# PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 47 | November 2024

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS

Lead Feature: Pringles is a Verb: Fabrication + Exhibition of "the Big Object"

Features: Rise of the Serpent-God: The Apocalypse Plot, Project Hyperion, Glasgow 24 SF WorldCon, i4is' SF Anthology and Book Club

News Features: IAC24 Interstellar #1, Space Propulsion 2024, The Wow! Signal – explained?, 1st European Interstellar Symposium - Abstracts

Interstellar News

The Journals: JBIS and Acta Astronautica

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# EDITORIAL

Welcome to issue 47 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is *Pringles is a Verb: Fabrication and Exhibition of "the Big Object"* the first outing of our laser propelled interstellar probe replica.

We have five News Features *International Astronautical Congress IAC24: The Interstellar Presentations Part 1, Report from the Space Propulsion Conference 2024 Glasgow, 20-23 May 2024, The Wow! Signal – explained?: A review of Arecibo Wow! I: An Astrophysical Explanation for the Wow! Signal* and *First European Interstellar Symposium: The Abstracts*. Also nine 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*.

And we have Features - In *Rise of the Serpent-God: The Apocalypse Plot*, Adam Hibberd explains the trajectory of Apophis which has a finite chance of hitting Earth in 2028, and how to deflect it. We introduce the new *i4is Project Hyperion*, a design competition for the habitability of a multigenerational worldship. Our volunteers recount *Glasgow 24 SF WorldCon: What we did at the Con* and we have more about the *i4is' Science Fiction Anthology and Book Club*.

Our front cover image is an envisaged interior for a worldship from the *Project Hyperion* competition briefing. The rear cover image is two images of Vega from the veteran Hubble space telescope and its recent, bigger, younger sibling, the James Webb space telescope. 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, P48 in February 2025, we will have the second report of interstellar items from the 2024 International Astronautical Congress in Milan. And the usual Interstellar News and journal reports. More details on P48 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 28.

**After 10 years and 41 issues John Davies will be stepping down as Editor after the 50th issue, August 2025. He will be working with Deputy Editor Patrick Mahon and the i4is Board of Directors over the next three months to appoint a successor and a broader team, sharing responsibilities for the magazine, in time for a transition period. Please get in touch with either of us if you would like to be part of the Principium team,**

**John I Davies, Editor,** john.davies@i4is.org

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

## MEMBERSHIP OF i4is

Please support us through membership of **i4is**. Join the interstellar community and help to reach the stars! Privileges for members and discounts for students, seniors and BIS members. Details in *Become an i4is member* in this issue and at i4is.org/membership.

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

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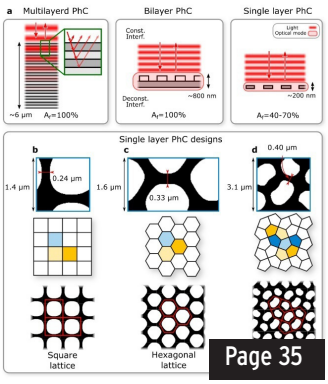

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## REGULARS

# *Pringles is a Verb*
## *Fabrication and Exhibition of "the Big Object" at WorldCon 82 in Glasgow [1]*

**Robert G Kennedy III, PE (K3TVO)**

A team of experts from i4is and Space Initiatives Inc has been working on concepts to overcome the downlink problems raised by the necessarily tiny mass of laser-propelled probes. The result has been a swarm concept developed under successive grants from Breakthrough Starshot and the NASA Innovative Advanced Concepts (NIAC) programme.
As an initiative to demonstrate the concept in a single probe to two very different audiences i4is conceived and constructed replicas which were displayed at the Glasgow 2024 World Science Fiction Convention (WorldCon) in August 2024 and the September 2024 NASA NIAC Symposium in Pasadena.
Here the president of i4is-US, Robert Kennedy (robert.kennedy@i4is.org), explains how this was achieved and delivered at the WorldCon (more about our presence at the WorldCon elsewhere in this issue). In our next issue he will take us to the NIAC Symposium where the second replica was displayed alongside the team's presentation of the concept.

As reported in issue P41 of Principium, May 2023, i4is (in partnership with Space Initiatives Inc, hereinafter "SII") satisfactorily completed our contract with Breakthrough Starshot for system engineering of the communications challenge in getting a useful signal across four light-years from objects massing only four grams. The result of this work, posted at arxiv.org/abs/2309.07061) is a feasible (to be understood as "not impossible") concept of what the first mission to another star this century will probably look like. A large flat thing, basically a giant monolithic integrated circuit, 10X the diameter of the biggest wafer-scale integrated circuit (WSI) that's ever been made, built into a substrate of ultralightweight aerographene of miniscule mass: few grams (a US penny). We now call it "the Interstellar Coracle".
Once this was behind us, i4is began planning a year ahead of time to take advantage of a once-in-a-generation chance to exhibit our work at the 82nd World Science Fiction Convention (https://glasgow2024.org/), which would take place right in the neighborhood at the Scottish Event Center in Glasgow, Scotland. A committee to fabricate a full-scale model of our interstellar probe was stood up and chaired by the remarkable Gill Norman, former ExecDir of the British Interplanetary Society, with members Cassidy Cobbs, John Davies, Michel Lamontagne, Tam O'Neill, Terry Regan, Rob Swinney, and "Your Humble Narrator" (YHN). Honorable mentions also to: seamstress Denise Johnson of Oak Ridge Tennessee, who sewed the three existing mockups; Dan Sparkes of SparkGraphik (www.sparkgraphik.com) who had the holographic rings manufactured; and Paul Blasé who engineered and built the LED simulants of the probe-to-probe lasers.

[1] "Pringles" is an American brand of synthetic potato chip, or as our cousins across the pond call it, "crisp", which is produced in a trademarked saddle shape. This will make sense later.


Figure 1 (from left to right): Adam Lear; our good friend and JBIS co-author Cassidy Cobbs the evolutionary biologist (see Principium P29 & P30), Tam O'Neill (i4is UK Board of Directors); Gillian Norman the former Exec Director of the British Interplanetary Society, our "Swarming Proxima" teammate the orbital dynamicist Adam Hibberd; Gill's hubby Ian Norman. Note all the copies of the famous "red cover" (interstellar) issues of JBIS. The conceptual artwork of a coalesced fleet of probes flying by Proxima's planet b is by my good French Canadian friend, the remarkable Michel Lamontagne, P Eng, artist and engineer. i4is is fortunate indeed to have Michel as part of the team.

Rather than build a mockup 3.5 meters (11.5 feet) across with plywood, which would have been massive and also difficult to assemble and rig, and then break down in a reversible way for transport in either direction we needed a different approach. But what to do?. That was a knotty one. The approach selected by your correspondent was inspired by those springy wire thingies one twists and unfolds with single motion behind the windscreen of one's car to keep the sun out whilst parked. But scaled up by a factor of 10. The committee quickly dubbed the item with the internal working moniker "Big Object". Very much like the ultimate probes themselves, the mockup's mass is concentrated in a springy hoop 36 feet around, stretching a large circular membrane. Such an arrangement is naturally self-tightening since it seeks minimum energy level.

To serve as a cheap analogue for aerographene (remember, show business is all about fooling the eye at minimum cost), your correspondent selected black nylon ripstop tent fabric, which conveys a probe's color, thinness, and flatness, albeit at a thousand times the areal mass density that the actual launched spacecraft would be 30-50 years hence [1]. It is cheap and ubiquitous. Regrettably, the largest readily available material was 60 inches width, which limited the scale of the mockup to 3.5 m width (11.5 feet) or 88% full size. The simplest and easiest approach to build up a circle from a long strip of fabric is to work with equilateral triangles – in the fashion world, these bits are called "gores", the curved bits are "lunes" – which maximizes straight cuts, minimizes curved cuts, and minimizes labor-intensive seams. See figure 2 below (next page). Enough was left over in two 10-meter rolls to provide for three Big Objects.

