If we have a flat optics device capable of achieving what the LORRI can achieve with 1,000th of the mass, let us also downsize the overall spacecraft mass of New Horizons (~500 kg) by a similar ratio giving a mass of the spacecraft of ~0.5 kg, that is quite small and introduces the possibility of that 100 kg overall payload mass discussed above, potentially holding ~200 of these putative 0.5 kg craft in all. If we assume they are distributed across a plane in a hexagonal close packed arrangement, how far apart must this swarm of spacecraft be in order that three, say, must detect 'Oumuamua?
First, as we have seen, for a probe to resolve 'Oumuamua by a pixel, it needs to be within d = 50,000 km of 'Oumuamua. Assuming hexagonal close packing of the swarm, the distance between adjacent probes so that three are able to resolve 'Oumuamua, turns out also to be R = 50,000 km. this corresponds to an areal number density, ρ, as follows:

$$\rho = \frac{2\sqrt{3}}{3R^2}$$

which in turn gives $\rho = 4.6 \times 10^{-10}$ km^{-2}. For N=200 probes, that translates to a circular swarm diameter of ~ 0.75 million km, or 0.005 au. Figure 5 gives the dependency of swarm diameter on number of probes. If we examine Figure 5 we see that in order to achieve an overall swarm diameter of around 500,000 km (which as already mentioned is 'Oumuamua's positional uncertainty), we would need as few as N ~ 90 probes. However let us proceed with the assumed N=200, with a swarm diameter of ~ 0.75 million km, because that means we are building into our mission design some tolerance to larger errors in 'Oumuamua's position.

Figure 5



As already mentioned, at a distance of 5 million km from closest approach, and with an 11 hour exposure time, the swarm should be capable of detecting 'Oumuamua. For our Starship mission with 100 kg payload, that turns out to have a spacecraft arrival speed of 21.4 km/s wrt 'Oumuamua, thus imaging would take place at ~ 65 hours before closest approach.
The closest probe to 'Oumuamua in the lateral hexagonal-packed plane arrangement would be at most displaced laterally from 'Oumuamua by ~22,000 km. Figure 6 gives the apparent lateral velocity of 'Oumuamua as observed by this probe.

As previously mentioned at 65 hours out, a pixel in our flat-optical device would be ~25 km at this distance, and it turns out 'Oumuamua would take only about 271 seconds to traverse this pixel. Compare this with the exposure time of 11 hours, one would be surprised if 'Oumuamua could be resolved at all at this distance. Plot 7 gives the ratio of pixel transit time against exposure time as the probe approaches 'Oumuamua, and from this figure we can conclude that the most likely time we could observe 'Oumuamua would be from around quarter of an hour before closest approach.

Figure 6 Project Lyra: Lateral Velocity of 'Oumuamua as Observed by the Closest Probe to it in a Swarm and Assuming an Inter-Probe Distance of ~ 50,000km vs. Time Before Encounter (Rel. Speed of Swarm = 21.4 km/s)

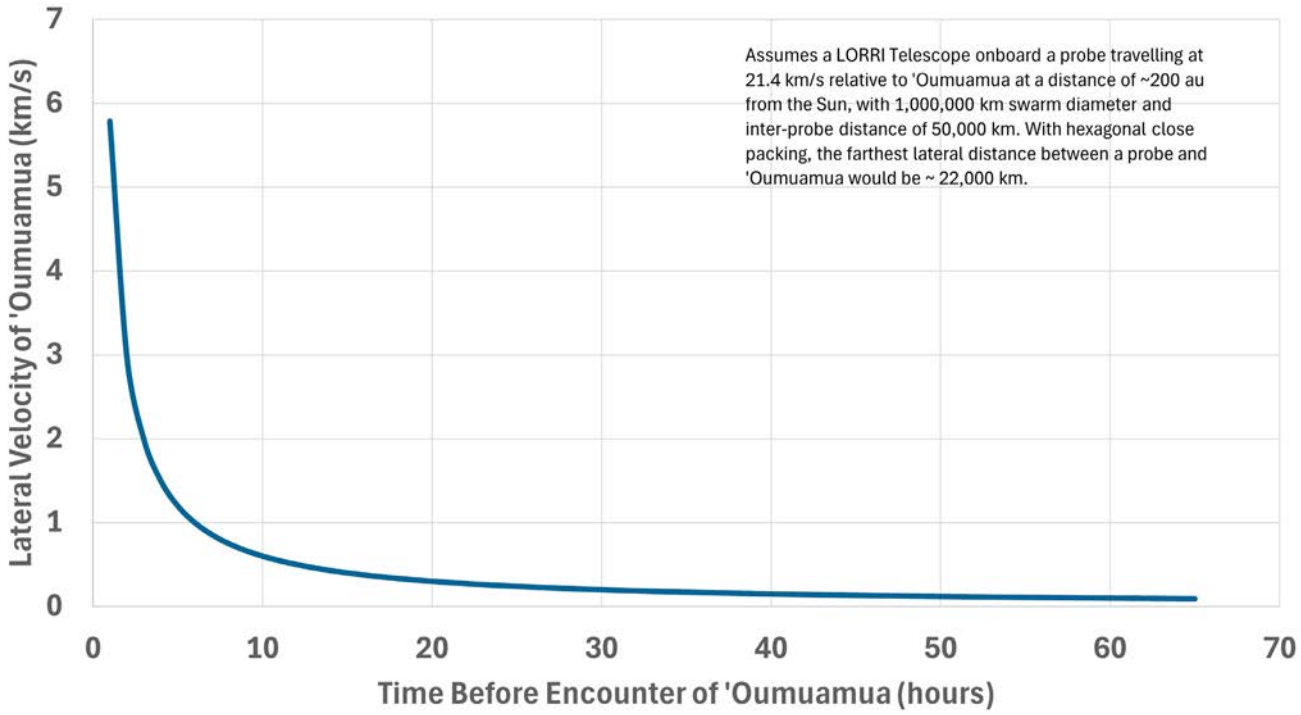
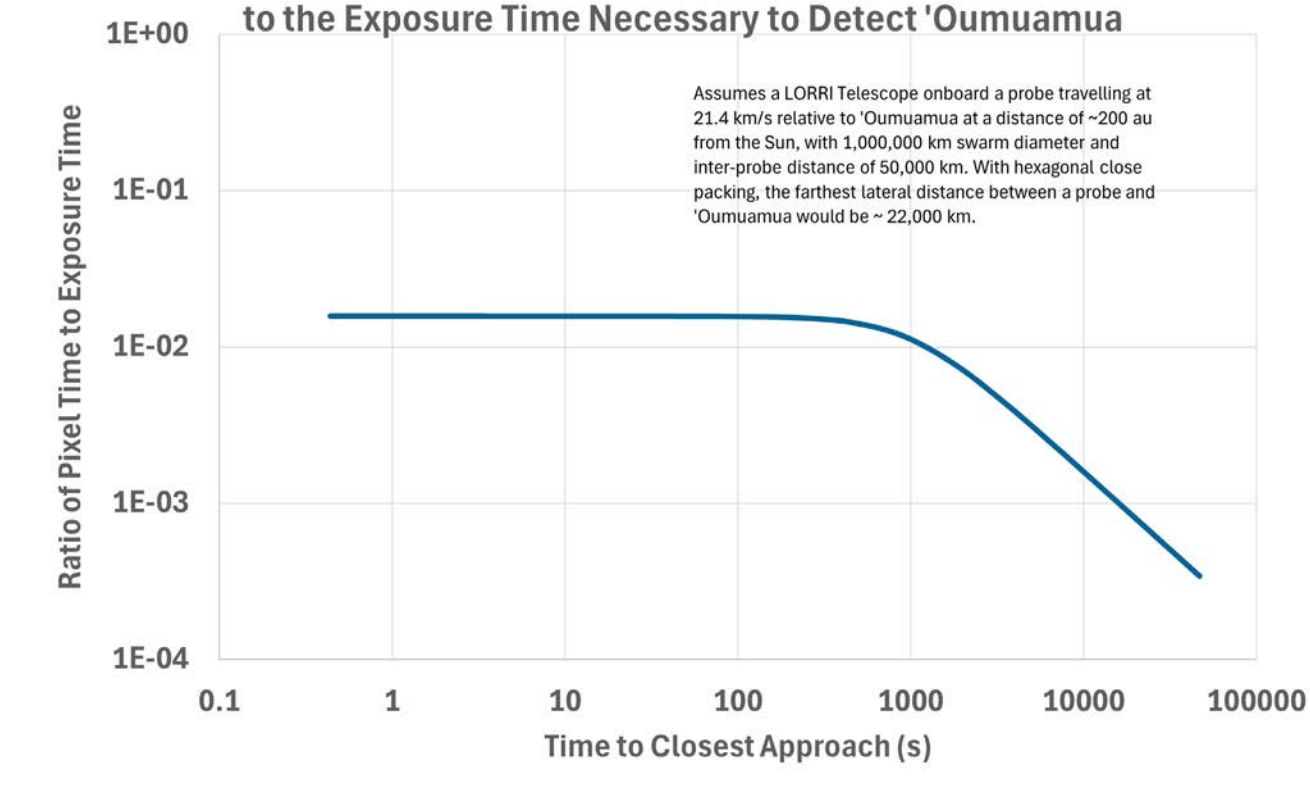
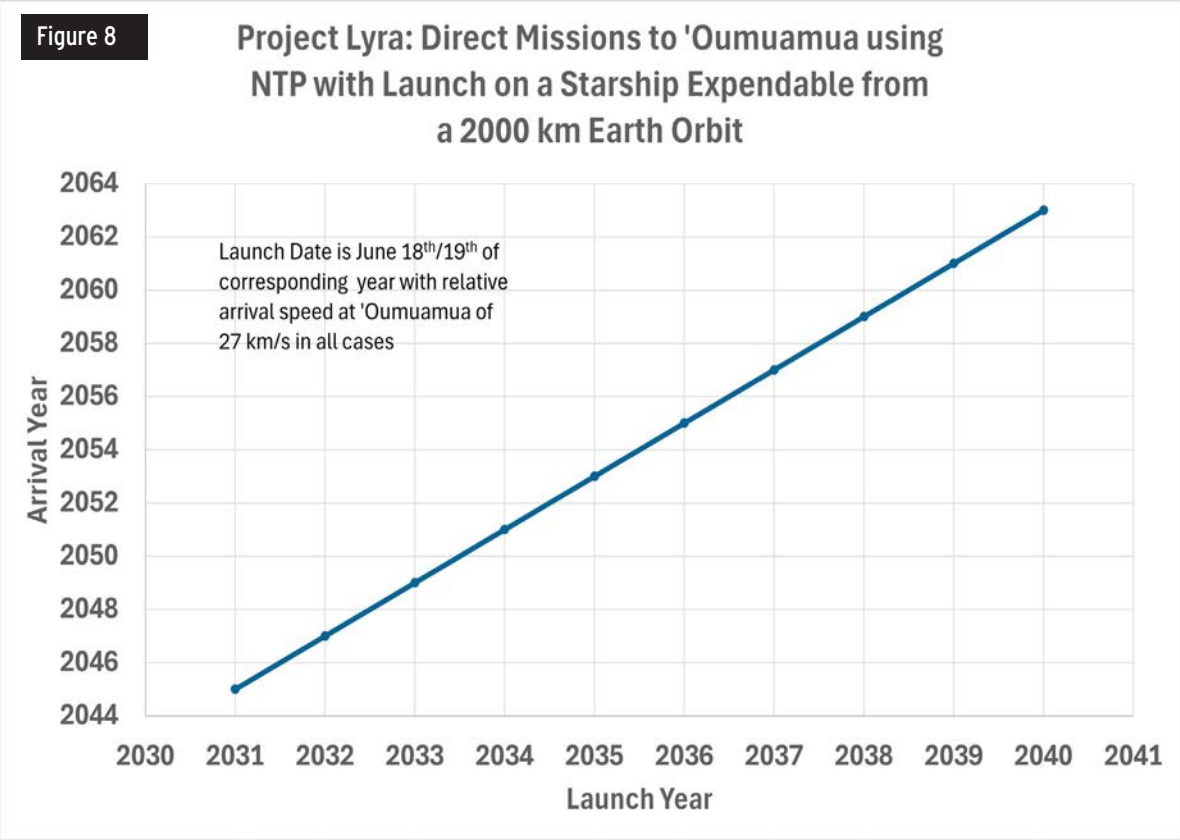


Figure 7 Ratio of Time over which 'Oumuamua Occupies the Same Pixels to the Exposure Time Necessary to Detect 'Oumuamua



However if you reference this Figure 7, it seems this ratio is always much less than 1, does this suggest our flat-optical device is not up to the job? It turns out, not so! With the implementation of high dynamic range imagery - taking lots of short pictures with good quantum efficiency, and then combining them to get the needed exposure time, the apparent problem is resolved.
So we now have a fix on 'Oumuamua from three probes, it is time now to communicate this, but to whom? Let us say we have a second interstellar probe of 500 kg following on behind the 100 kg spacecraft. Referring to the relevant plot, we see that a mission with a Centaur D, would arrive in ~ 2057. This would have been launched around the same time as the 100 kg spacecraft but would take a longer time to arrive, due to its larger payload. Having received the trajectory data from the probes, it would be able to make a sufficient alteration to its path so that after six years it would intercept 'Oumuamua and establish exactly what this strange object is.
This is all rather straightforward in theory, however in practice, will this flat-optics technology so important to the mission architecture elucidated above, have been developed by the PJGA launch year of 2032? If the necessary advancements do not come to fruition by then it would appear we have a problem. So let us now examine the game-changer of Nuclear Thermal Propulsion (NTP) in the context of Project Lyra.
I have already researched missions to 'Oumuamua using NTP, written-up both in an Acta Astronautica paper with Andreas Hein which can be found here [1], and in a subsequent additional preprint which further addresses use of a SpaceX Starship holding an NTP spacecraft payload (which is here [2]).
It turns out from this latter preprint, and contrary to the findings of the first Project Lyra paper (which on this particular point was applicable to chemical propulsion only), that if we adopt a Starship Expendable launch vehicle to launch the NTP craft, then this offers the possibility of a direct flight straight from Earth orbit to 'Oumuamua.
The details can be found in the latter preprint, but the essentials are that we have a 3 metric ton NTP spacecraft, with an extra 500 kg payload mass and furthermore with Liquid hydrogen (LH_2) cryogenic propellant, a specific impulse of 900 seconds can be generated.
Refer to figure 8 for the arrival date against launch date for this direct Starship Expendable + NTP mission. To generate this plot, and to maintain consistency with the analysis already performed above for chemical, I have replaced that 500 kg payload adopted in the preprint by a 100 kg one.

Figure 8



[1] *Project Lyra: Catching 1I/'Oumuamua Using Nuclear Thermal Rockets*, Hibberd et al arxiv.org/abs/2008.05435
[2] *Initiative for Interstellar Studies Project Lyra with Nuclear Thermal Propulsion II Project Lyra with Nuclear Thermal Propulsion*, Hibberd. www.researchgate.net/publication/376190502_Initiative_for_Interstellar_Studies_Project_Lyra_with_Nuclear_Thermal_Propulsion_II_Project_Lyra_with_Nuclear_Thermal_Propulsion

When we look at this Figure 8 plot, we see that for yearly launch dates from 2031 to 2040, the arrival years at 'Oumuamua happen from 2045 to 2063 respectively, with mission durations increasing by 1 extra year for every year the launch is delayed. For information that the relative arrival velocity wrt 'Oumuamua for all these missions is ~27 km/s.

But how do these results impact on the preceding discussion? To this end, let us propose an alternative yet similar mission design, something along the following lines.

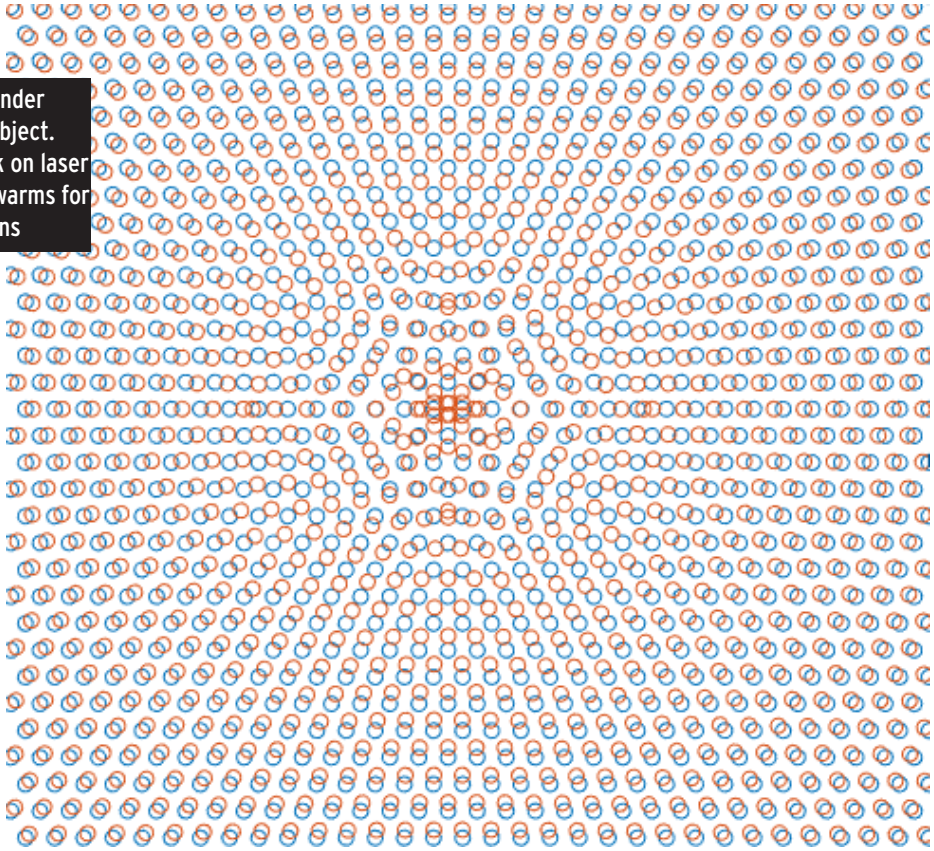
We suppose an 860 kg mass Interstellar Probe following a PJGA trajectory, and launched in 2032 on board a Starship. This chemical-propelled mission is along the lines JHU has proposed already but although their design also assumes a PJGA, nevertheless their trajectory analysis obviously neglects 'Oumuamua as a target. However, let us now, in what follows, rectify that.