[1] If the reader thinks a 4-meter-wide object massing only 4 grams is outlandish, then consider the Trisolarans' "sophon" probes as imagined in the Three Body Problem trilogy, which were spherical thin-shell supercomputers based on femtotechnology, unfolded the size of a planet but folded just the mass and size of a proton. See Cixin Liu, The Three Body Problem, Chongqing Publishing Group, Chongqing, China, 2006, English translation by Ken Liu, from *Tor Books*, New York, 2014 or *Head of Zeus* (now *Bloomsbury Publishing*), UK, 2015.

Now to find someone willing and able to do the work. Other than YHN's spouse, that is. Google Maps to the rescue, keywords "seamstress" and "Oak Ridge": YHN called the first number to pop up, which happened to be the mobile of someone who altered bridal gowns for a living, and hired Ms Denise Johnson on the spot. The challenge was shoehorning in the production of what turned out to be three Big Objects in the midst of summer, which is the peak of the wedding season. What both endeavors have in common is manipulating large amounts of thin material; compared to a wedding dress, an interstellar probe is lead pipe simple.

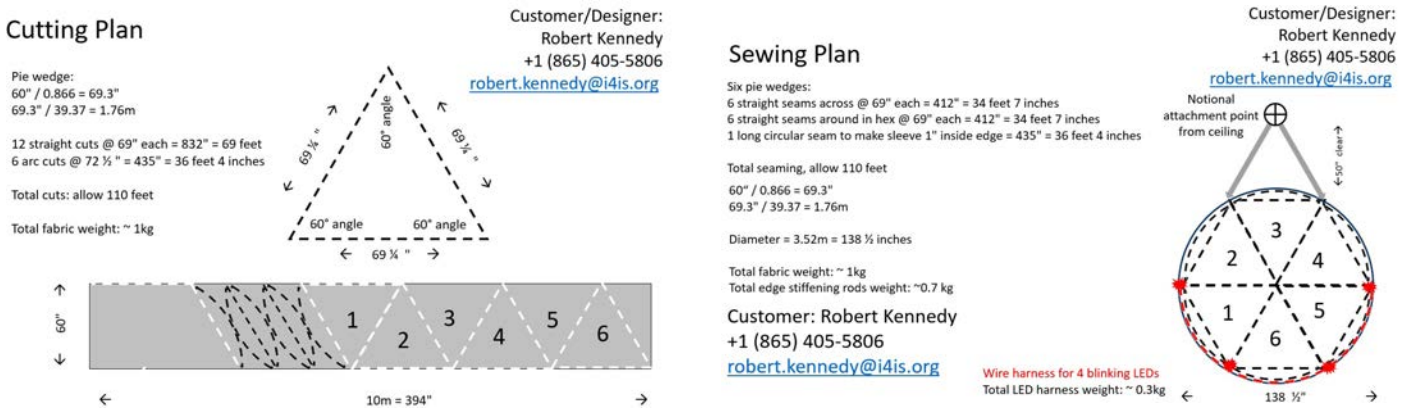



Figure 2. How An Engineer Communicates With A Seamstress. Overkill?

Ms Johnson provided a 1-inch sleeve around the periphery of the Big Objects, to accommodate the bendy poles that formed the circular frame. At first, actual carbon fiber tent poles were tried, and fishing rods, but what turned out

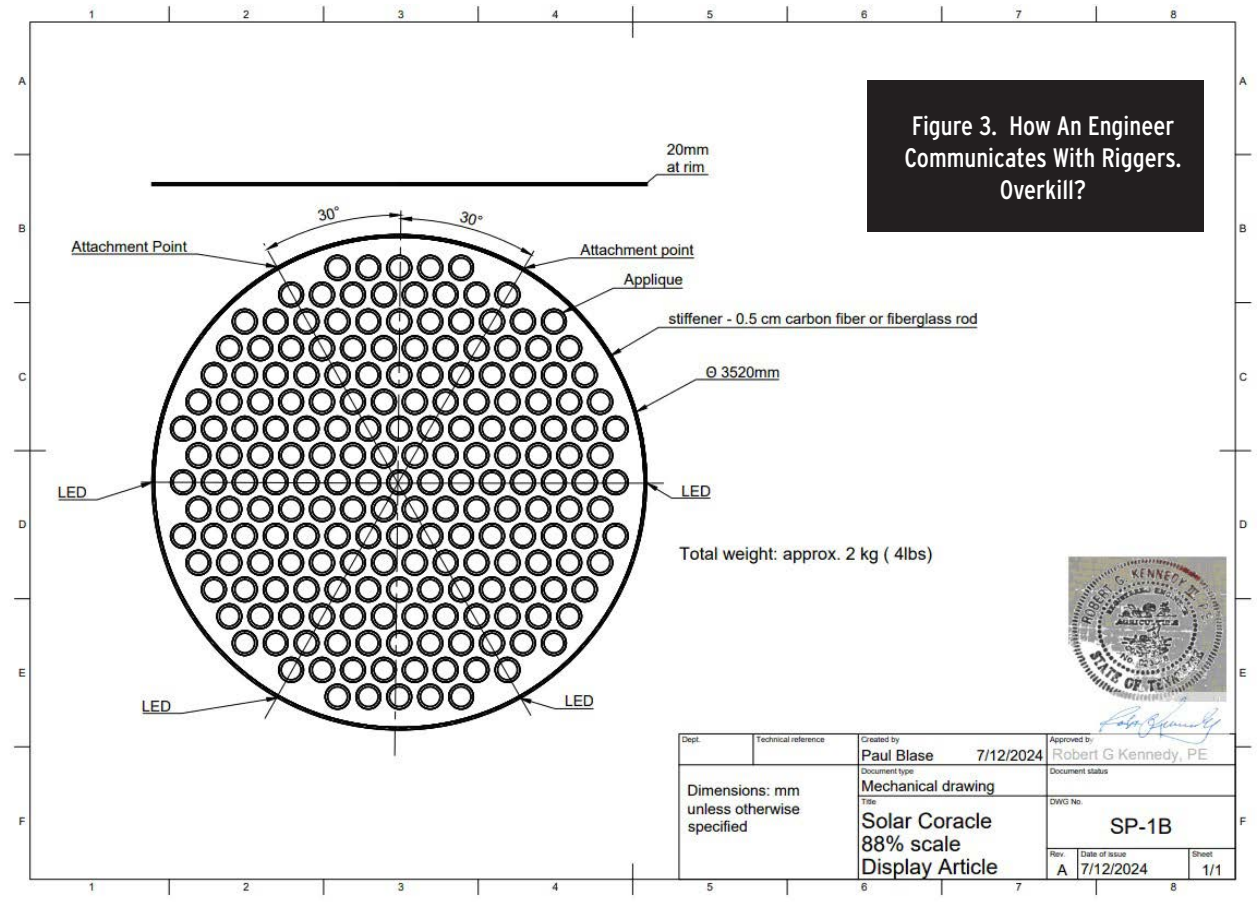
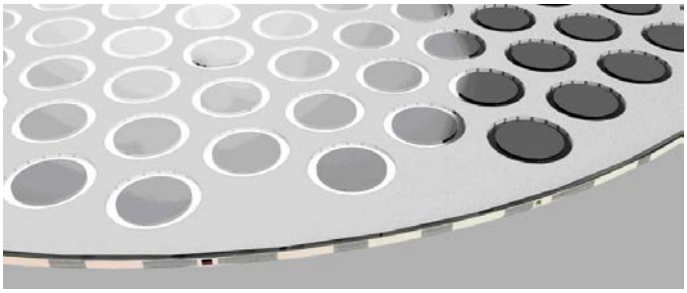



Figure 3. How An Engineer Communicates With Riggers. Overkill?

to be the simplest cheapest solution was those thin 0.3-inch fiberglass rods about a meter long that are bent into hoops and stuck in the ground to frame field-expedient winter greenhouses made of transparent plastic sheeting. One is connected to the next with little aluminum ferrules – string enough together and they will hang in a semicircle just by their own weight, which eliminated concerns about snapping rods during rigging.