Refer to Figure 4 for the relevant results for a mission to 'Oumuamua with 860 kg payload and assuming chemical propulsion, and we see that a Centaur D followed by Castor 30B and STAR 48 would arrive at 'Oumuamua via Jupiter in 2060. But this mission would still have that inherent and unresolved uncertainty in 'Oumuamua's position at intercept. This is where NTP steps in.

Let us say in addition to this chemical mission, we launch a separate Lyra craft onboard an expendable Starship with NTP and 100 kg payload, the latter comprising the N=200 probes each of mass 500 grams, as we assumed for our chemical mission earlier. This NTP craft is sent on its way much later than the Interstellar Probe, say in the year 2037 or 2038, by which time NTP will have been qualified and fully operational, and moreover the technology for the flat optics will also have been accomplished, together with the capability to miniaturize other important electronic components, etc.

This swarm of probes will arrive at 'Oumuamua at least 1 year before the Interstellar Probe and would allow, as articulated above, determination of 'Oumuamua's position with sufficient accuracy so that the data can be relayed back to the approaching 860 kg craft. Armed with this important trajectory data, it would then adjust its own trajectory to ensure a close flyby of 'Oumuamua.

I have elucidated two architectures which would work for Project Lyra, but there are many more which can equally well be examined, for example we may wish to use a single mothercraft with a deployable swarm of probes onboard to be sent on in advance of the main craft. I suppose the problem with Project Lyra is NOT whether this project would succeed or not, it is rather how apathetic is humanity?



Swarm deviating under gravity of target object. Based on i4is work on laser propelled probe swarms for interstellar missions

Breakthrough Discuss 2024

What was discussed and what was not

John I Davies

Breakthrough Discuss 2024 was held on July 18 and 19, hosted by the University of Oxford department of physics. Principium Editor John Davies was invited and reports here [1]. He was unable to cover all sessions and apologises to those unreported here.

This was the first Breakthrough Discuss meeting outside North America and it marks the move of Breakthrough Listen, the SETI initiative, to Oxford. The interstellar travel elements of the Breakthrough programme did not play a role this time.

There were three sessions, labelled "strands" though these were not parallel sessions:

Strand 1: Science Transformed by Artificial Intelligence - data science and AI "weaving new dimensions to astronomy, including innovative approaches of searching for evidence of life beyond the Earth – both biosignatures and technosignatures".

Strand 2: Fabric of Life on and off the Earth - evidence from extreme habitats, studies of the distant past, the broad range of environments in the Solar System and the diversity of exoplanets enriching understanding of "the tapestry of life and its potential extent in the cosmos".

Strand 3: New Frontiers in Space Exploration - new launch capabilities with novel robotic technologies - a new era in space missions "these capabilities present a new canvas for scientific exploration".

The first strand, Science Transformed by Artificial Intelligence, began with Michelle Lochner (University of the Western Cape) on Jocelyn Bell Burnell's pulsar discovery - with the famous "LGM?" note on the pen chart and much of the rest centred on the unexpectedness of much astronomical discovery. Subsequent presentations included much Earth-related research with no reference to interstellar.

The first was Alexis Boukouvalas of Google DeepMind who explained their Earth-related geospatial work. The Earth science theme continued with Regu Angappan of SandboxAQ who introduced their AQNav, AI with quantum navigation - using natural magnetic field for navigation with quantum magnetometers. He illustrated their very wide dynamic range of magnetic signals - as small as heart monitoring to MRI scanner levels. The "GPS denied" situation is an obvious requirement in our increasingly hostile world.

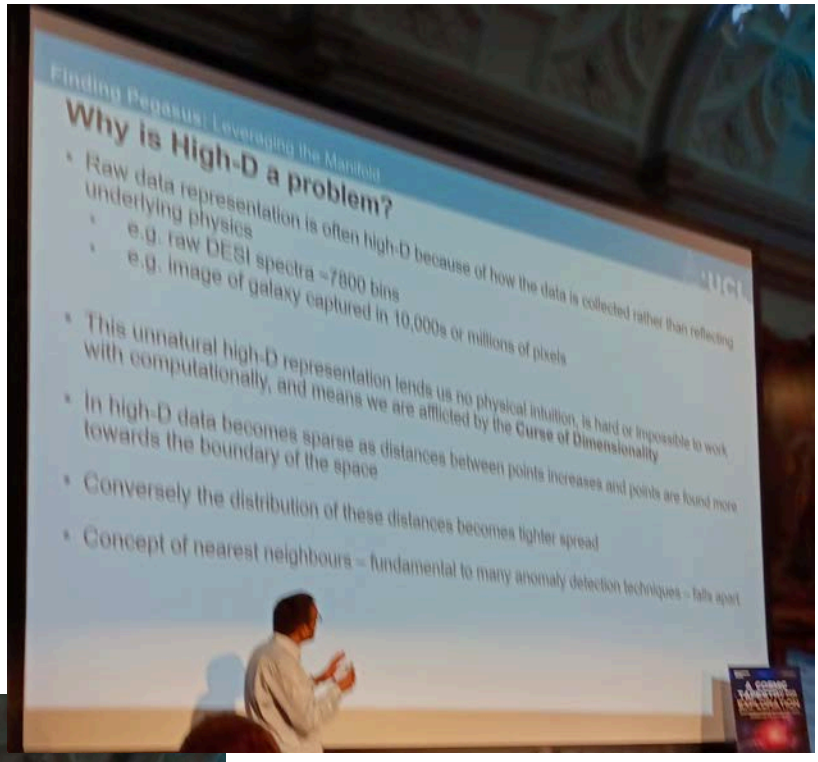
Ashley Villar connected in from Harvard University, widening things with a discussion of astronomical transitory phenomena. A striking example is the kilonova - the merging of compact binary systems consisting of neutron stars or a neutron star and a black hole. But there are millions of transient phenomena per year. Which should we follow up? Looking for this particular sort of needle in a haystack remains a challenge.

Image from the VST telescope at ESO's Paranal Observatory of galaxy NGC 4993 showing aftermath of the explosion of a pair of merging neutron stars, a kilonova (just above and slightly to the left of the centre of the galaxy) producing gravitational waves and gamma rays. Credit: European Southern Observatory / A Gradoge. www.eso.org/public/images/eso1733m/

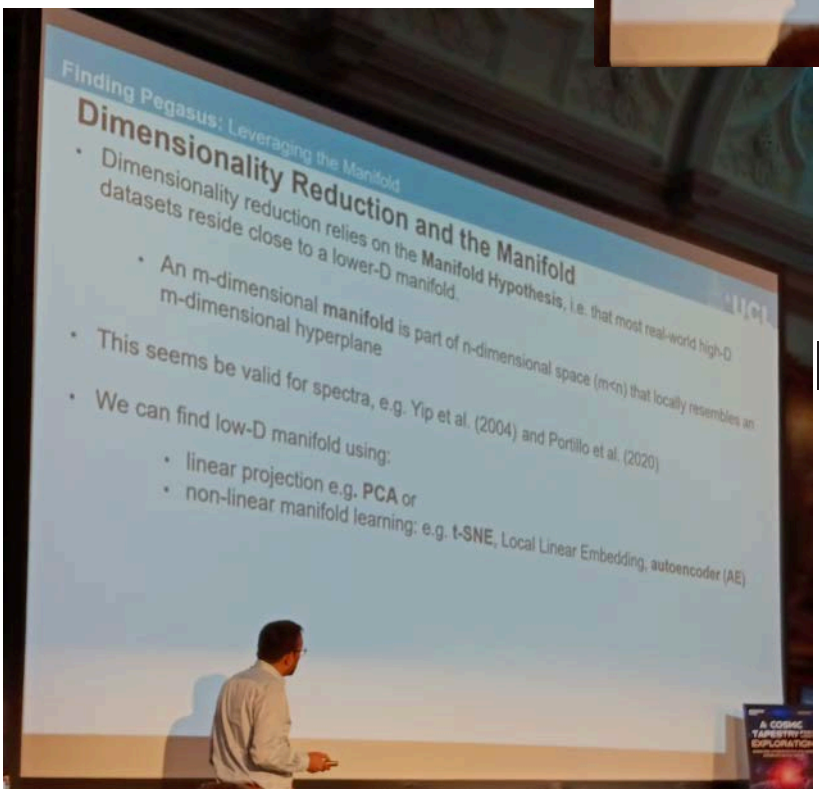
Subsequent images - Credit: John Davies.