Next challenge: how to inexpensively mimic the hundred-plus annular flat optical transceivers? Another knotty problem. It would have to be reflective, easily and quickly applied yet stick like a poor relation once on, a low scrap rate, and above all, cheap. (See rule about show biz above. Actually, your correspondent was willing to slide on this one because his time is worth something too.)



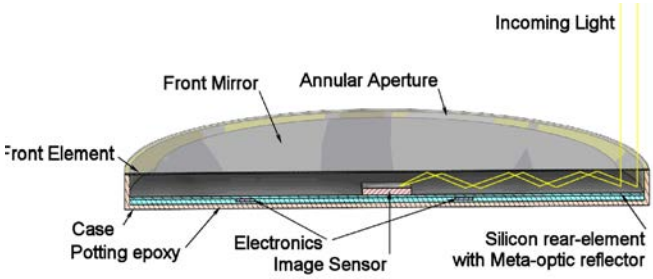
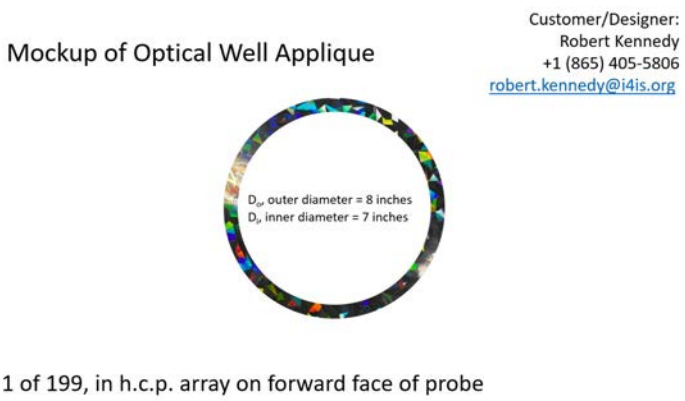



Figure 4 (left): Oblique view of the forward/top face of the probe. (right) Zoomed sectional view of one flat optical transceiver.

What was desired was something that would suggest an optical transceiver at a distance if one squinted, without building an actual optical transceiver, let alone hundreds of them. It would necessarily be shiny and high-tech. We experimented with metallic spray paint and stencils and discarded the idea as not reversible enough in case of inevitable goofs. Luckily, your correspondent has a relative by marriage, Dan Sparkes, who runs a business, SparkGraphik, printing weird stuff for advertising purposes. Your correspondent figured if anyone knew where to procure such a thing, it would be his "nephew-in-law" (is that a legal term?). Sure enough, he had a supplier who prints and die-cuts Mylar™ foil for a living, and one of those foils was even holographic with a vaguely spacy theme and self-sticking. O happy day!



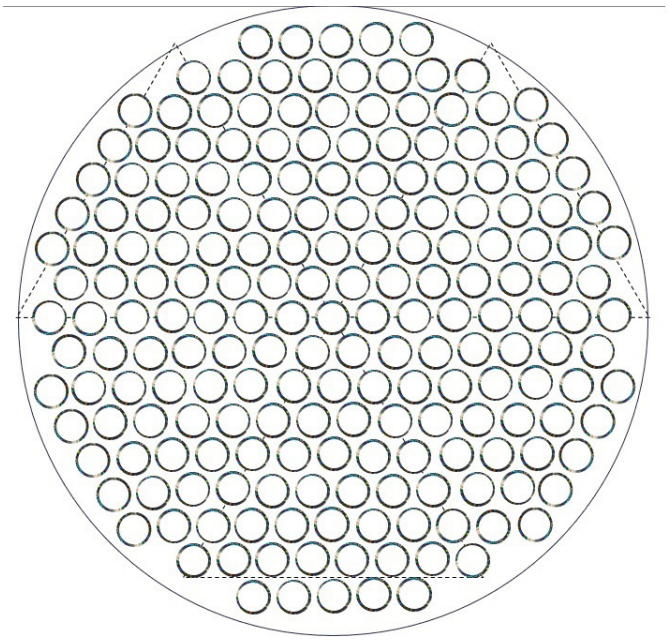



Figure 5
(left): A single holographic ring.
(right) Layout of Big Object #1 fully populated by rings.

YHN commandeered his spouse's living room to make sure everything worked. See left side of Fig 7 below. One small divergence from the master concept: those freaking rings turned out to be a pain to apply. First consider how wobbly a Mylar™ ring that's only a half-inch wide yet 8 inches across is. Now add to the situation strong adhesive that wants to stick to everything including the user, itself, and anything else in the vicinity except the workpiece. The first Big Object consumed 163 of them (not 199 as calculated), with an average installation time of 6 minutes apiece, over one marathon night and day, because the show was about to start in Glasgow, yet it was still on YHN's side of the Pond. Do the math. Half this time was consumed measuring and drawing construction lines on the black fabric to precisely locate the rings. Only five scrapped, amazing! YHN began to feel like he could fix more than just a plate of white bread.

For the Big Object #2 (by now called "Interstellar Coracle") destined for NASA in Pasadena in September, your correspondent's spouse (who is a top-flight mathematician) suggested just following Ms Johnson's seams which were by definition 60 degrees apart. YHN abandoned precision measurement, and just eyeballed the placements. See right side of Fig 8 below. This reduced production time to just a bit over 2 minutes apiece. One develops a knack for placing these finicky things such that they drop into position with just a bit of smoothing; let muscle memory work. On the advice of a friend, your correspondent stopped placing rings once there were enough to form a perfect hexagon, because, as the guy stated, "hexagons are canonical". Besides, he was tired.
The next challenge was getting a metallic-looking gold surface that didn't suck for the back face of the probe.

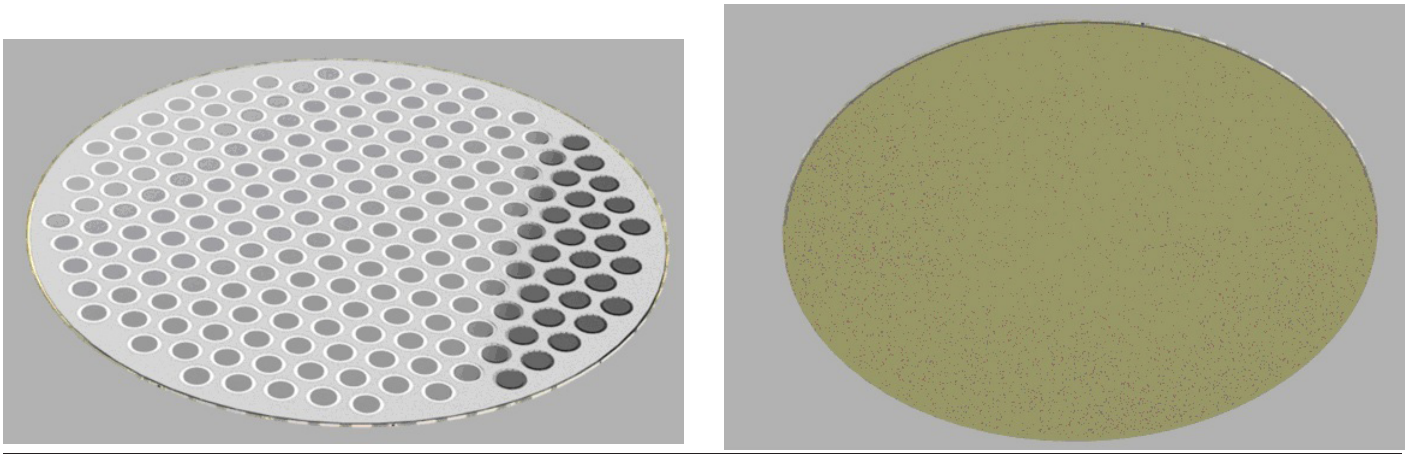


Figure 6
(left): Oblique perspective view of top face of probe with primary coms/cameras.
(right) Bottom dielectric side of probe, facing the launch laser. Note the secondary laser ports in the rim.

A number of tricks such as cutting six-foot pie wedges of gold Christmas wrapping or applying gold color by a person suspended in an armature holding a paint sprayer were experimented with and rejected. The simplest solution eluded us until near the end, too late for Big Object #1 (which is now back in the States), but just in time for Big Object #2 at NASA's NIAC Symposium in Pasadena. Space blankets! Kudos to Paul Blasé. See Fig 8 below. Given that the last FedEx flight that could put Big Object #1 into the hands of the venue's riggers in Scotland on Tuesday August 6th would take off on the afternoon of Wednesday August 1st, your correspondent made a command decision to skip the untested gold surface and ship the Big Object that afternoon as-is, figuring that the front side with LEDs would have sufficient pizzazz that no one would notice the dull back side. This worked out.

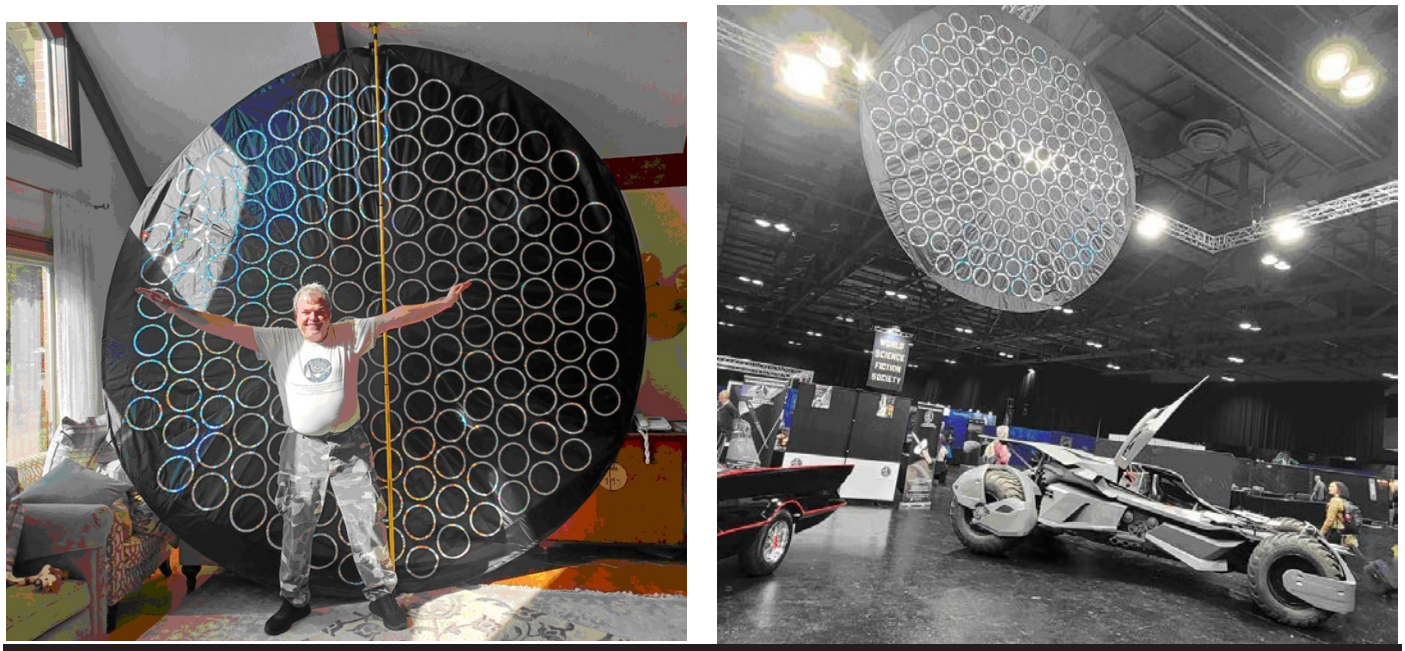


Figure 7
(left): Big Object #1 ready to go to WorldCon 82 in Glasgow in August.
(right) How Big Object #1 (above the Batmobile) looked at the i4is-UK booth at WorldCon 82 in Glasgow.

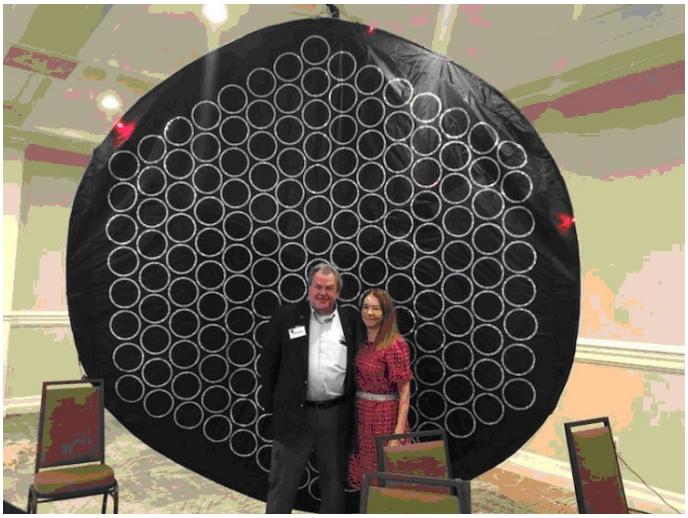


Figure 8
(left): Applying gold Mylar™ to Big Object #2 in the Vehicle Assembly Facility (aka living room) before the NIAC Symposium in Pasadena in September.
(right) How Big Object #2 looked in Pasadena. YHN with his patient clever spouse Barbara. Note the red LEDs. Note also the simpler hexagonal array – "hexagons are canonical".

An important technique in show biz, from set design, is that just a bit of "high frequency" detail draws the viewer's eye to it, away from the imperfections or blandness of the background, allowing the designer to expend little effort or expense on large "low frequency" areas of the visual field. In fact, like modern architecture, "less is more". So too with ginning up a convincing mockup of an interstellar spacecraft. In this case, the distracting detail came in the form of color and motion in time, namely, bright red blinking LEDs placed 'round the rim of the Big Objects, to simulate the secondary communications system of sideways probe-to-probe infrared lasers. Paul Blasé designed and fabricated a battery-powered LED harness, with LEDs so bright they left afterimages on viewers' retinas. See Fig 9 below.

Wonderful component selection! That makes a helluva impression especially when the venue lights are low [1].