[1] Also present were i4is Executive Director Dr Andreas Hein and long established technical team member Nikolaos Perakis. ▶

Paul Nathan, University College London, described an unsupervised anomaly detection project, Pegasus. Unsupervised machine learning means that the software sees no labelling of data. The results show high dimensionality - reduced using Principal Components Analysis.



Paul Nathan. Why is High-D a problem?



Paul Nathan. Dimensionality Reduction and the Manifold

More about his work at www.ucl.ac.uk/data-intensive-science-industry/research-projects/2024/jun/paul-nathan.

Daniel Muthukrishna, Massachusetts Institute of Technology, is also looking for anomalies and with high hopes for results from the Vera C Rubin Observatory (aka the Large Synoptic Survey Telescope, LSST) while acknowledging the importance of amateur astronomers in the detection of new appearances.

Guillermo Cabrera-Vives of University of Concepción described ALeRCE (Automatic Learning for the Rapid Classification of Events, alerce.science) acting as a broker yielding overnight alerts from anomaly detection. The key challenge is to explain WHY things are anomalous. Users query ALeRCE with what happened, what is weird, what looks like this, etc. Longer term the project aims to support automated observational follow-up.

Vishal Gajjar of the SETI Institute at UC Berkeley and Breakthrough Listen touched on early SETI, from thinking including Bracewell's ideas of self-multiplying probes from 1960 to Dyson spheres. Signatures of ETI on planets include atmospheric pollutants, EM radiation especially ultra narrow band and ultra narrow pulses. For example the VERITAS gamma ray detector (veritas.sao.arizona.edu) can spot narrow pulses. He suggested that Breakthrough Listen needs to expand to weaker signals.

Suzanne Aigrain, University of Oxford, observed that Earth would be undetectable by current methods if it was an exoplanet. She pointed out that measuring planet mass by stellar displacement takes a lot of telescope time. Professor Aigrain expects the ESA PLATO mission (sci.esa.int/web/plato) to find planets down to half Earth diameter [1].

Ross Anderson is a palaeontologist at the University of Oxford. He is looking at the evolution of Eukaryotes (cells with nuclei). Early eukaryotes were tiny and soft with no shell or skeleton. We are beginning to find them in specific types of mudstones, notably on Svalbard. Where else might we find them in the galaxy?

Raymond Pierrehumbert, University of Oxford, pointed out the need for pre-organic carbon processes to produce an Earth-like habitable environment. He noted that hydrogen is an excellent greenhouse gas which keeps Jupiter and Saturn warmer than they would be given their distance from the sun. This suggests that the habitable zone extends further from stars. However if methane forms then it can turn an atmosphere uninhabitable.

A panel of the first strand presenters made some interesting observations. Should we look for "life as we know it" or simply look for anomalies? [2]. Guillermo Cabrera-Vives had given examples of serendipity in his lecture.

Guillermo Cabrera-Vives gave examples of serendipity

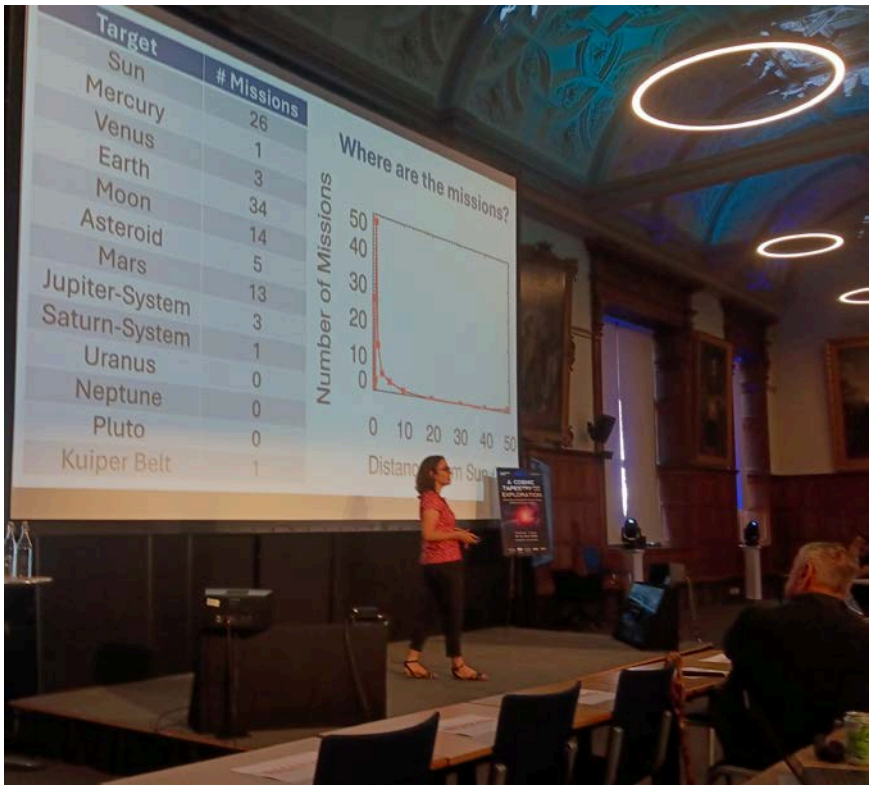
It was pointed out that Mars has no tectonics so a clear fossil record, if there is one, should be more findable. Pete Worden, Director of Breakthrough Initiatives, asked - Should we be more imaginative about chemistry? The panel mostly agreed, water is good but we should not exclude other environments. Suzanne Aigrain was most articulate about perspectives.

The panel discussions were made more interactive using voting on kahoot.it. Recommended!

On the second day, Rob Fender, head of physics, University of Oxford, opened the second strand, reporting that the new Oxford team is already swamped with transient data but is optimistic about the world's ability to handle data from the Square Kilometre Array (SKA) multi-wavelength systems and the Vera Rubin LSST telescope. He expects extra-terrestrial life will be found beyond the solar system in next 10-20 years. Philip Diamond, Director-General of the SKA Organisation, appeared online to wish the conference and the new Breakthrough Listen team all the best!

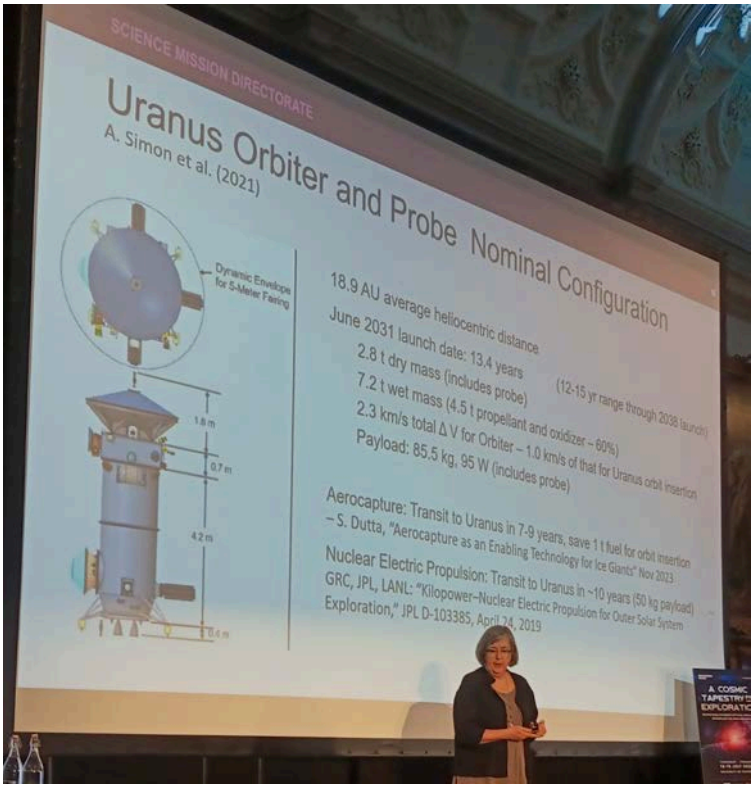
[1] It's worth noting that this will be yet another astronomical mission located at the Earth-Sun Lagrange 2 point but we need not worry about overcrowding since L2 is unstable - any defunct spacecraft will drift away - and they are correspondingly easy to move away to "graveyard" orbits.
[2] At past lectures Jocelyn Bell Burnell has used the phrase "That's funny" to characterise how we should assess and react to what we find.

The third strand of Breakthrough Discuss 2024 was New Frontiers in Space Exploration. Chair Carly Howett, University of Oxford, began with a sceptical question - Is it worth the effort and the wait? She presented a table of science missions versus planets and distances.



Dr Carly Howett (www.physics.ox.ac.uk/our-people/howett) shows missions and distances. Pete Worden (breakthroughinitiatives.org/leaders/3) in foreground.

She contrasted Pluto images from near Earth and from the New Horizons probe. Only the latter showed the extensive area with no craters - implying geophysical activity and therefore heat inside and thus perhaps a subsurface ocean, maybe even life. We only know this by going there! There are other such possibilities in the outer solar system, maybe life on Enceladus and Europa? Triton is a Kuiper Belt Object (KBO) captured by Neptune. Dark spots on it may be caused by emitted plumes. Is there a high altitude wind? And maybe a subsurface ocean? We have to go!

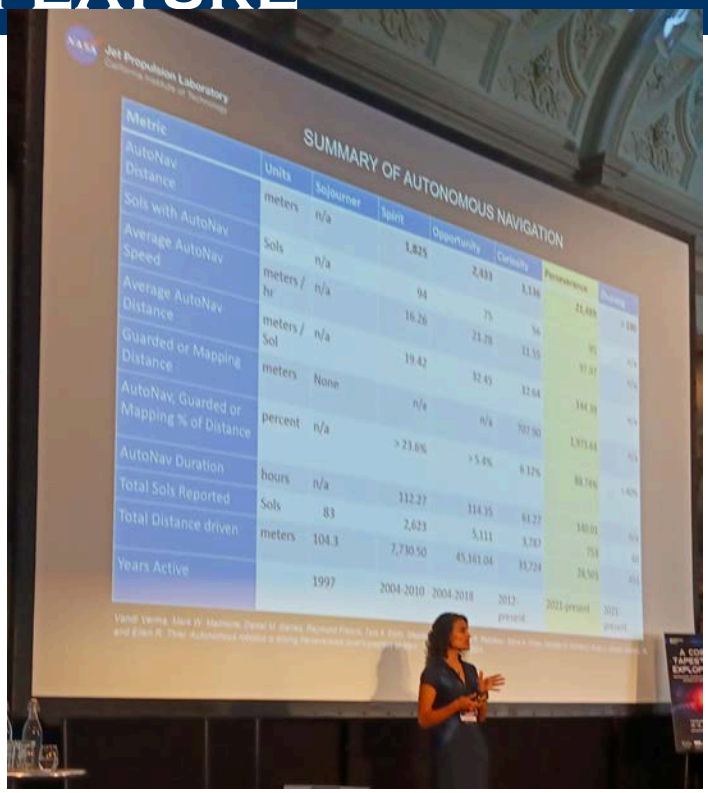


Carolyn Mercer, Chief Technologist at NASA Science Mission Directorate, described planned missions including the Dragonfly helicopter on Titan and Europa Clipper (scanning the moon Europa while in orbit around Jupiter). In the next 10 years we can expect a Uranus orbiter and probe. This will be a long journey since it's rendezvous, not flyby, and 60% of mass is propellant. Aerocapture braking to go into orbit is not yet feasible since the atmosphere is not sufficiently known.

Carolyn Mercer with current thinking for a Uranus mission.

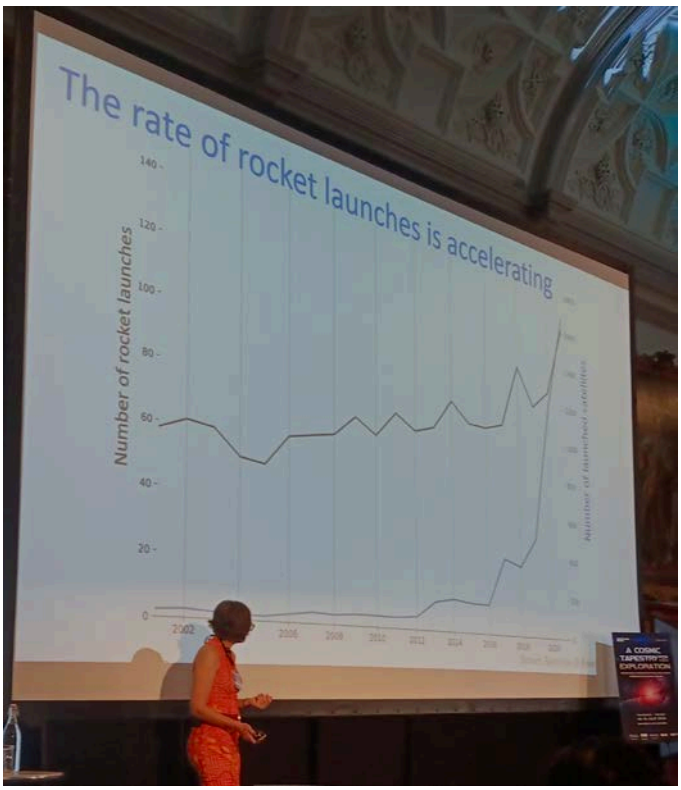
NASA is also working on nuclear propulsion and a mission to Enceladus to follow discoveries by the Cassini mission. Technologies being studied include high performance computing onboard missions and higher speed downlinks - Dr Mercer mentioned data at 6 Mbps for 2 watts laser power - happening now (en.wikipedia.org/wiki/Deep_Space_Optical_Communications).

Vandi Verma of NASA Jet Propulsion Laboratory looked at local autonomy for Mars missions. This has been much enhanced for Perseverance - including delivering selective uplink images. The lander uses FPGAs [1] at the front end of data collection.



Dr Vandi Verma summarises autonomy for navigation.

NASA is still uplinking revised autonomy software to Perseverance but Dr Verma emphasised that autonomy is still hard!

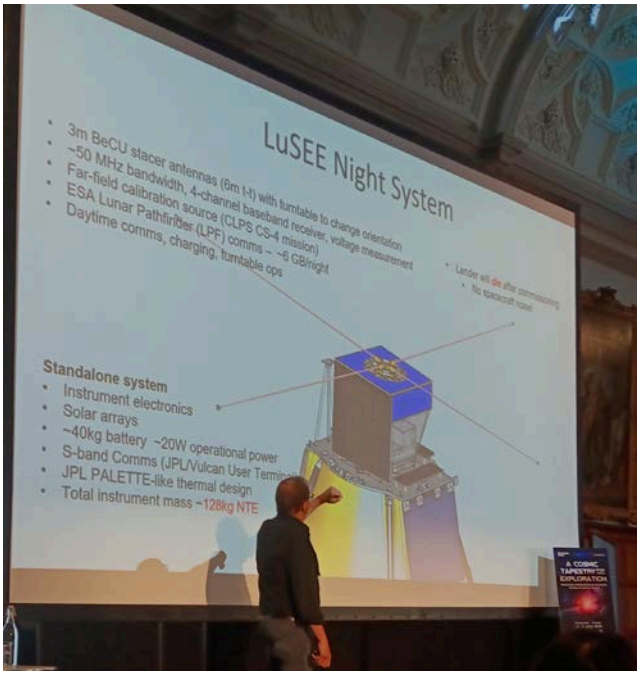


Michele Bannister, University of Canterbury New Zealand [2], quoting Maori proverbs, suggested that we have too much rocketry and that "charismatic technology" leads to means dominating ends - citing stratospheric emissions from launches which are much higher than aircraft, the current doubling launch rate and a massive increase in the LEO population.
These also lead to both optical and RF pollution.

Dr Michele Bannister on the increasing launch rate.

Dr Stuart Bale of UC Berkeley Space Sciences Lab discussed astronomy from the lunar farside. Specifically looking for the 21 cm hydrogen line from the "dark age" of the universe but the galactic background is a million times brighter. There is already a lot of RFI even out at Earth-Sun Lagrange 2.

[1] A field-programmable gate array (FPGA) is a configurable integrated circuit chip that can be programmed to specific tasks. Note this is a not a processor and its performance is therefore limited only by gate propagation times.
[2] Formerly of Queens University Belfast where she was lead author of *The Natural History of 'Oumuamua*, Nature Astronomy, 2019. pure.qub.ac.uk/en/publications/the-natural-history-of-oumuamua. See also *An Interstellar Visitor: sorting the fact from the speculation* by Professor Alan Aylward in Principium 32 February 2021, i4is.org/principium-32.



Dr Bale outlined the proposed LuSEE Night System mission, landing in January 2026 although observing that the lunar regolith is a dielectric, producing non-wanted interference.