As built, even with enough batteries to run nonstop for 120 hours, Big Object #1 came to 5 lbs, well under 2 kilos. Yet this is still three orders of magnitude more than the final spacecraft must be, which is 4 grams, about the same as a US nickel. Like YHN in Figures 7 and 8 above, the Interstellar Coracle has a lot of weight to lose before it can fly among the stars sometime after mid-century. Aerographene already has nearly magical density like the staple materials of science fiction: unobtainium, balonium, and wishalloy. However, this mass reduction requirement is not as daunting as it seems. Three orders of magnitude over three decades corresponds to one order every 10 years, which means roughly one doubling every three years. Human beings already have two well-known technologies that maintained a long-term rate of improvement equal to that or better: namely the packing density hence power of integrated circuits (described by "Moore's Law") and the reduction in the cost of photovoltaic modules (described by "Swanson's Law"). If we put our minds to it, and dedicate the resources, structural materials will seem to become quasi-magical. Remember Clarke's Third Law.

Once assembled, the last two rods overlap just a bit, and are held together by an extruded bit of aluminum with a figure-8 cross-section. The tautness of the ring-framed disk is controlled by sliding the fiberglass rods. Moving the ends towards each other increases the diameter of the ring hence tightens the membrane. Sliding the ends away from each other achieves the opposite effect – loosening the membrane. Simple! One wrinkle that was not foreseen is the sensitivity of this arrangement to very small adjustments in the relative motion. Less than 1 cm too much tightening, and the disk pops itself into a compound curved saddle shape, rather like a Pringles™ potato chip – but a crisp 11 feet in diameter. It turns out that can be an issue with deploying large wire-stiffened shapes from real spacecraft, too. Hence the title of this part of the article.

[1] Lighting at the WorldCon was expected to far outshine the LEDs so the Glasgow onsite team decided to leave them switched off.

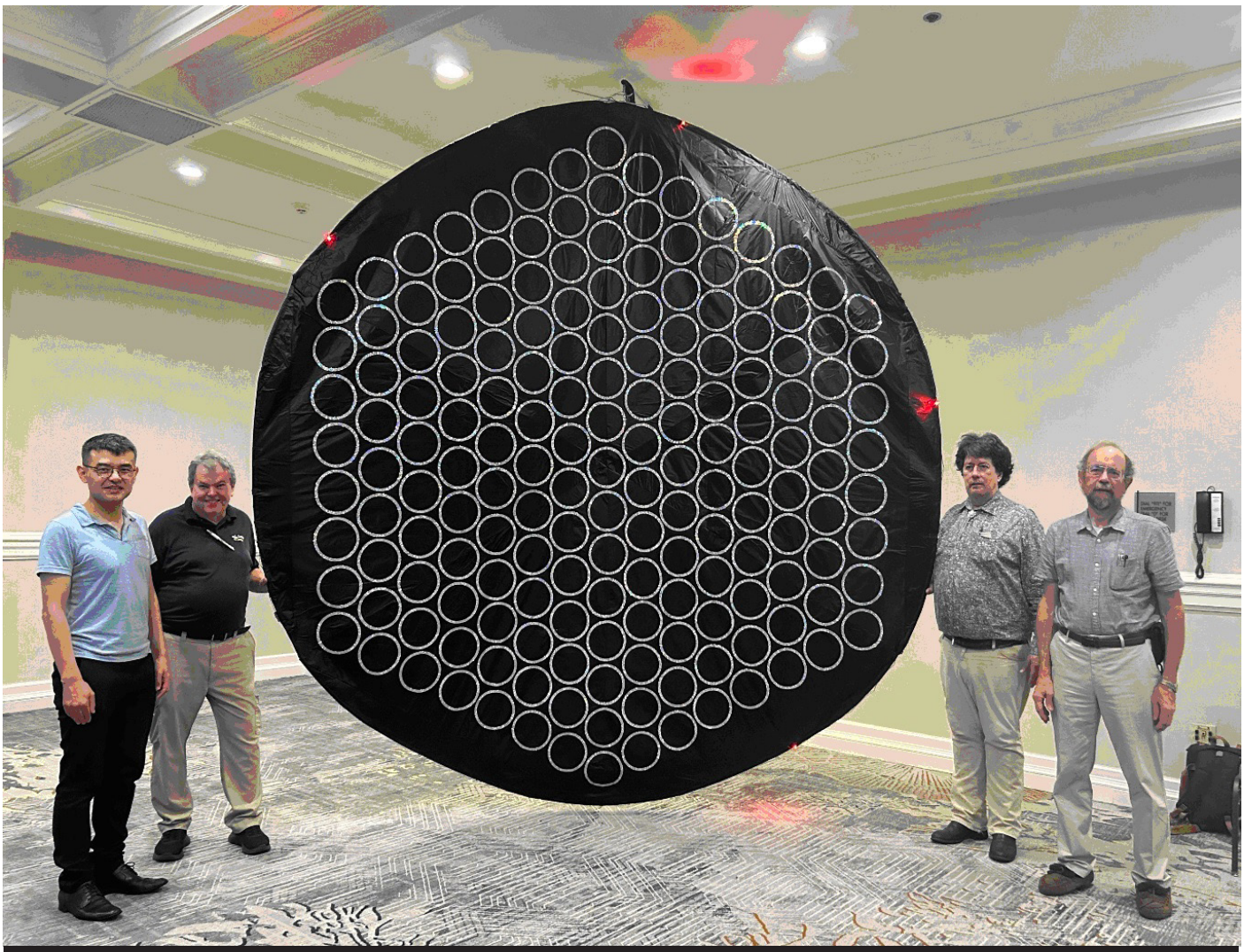
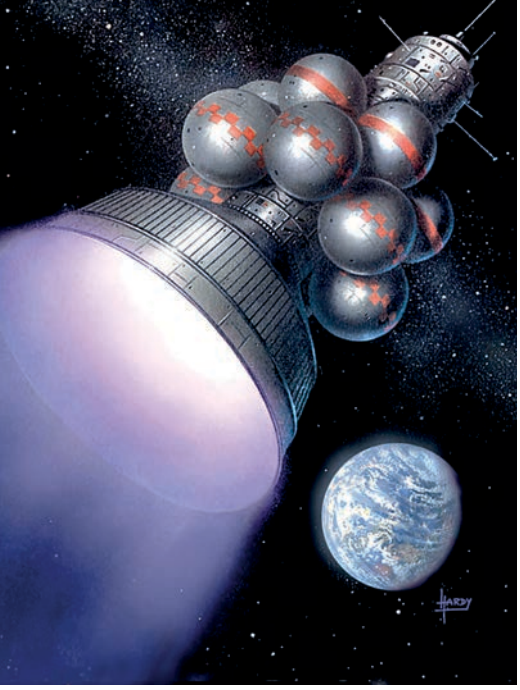


Figure 9 (from left to right): The Swarming Proxima Centauri team with their Interstellar Coracle, aka Big Object #2, in Pasadena: Dr Andreas Hein, ExecDir i4is-UK, Robert Kennedy PE, i4is-US, T Marshall Eubanks, chief scientist of SII, W Paul Blasé, chief engineer of SII. Not present: Adam Hibberd and Manasvi Lingam, PhD of i4is. Again, note the actinically bright LEDs. Note also the mere inch of clearance between the Big Object and the ceiling and the floor.