Dr Stuart Bale describes the LuSEE Night System.

Right now Breakthrough Listen results from the Low-Frequency Array (LOFAR) sees SpaceX Starlink producing perfect false technosignatures. We need to get lunar farside observations moving before they too are polluted.

Dr Edward Balaban of NASA Ames Research Center described Mission FLUTE, a spinning liquid mirror in space which can scale to hundreds of metres in diameter. In practice this may solidify or be left as liquid, allowing adjustable focal length. The idea is already testing with parabolic flights and on the International Space Station following a NASA NIAC grant last year.

The third and final session wrapped up with a panel of the presenters. In a debate on human versus robotic, the NASA people backed both.

David Deutsch, pioneer of quantum computing, gave the final presentation from the University of Oxford. Amongst the concepts he mentioned were a "Cornucopia" delivered by systems based on John von Neumann's idea of a self-replicating universal constructor. Professor Deutsch sees Artificial Intelligence (AI) as understood now and the more distant Artificial General Intelligence (AGI) as almost opposites.

Pete Worden gives the closing address to Breakthrough Discuss 2024.
Prof Chris Lintott in the foreground.

Breakthrough Discuss 2024 [1] ended with an address from Pete Worden.

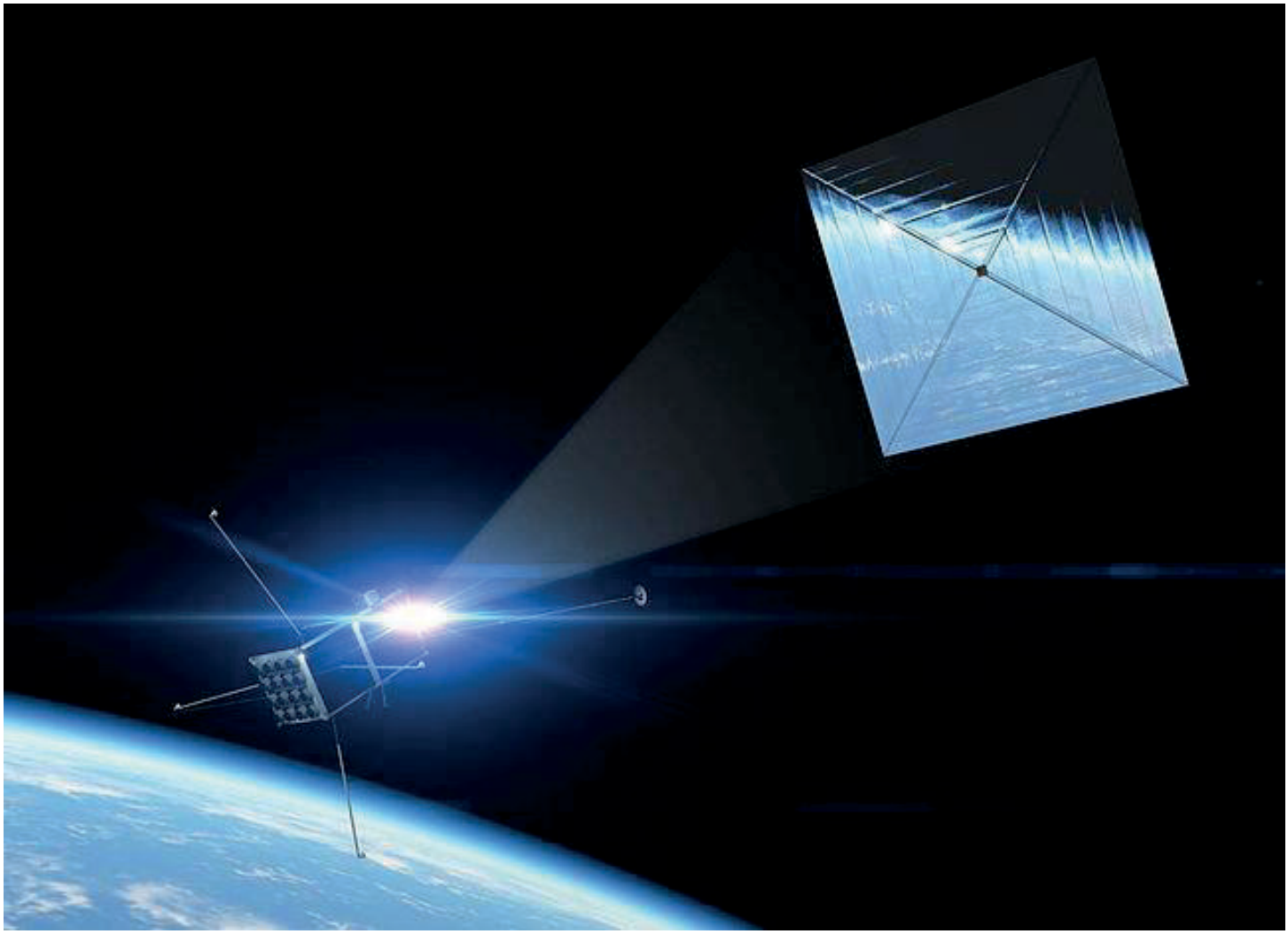
I was privileged to meet Dr Worden for the first time on Thursday evening, a pint or two with other interstellar thinkers in the Kings Arms!

[1] The programme for the conference is no longer available on the university website but can be found at web.archive.org/web/20240716154031/https://www.physics.ox.ac.uk/research/group/breakthrough-listen/breakthrough-discuss-2024

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.

JBIS

Three issues of JBIS online, November & December 2023, January 2024 have appeared since the report in our last issue. P45. Later issues are in print but not yet online.

Title	Author	Affiliation
Abstract/Précis/Highlights		

JBIS VOLUME 76 #11 NOVEMBER 2023		
Illuminating the Future: Space-Based Solar Power As a Cornerstone in the New Space Economy	**F Schoofs, M Hontoir, E Ryan, V Drigo & D A Homfray**	**Satellite Applications Catapult, Harwell, UK**
The realisation of space-based solar power (SBSP) will be a transformative milestone for the economy, technology and environment in both space and on Earth in the next two decades. Recent advancements and ongoing efforts at the Satellite Applications Catapult and Space Solar have demonstrated that SBSP is not just a futuristic concept but a near-term possibility. Here we aim to shed light on the ecosystem opportunities that SBSP can unlock within the emerging new space economy, based on our work. Realising the benefits of SBSP will require cross-sector and international collaboration, to navigate the unique challenges and issues associated with this groundbreaking endeavour.		

JBIS VOLUME 77 #1 JANUARY 2024 Interstellar Issue		
Modifications to The Alcubierre Warp Field Metric in Anisotropic Matter and Implications to Detection of Warp Fields	**Travis S Taylor**	**Radiance Technologies, Huntsville, Alabama**
The Alcubierre warp drive concept demonstrates a designed spacetime metric which enables hyperfast travel within the framework of known physics and has become one of the most widely studied spacetimes in the community. However, there has always been a singular issue with practical realization of the "warp drive" in that a large amount of matter with unattainable properties (such as negative or "exotic" matter/energy densities) are required. The negative matter-energy or "exotic" mass-energy density requirements violating the Averaged Weak and Null Energy Conditions mainly arise from solutions to the Einstein equations with little consideration of the matter content and characteristics within the metric. Recent efforts have shown that investigating details of the matter characteristics might offer new insights to practical warp field design and might lead to realizable solutions. This paper gives analysis of an anisotropic matter field solution, hypothetical applied variations to the Einstein coupling constant (via a multiplier function), and a multilayered warp bubble approach to reducing the warp field mass requirements to realizable forms and quantities. A discussion on the detection of such an advanced warp field is also given.		

JBIS VOLUME 77 #1 JANUARY 2024 Interstellar Issue		
Space Butterfly: Combining Artificial Intelligence and Genetic Engineering to Explore Multiple Stellar Systems	**Greg Matloff & C Bangs**	**New York City College of Technology**
In their classic 1965 treatment of extraterrestrial intelligence, I S Shlovskii and Carl Sagan postulate that an advanced galactic civilization would use relativistic inhabited spacecraft to explore the galaxy. Because such craft might forever be technologically or sociologically infeasible, an alternative approach is suggested. Artificial intelligence, genetic engineering and other technologies might be employed to develop autonomous, solar-photon-sail propelled probes that might cruise the galaxy and unfold their photon-sail "wings" during close stellar flybys while studying the destination planetary system. The sail could be used for acceleration, deceleration or to direct the probe to further destinations. The similarity between 'Oumuamua, the first known interstellar object to visit our solar system and the proposed "Space Butterfly" is noted. It is unfortunate that this object is moving so fast and is so distant that a robotic Earth-launched probe to it is unlikely.		

JBIS VOLUME 77 #1 JANUARY 2024 Interstellar Issue		
The Destination Energy Debt of Interstellar Voyages	**Arthur Kennedy**	**Project Chronolith, Seville, Spain**
This paper introduces the strategic concept of energy debt acquired by interstellar migrations at their destination. For such voyages an energy debt of travel can be calculated, where KE $\propto V^2 \propto M \propto$ Travel Population $\propto$ Distance to Destination. In addition, at destination, growth must be initiated to fill the energy and resource needs of the arrivals. A targeted solar system must contain sufficient resources to supply a growth that provides the technological needs of the arriving society and eventually to develop the capability of escaping the system equivalent to that which had been required for the initial launch. Thus, the capacity of the destination to fill the energy debt of the voyage, at a first approximation given by the planetary and solar masses, is a significant factor in the decision to make the voyage. A simple utility ratio, τ, relating voyage time to technological growth time at destination is proposed and two destinations from Earth are considered in terms of this factor. It is proposed that a Kardashev Type II phase of growth results in such a dependency on energy that investing in high resource-use interstellar voyages will be a necessary means by which a technological civilisation can retard consuming its system's entire carrying capacity. Some practical methods of avoiding the voyage's energy debt, including in-flight refuelling, fly-by 'seeding' scenarios and the potentials of exotic physics or higher dimensional life are discussed and shown to be ineffective. Other classes of exploratory voyages such as the Icarus Project's Firefly and those using beamed propulsion methods will also be discussed in relation to the utility ratio. Applying this utility ratio to the likelihood of ETI encounters in any form with Humans at their current stage of development leads to the conclusion that alien encounters will be rare and no scenario for current alien activity on Earth is likely to be correct.		

JBIS VOLUME 77 #1 JANUARY 2024 Interstellar Issue		
Minimum Condition Requirements in Laser Driven ICF for Advanced Space Propulsion Applications	**Kelvin F Long**	**Interstellar Research Centre, UK**
Inertial Confinement Fusion (ICF) is one of the candidate methods by which spacecraft can be propelled onto interplanetary and interstellar trajectories. In this paper we discuss the application of laser driven ICF to advanced space propulsion and present fundamental equations which relate the capsule mass and nozzle jet efficiency to propulsion parameters. This is also shown for the scenario of using expellant propellant for the purpose of thrust augmentation.		

Acta Astronautica

Acta Astronautica papers are published online before print. These issues with relevant papers have appeared since our last issue, Principium P45.

Title	Number+date	Author
Abstract or Summary		

Is artificial intelligence the great filter that makes advanced technical civilisations rare in the universe?	**Volume 219 June 2024**	**Michael A Garrett [1]**

This study examines the hypothesis that the rapid development of Artificial Intelligence (AI), culminating in the emergence of Artificial Superintelligence (ASI), could act as a "Great Filter" that is responsible for the scarcity of advanced technological civilisations in the universe. It is proposed that such a filter emerges before these civilisations can develop a stable, multiplanetary existence, suggesting the typical longevity (L) of a technical civilization is less than 200 years. Such estimates for L, when applied to optimistic versions of the Drake equation, are consistent with the null results obtained by recent SETI surveys, and other efforts to detect various technosignatures across the electromagnetic spectrum. Through the lens of SETI, we reflect on humanity's current technological trajectory – the modest projections for L suggested here, underscore the critical need to quickly establish regulatory frameworks for AI development on Earth and the advancement of a multiplanetary society to mitigate against such existential threats. The persistence of intelligent and conscious life in the universe could hinge on the timely and effective implementation of such international regulatory measures and technological endeavours.

Ultrafast transfer of low-mass payloads to Mars and beyond using aerographite solar sails	**Volume 219 June 2024**	**Julius Karlapp, René Heller, Martin Tajmar**

With interstellar mission concepts now being under study by various space agencies and institutions, a feasible and worthy interstellar precursor mission concept will be key to the success of the long shot. Here we investigate interstellar-bound trajectories of solar sails made of the ultra lightweight material aerographite. Due to its extremely low density and high absorptivity, a thin shell can pick up an enormous acceleration from the solar irradiation. Payloads of up to 1 kg can be transported rapidly throughout the solar system, eg to Mars and beyond. Our simulations consider various launch scenarios from a polar orbit around Earth including directly outbound launches as well as Sun-diver launches towards the Sun with subsequent outward acceleration. We use the poliastro Python library for astrodynamic calculations. For a spacecraft with a total mass of 1 kg (including 720 g aerographite) and a cross-sectional area of 1,000 square metres, corresponding to a shell with a radius of 56 m, we calculate the positions, velocities, and accelerations based on the combination of gravitational and radiation forces on the sail. We find that the direct outward transfer to Mars near opposition to Earth results in a relative velocity of 65 km/sec with a minimum required transfer time of 26 d. Using an inward transfer with solar sail deployment at 0.6 AU from the Sun, the sail's velocity relative to Mars is 118 km/sec with a transfer time of 126 d, where Mars is required to be in one of the nodes of the two orbital planes upon sail arrival. Transfer times and relative velocities can vary substantially depending on the constellation between Earth and Mars and the requirements on the injection trajectory to the Sun diving orbit. The direct interstellar trajectory has a final velocity of 109 km/sec. Assuming a distance to the heliopause of 120 AU, the spacecraft reaches interstellar space after 5.3 yr. When using an initial Sun dive to 0.6 AU instead, the solar sail obtains an escape velocity of 148 km/sec from the solar system with a transfer time of 4.2 yr to the heliopause. Values may differ depending on the rapidity of the Sun dive and the minimum distance to the Sun. The mission concepts presented in this paper are extensions of the 0.5 kg tip mass and 196 square metre design of the successful IKAROS mission to Venus towards an interstellar solar sail mission. They allow fast flybys at Mars and into the deep solar system. For delivery (rather than flyby) missions of a sub-kg payload, for example medical supply or replenishment of essential materials, the biggest obstacle remains in the deceleration upon arrival.

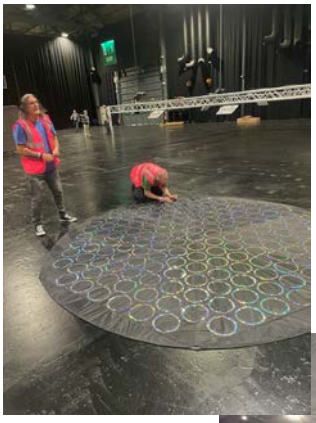
[1] Professor Garret's paper was reviewed in Principium 45 May 2024 (i4is.org/principium-45/). *Biological intelligence vs AI - and the Fermi Paradox*
i4is.org/wp-content/uploads/2024/05/Biological-intelligence-vs-AI-and-the-Principium45-2405171117-comp.pdf

BECOME AN i4is MEMBER

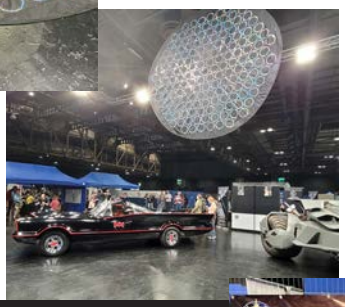
Are you intrigued by what lies beyond our solar system?
Would you like to support research towards interstellar space missions?
Does interstellar research fascinate you?
If so....BECOME AN i4is MEMBER!

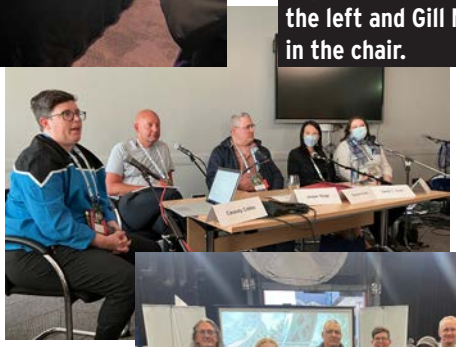
John I Davies

i4is at the Glasgow24 SF Worldcon.



I4is at the Glasgow24 SF Worldcon. Worldship panels chaired by Cassidy Cobbs (i4is-US).
And the whole crew plus supporters on our stand. Organisers Tam O'Neill on the left and Gill Norman in the chair.





Our 3.5 m laser probe replica being assembled and hanging over the exhibition.
Our big Firefly fusion ship banner.
All will reappear at other events to promote the interstellar message.

We will have a full report of Glasgow24 in our next issue. Members will see a preprint well before that.

The Initiative for Interstellar Studies (i4is) has a membership scheme intended to build an active community of enthusiasts whose sights are set firmly on the stars. You can directly support interstellar programmes and even get involved with our projects! We are an interstellar advocacy organization that conducts theoretical and experimental research and development projects and supports interstellar education and research in schools and universities.
By becoming a member, you are not just supporting our cause, but will also gain:

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

Reach for the stars with us by becoming a member today at
i4is.org/membership/
Students are eligible for a 90% discount!

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 preprints.

Meet the team - and the world

i4is team members will be at two more in-person events later this year.