**About the Author**

Robert G Kennedy III, PE, is President of the Institute for Interstellar Studies - US, the American sibling organization of the Initiative for Interstellar Studies. He was co-author of *Project LYRA: Sending a Spacecraft to 1I/'Oumuamua (formerly A/2017 U1), the Interstellar Asteroid*, the first published proposal to investigate this, our first observed interstellar object (ISO) and of numerous papers in Interstellar Studies including *Project Lyra: A mission to 1I/'Oumuamua without solar oberth manoeuvre, Shell Worlds-An Approach To Terraforming Moons, Small Planets and Plutoids, Interstellar Now! Missions to and sample returns from nearby interstellar objects, Technology development for a low-mass solar system and interstellar communications system, Interplanetary radio transmission through serial ionospheric and material barriers* and, of course, *Swarming Proxima Centauri: Optical Communication Over Interstellar Distances* as referenced in this article.

He was a co-founder of Tennessee Valley Interstellar Workshop (tviw.us) now trading as the Interstellar Research Group (IRG).



# Initiative for Interstellar Studies*

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

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


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

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

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

# Glasgow 24 SF WorldCon

## What we did at the Con

## Gill Norman and Tam O'Neill

The SF world has been the unruly cousin of space technology and exploration since both began in the 19th century. Many space pioneers have been inspired by fiction from the novels of Jules Verne and H G Wells to the comic adventures of Dan Dare in the UK and Flash Gordon in the USA. We were at the World Science Fiction Convention, Glasgow24, this year following our big show at the London WorldCon in 2014, see Principium issue 8, *The Interstellar Space at London's greatest science fiction convention*, issue 9 *Feature: i4is At the World Science Fiction Convention* and issue 10, *What we did at the WorldCon in August 2014*.

Here Gill Norman and Tam O'Neill give a personal account of how Glasgow24 all happened, "thrills and spills" and all! Simone Caroti contributed some helpful memories and corrections.

**The morning of 8th August arrived all too soon...**

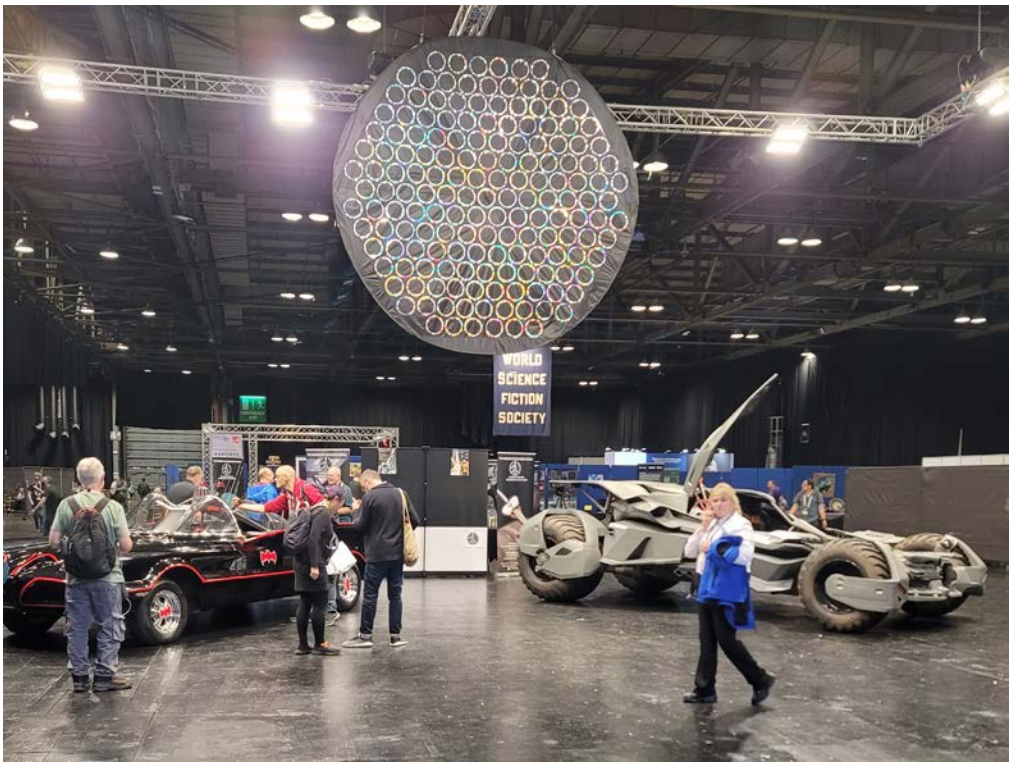
It was with bated breath that Tam, Ian and Gill peered into the cavernous exhibition hall to see how our model laser sail spacecraft looked in the air, suspended from the ceiling. We'd had to leave it in the hands of the riggers the night before, after receiving promises that they would look after it.

My calendar tells me the first conversation about our possible presence at the Glasgow24 WorldCon was in January 2023. Months of organising with a global group of dedicated volunteers. The model was called the Big Object right up to the Con.

Regular readers may remember the 4 metre tall monolith that we constructed for the 72nd WorldCon, Loncon3. After the success of that appearance a decade ago, we decided to repeat the experience; admittedly with an 'easier to construct' Big Object.

At least that was the plan. Being best laid and all, the Big Object took many months to coalesce into something we could create and ship to Glasgow.

Our Board member and head of i4is-US, Robert G Kennedy III, rose to the challenge of building the 4 m diameter model probe, more of which can be seen in Principium Issue 45, May 2024, featuring an artist's impression on the front cover. We handed out about 100+ copies of Principium 45, printed especially for the occasion.




The mighty i4is "Coracle" probe model looms over the Batmobiles at the Con. The Space Initiatives/i4is NASA NIAC study conceives swarms of a thousand or so of these probes getting to Proxima Centauri just 20 years from launch.

It was good news that a similar model was built for the NASA NIAC event in September, where Robert and Andreas Hein (i4is Executive Director) supported Principal Investigator of Space Initiatives Inc, Marshall Eubanks, who delivered the results of their study with his colleague, Paul Blase [1]. For more on this see Robert's piece, *Pringles Is A Verb*, elsewhere in this issue. Robert's wide range of skills, experience and contacts were very much appreciated and utilised. Getting the plans rubber-stamped by the exhibition organisers at unexpected intervals was taxing. Then the shipping process was even more taxing (pun fully intended). Robert could recount the entire adventure although I'm unsure whether some of it would be printable.

It's fair to say that the model for the NASA event was not swaying gently in the air currents 4 meters above two fully functioning Batmobiles. But what do you expect at the 82nd WorldCon?

For more details about our intrepid model probe and its future swarm family, please see elsewhere in this issue and in previous issues.

The remainder of our exhibition space was roomy and comfortable, providing a homely base for our members and friends and a welcoming atmosphere to engage visiting enthusiasts during the week. The magnificent banner artwork created by Michel Lamontagne was displayed on a main thoroughfare and admired by many.


Sky News covered the Con. Here's one of their images - Tam O'Neill and Adam Hibberd with one of our four banners designed by Michel Lamontagne. This one shows probes passing Proxima Centauri - a vision based on the NASA NIAC study by Space Initiatives and i4is.

Our four banners are shown at the end of this report.

[1] More about our NASA NIAC study in Principium 44 *NASA NIAC funds swarming study: Space Initiatives and i4is team to further their study of interstellar swarming mission* (https://i4is.org/principium-44)

One surprise was the adamantine-reinforced poster boards. Their stubbornness in yielding to conventional drawing pins was an opportunity to make friends with some of our co-exhibitors whilst stand-building. Our display remained static for the duration, given that industrial strength pliers were required to remove the posters.


Our static poster board display - we had a lot more posters to show!