In October we will be at the **International Astronautical Congress**, the big astronautics event of the year, in Milan, Italy - 14-18 October. Details at www.iac2024.org.

In December we will be at the **First European Interstellar Symposium** 2-5 December. Hosted by the University of Luxembourg with the major participation of i4is, the Interstellar Research Group (formerly TVIW), Breakthrough Initiatives and the Luxembourg Space Agency. Details at irg.space/first-european-interstellar-symposium.

As soon as you decide to be at any of these then email Principium@i4is.org and let us know when you will be there.

And even if you aren't travelling then you can meet us online at our SF Book Club. To join the club, email bookclub@i4is.org.

Recent member newsletters

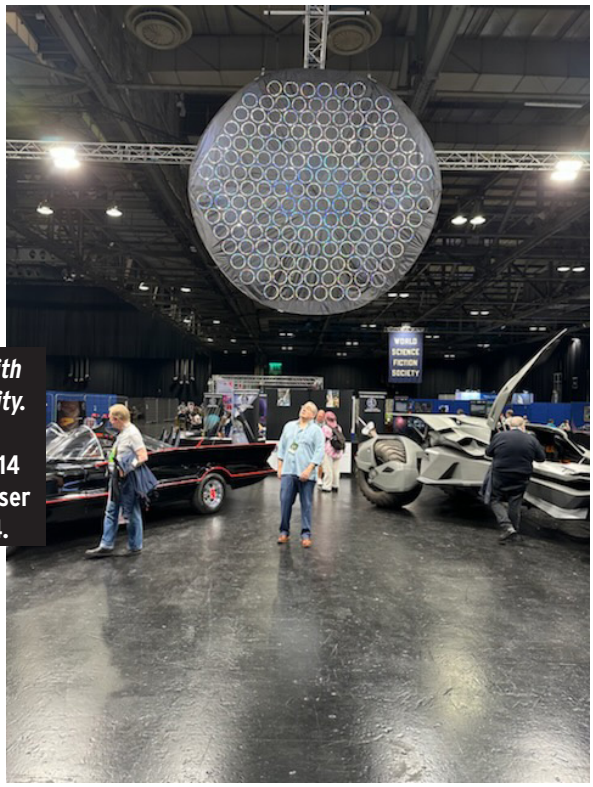
There have been 2 member newsletters since P45, our last issue. All member newsletters are available from the members-only area on the website - i4is.org/members.

Glasgow World Science Convention

i4is was there in force at the Glasgow World Science Convention in August. Especially for the major programme item, Worldships. This makes 2024 our year of the worldship. We also announced the Project Hyperion worldship design competition (www.projecthyperion.org).

Our full scale replica of a laser propelled interstellar probe was a big attrction at the exhibition and it will be appearing in both USA and Europe in the coming months.

We thus continue the tradition begun in 2014 of spectacular objects at these Cons.



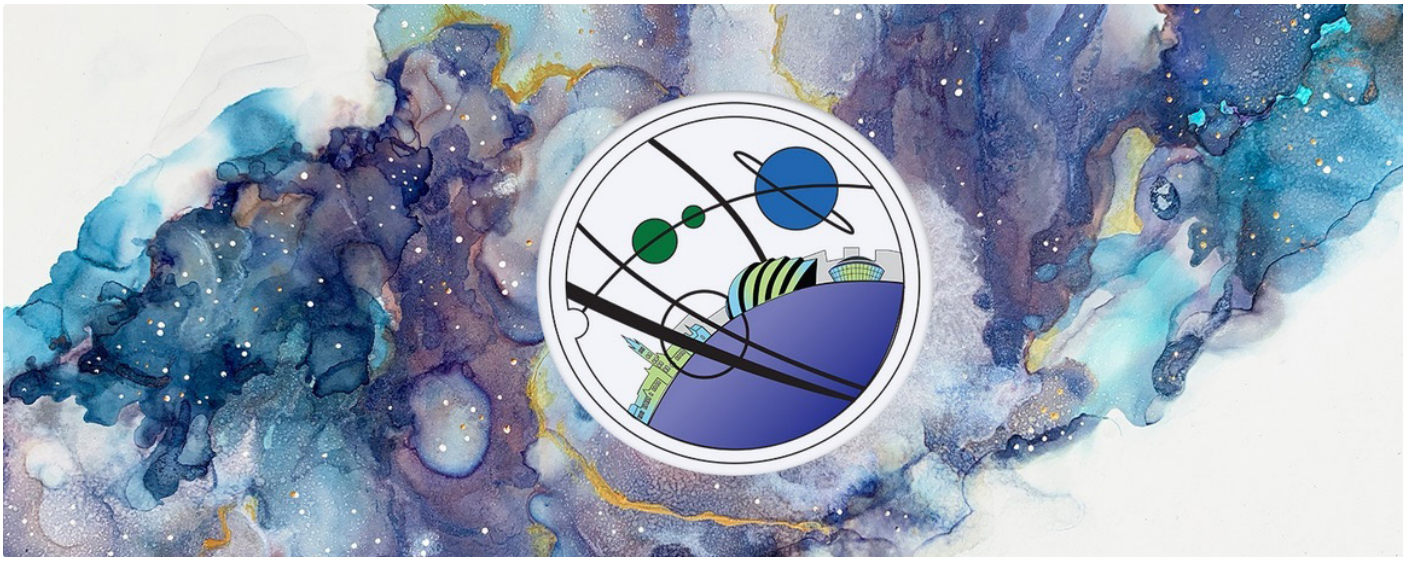
i4is engages with the SF community. **Our 4 m high monolith in 2014 and our 3.5m laser probe in 2024.**

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.

NEXT ISSUE

IAC24
First report of interstellar items from October's 2024 International Astronautical Congress in Milan.



2024 SF Worldcon in Glasgow
A full report on what i4is did and all else of interstellar relevance.

First European Interstellar Symposium
A detailed preview of this unique event hosted by our Executive Director Andreas Hein at the University of Luxembourg.

Plus **Interstellar News** and interstellar papers in **The Journals**.

First European Interstellar Symposium

2-5 December 2024, Luxembourg

UNIVERSITÉ DU LUXEMBOURG

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INITIATIVE FOR INTERSTELLAR STUDIES

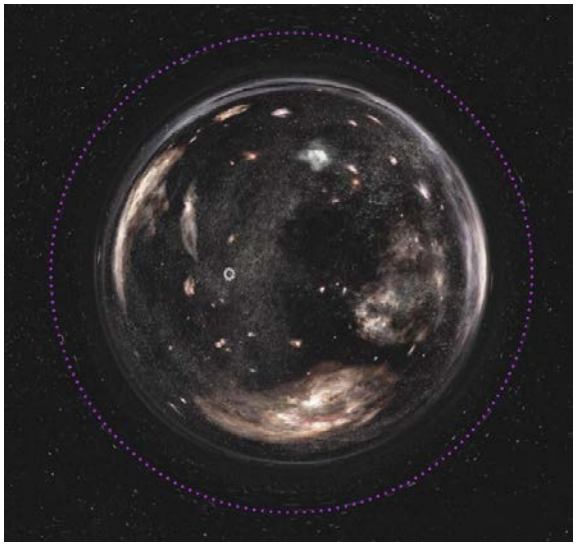
BREAKTHROUGH INITIATIVES
BREAKTHROUGH PRIZE FOUNDATION

LUXEMBOURG SPACE AGENCY

COVER IMAGES

Our cover images for this issue show a wormhole as envisaged by CGI specialists advised by an eminent physicist and visual effects company - and a worldship interior envisaged, lookin out as part of i4is Project Hyperion.

FRONT COVER



Front cover
The effects team at Double Negative (www.dneg.com) worked with Kip Thorne, Feynman Professor of Theoretical Physics at Caltech, to imagine a wormhole for the film *Interstellar*. Here you see the (relatively tiny) rotating spacecraft, Endurance, entering the wormhole.

Credit: Double Negative from paper: *Visualizing Interstellar's Wormhole*, Oliver James, Eugénie von Tunzelmann, Paul Franklin, Kip S Thorne, American Journal of Physics 83, 486-499 (2015), pubs.aip.org/aapt/ajp/article/83/6/486/1057802/Visualizing-Interstellar-s-Wormhole
and Kip Thorne, www.its.caltech.edu/~kip/index.html/interstellar.html.

BACK COVER

Back cover
This visualisation of the interior of a worldship looking out is part of the material created by the i4is Project Hyperion organising group. The Project Hyperion competition is a design challenge to provide an assessment of the feasibility of crewed interstellar flight using current and near-future technologies. Keep an eye on www.projecthyperion.org and get your team together soon!

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.

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

SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

Front cover: A wormhole imagined for the film Interstellar.
Credit: Double Negative

Back cover: Visualisation of the interior of a worldship looking out.
Credit: i4is Project Hyperion organising group.

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.