Credit: Gill Norman


Some of our display at the Con - with free copies of Principium 45.
We featured City of Glasgow College who were on standby to help check out the Big Object but it arrived too late!

Credit: Gill Norman

Our literature was spread freely over the display tables and proved popular; thanks to our volunteers who engaged with stand visitors on a wide variety of interstellar topics.

The other major segment of our outreach activity is our organised talks, lectures and discussions. For this, our second WorldCon, our exhibition space was to be dominated by a model probe that can be considered as feasible technology in this century. So for our series of panels we wanted a contrasting topic that encompassed far longer term interstellar possibilities.

We were privileged to have Simone Caroti on board as an enthusiastic advocate. The theme of Generational Worldships was hard to ignore, especially when Simone was keen to lead our discussions. As reported in Principium 45, Simone "wrote the book" in the form of his *The Generation Starship in Science Fiction: A Critical History, 1934-2001*, Simone Caroti, McFarland & Company 2011.[1] We were honoured that he became our Worldships advocate and Co-Lead in our planning meetings with the Programme organisers.

[1] McFarland (mcfarlandbooks.com/product/the-generation-starship-in-science-fiction/), Foyles (www.foyles.co.uk/book/the-generation-starship-in-science-fiction/simone-caroti/9780786460670), Hive (www.hive.co.uk/Product/Simone-Caroti/The-Generation-Starship-in-Science-Fiction--A-Critical-History-1934-2001/15272548)

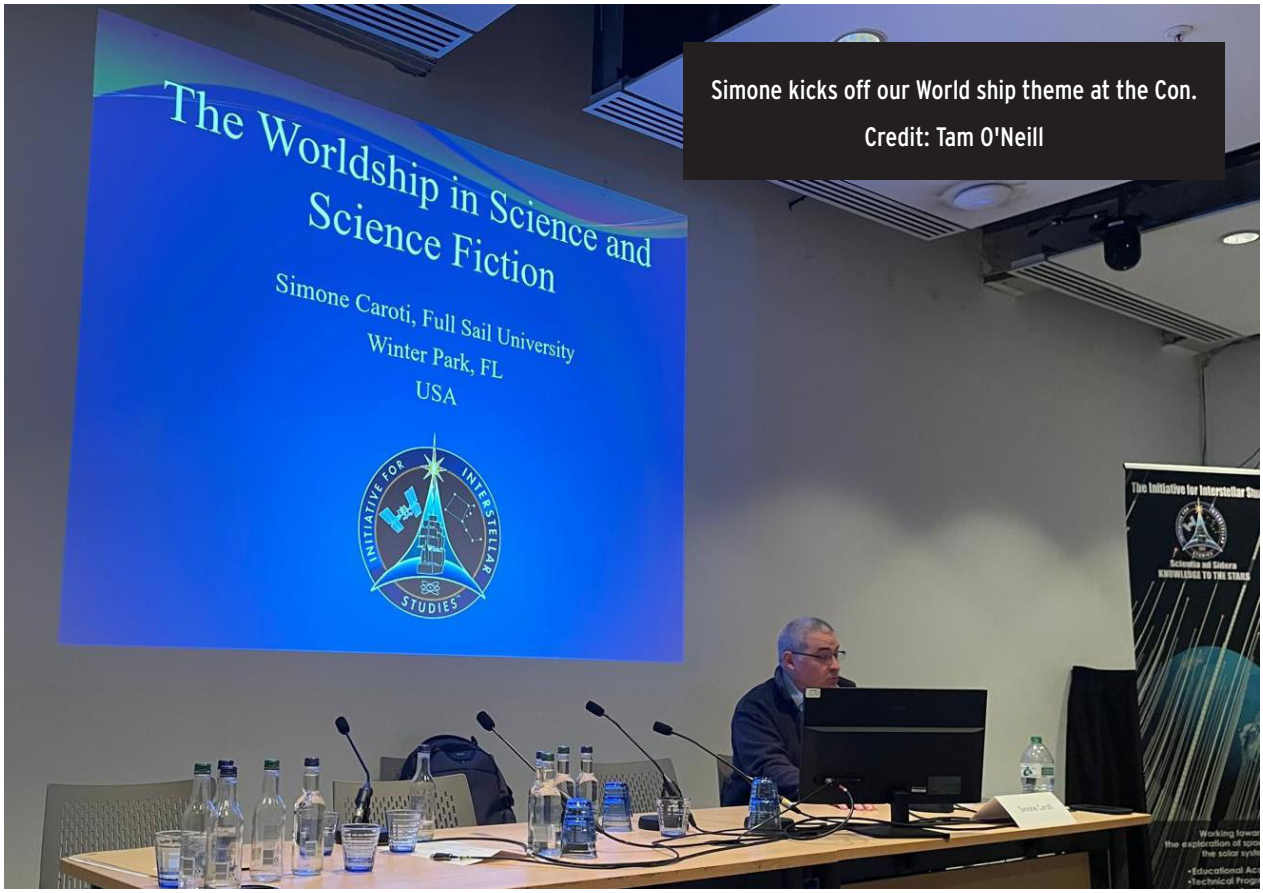
We were just as privileged to have molecular biologist and Con expert Cassidy Cobbs, Senior Project Manager at Memorial Sloan Kettering Cancer Center (NYC) - and Secretary of i4is-USA, on board - an invaluable guide through the labyrinth of procedures.

Our initial draft programme of Worldship panels was greeted with enthusiasm by our two contacts in the Programme Organising Committee, Dr Christine Davidson (Strathclyde University) and her husband Michael. They headed up the WorldCon Science & Technology Programme and were delighted to consider our proposals. In addition to their day jobs, they organise Scotland's national SF Convention, which focusses strongly on the interface (and cross over) between Science Fiction and Science Fact. A perfect match.

Given that it's near impossible to do justice to that topic in an hour, we conceived four separate sessions, spaced throughout the week. This would also give as many Con-goers the chance to attend at least one. We were whittled down to three sessions in the end; however we were assured that our acceptance success rate was high!

Our SF theme is echoed by a recently launched study competition addressing internal issues in worldships *Project Hyperion* (www.projecthyperion.org/about-1) building on work i4is coordinated at the International Space University, Strasbourg, in 2011. The renewed project is sponsored by the Initiative for Interstellar Studies and features an Organisation Team headed by our Executive Director, Dr Andreas Hein, and including our Deputy Technical Director, Dr Dan Fries and our prolific collaborator, Michel Lamontagne.

Our first session, *Worldships 1: Introduction*, on the opening day Monday 8th August was an introductory talk from Simone, opening up to Q&A. The premise that generation starships are both interesting science and an inexhaustible source of ideas for fiction material ensured a lively discussion. Simone covered the definition of the worldship concept and outlined its history in science (Goddard, Tsiolkovsky, Bernal). The next section was the science fiction literature (Heinlein, Aldiss, MacLeod et al). In addition, this Worldship session included a live stream for those physically not able to attend. The two later sessions unfortunately did not.




Simone kicks off our World ship theme at the Con.

Credit: Tam O'Neill

Friday 9th August saw our second session, *Worldships 2: Reasons for Going and What Can Be Achieved Soon*, delivered as a full panel discussion, with Cassidy facilitating the conversation around those 'Reasons' and on early feasibility. There are many reasons, with a very diverse range of prompts, that may result in a worldship mission, from ecological collapse or nuclear war, to exploration, colonization, or search for extra-terrestrial intelligence. One motivation for building probes to reach Alpha Centauri in the near term, as in our NASA NIAC study, is to provide intel on more sophisticated future uncrewed missions to our nearest interstellar neighbour. Feeding back data to Earth is as essential as getting a probe there. Cassidy was an excellent moderator and deftly handled an over-enthusiastic audience member by encouraging them to attend the next session where their questions would be answered (or at least, debated). We were grateful to have been introduced to Jesper Stage, Professor of Economics and Chair of the Economics Unit, Department of Social Sciences, Technology and Arts, Luleå University of Technology Sweden. He made a very welcome addition to our merry band of interstellar activists.


The panel *Worldships 2: Reasons for Going and What Can Be Achieved Soon* with (left to right) Cassidy, Simone, Jesper Stage, Geoff Landis and William Ledbetter.

Credit: Tam O'Neill

Near full house at the panel *Worldships 2: Reasons for Going and What Can Be Achieved Soon*.

Credit: Tam O'Neill

Our last panel was Sunday 11th August, with the title *Worldships 3: Generational Relations and Socio-Economic Structures*. More speculative than the previous two, it covered items such as daily life onboard a worldship. For example, governance, education, ethics, morals, religious beliefs, and wealth/resource management, with particular emphasis on the transmission of information and purpose.
Our enthusiastic audience member returned for this session, with so many more questions that we eventually ran out of time in the session. We encouraged him to come to our stand in the exhibition area the next day, where we had a lengthy discussion eventually leaving us with a copy of the Project Hyperion briefing document (www.projecthyperion.org) which we had at the stand.


Cassidy Cobbs (left) moderates our last panel, *Worldships 3: Generational Relations and Socio-Economic Structures* with (from the left) Cassidy, Jesper Stage, Simone Caroti, Sarah T Guan, Marina Berlin.

Credit: Tam O'Neill

On Monday, the last day, Jesper presented *Economics of Generation Starships*, examining the assumption that once you've solved all the other problems with generation starships, dealing with the economic problems involved would be trivial. He asked - Is that right, or would the economic problems be important as well? He explored what the economics of a generation starship might look like in practice, in comparison with how this is handled in science fiction.
Cassidy also moderated a Saturday panel *It's Life, Jim, but Not as We Know It*, discussing life beyond Earth and what it might look like. Will it be carbon-based? Will it have DNA? Will it resemble Earth's extremophiles? Or will it be so exotic that we may not even recognise it? What can we expect to find, where will we find it, and how will the nature of the host planet and star have influenced the way life has developed there?
Simone Caroti was also a panel member for the SF session, *The Sinister Underbelly of Iain M Banks' The Culture*. Most of these novels were set in the universe of The Culture, an advanced society of humans (or humanoids), intelligent drones and unfathomably advanced machine intelligences. Simone wrote the book on this too, *The Culture Series of Ian M Banks: A Critical Introduction*. Simone Caroti. McFarland & Company 2015 [1]. For those new to Banks' Culture series, see also *A Few Notes On The Culture*, Iain M Banks (http://www.vavatch.co.uk/books/banks/cultnote.htm).
I am pleased to report that each session was very well attended, with some lively and interesting discussions.

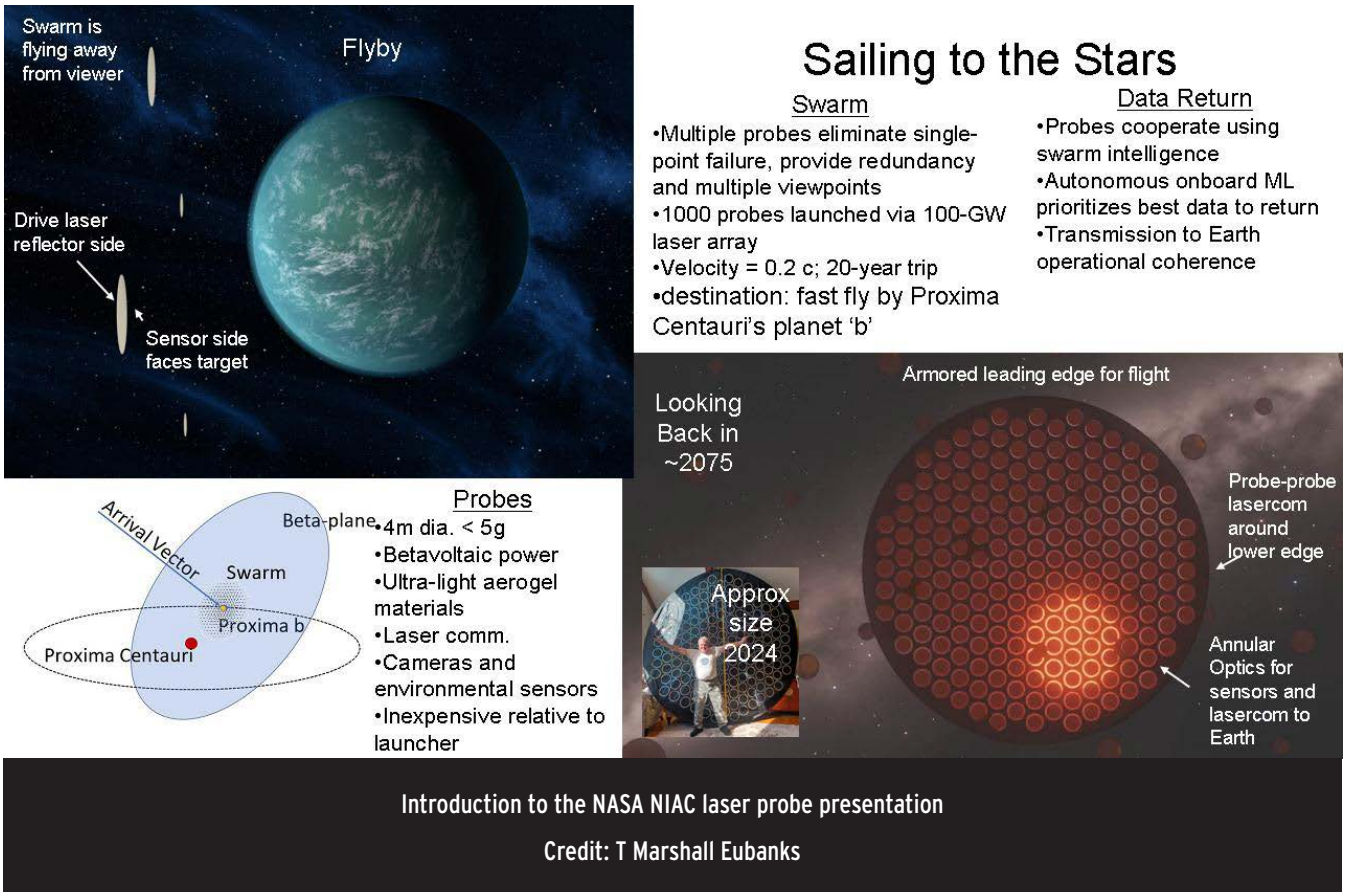
[1] McFarland (mcfarlandbooks.com/product/the-culture-series-of-iain-m-banks/), Foyles (www.foyles.co.uk/book/the-culture-series-of-iain-m-banks/simone-caroti/9780786494477), Hive (www.hive.co.uk/Product/Simone-Caroti/The-Culture-Series-of-Iain-M-Banks--A-Critical-Introduction/17254173).

Part of our exhibition presence included a series of at-stand talks to be delivered remotely by various interstellar luminaries during the week; alas, acoustic issues countermanded that plan. This contingency, delivering pre-recorded talks worked just as well and gathered interested audiences at times.


Project Hyperion introduced by video on our big screen by Yazgı Demirbaş Pech, Architect, Illustrator and Designer, one of the i4is worldship team.

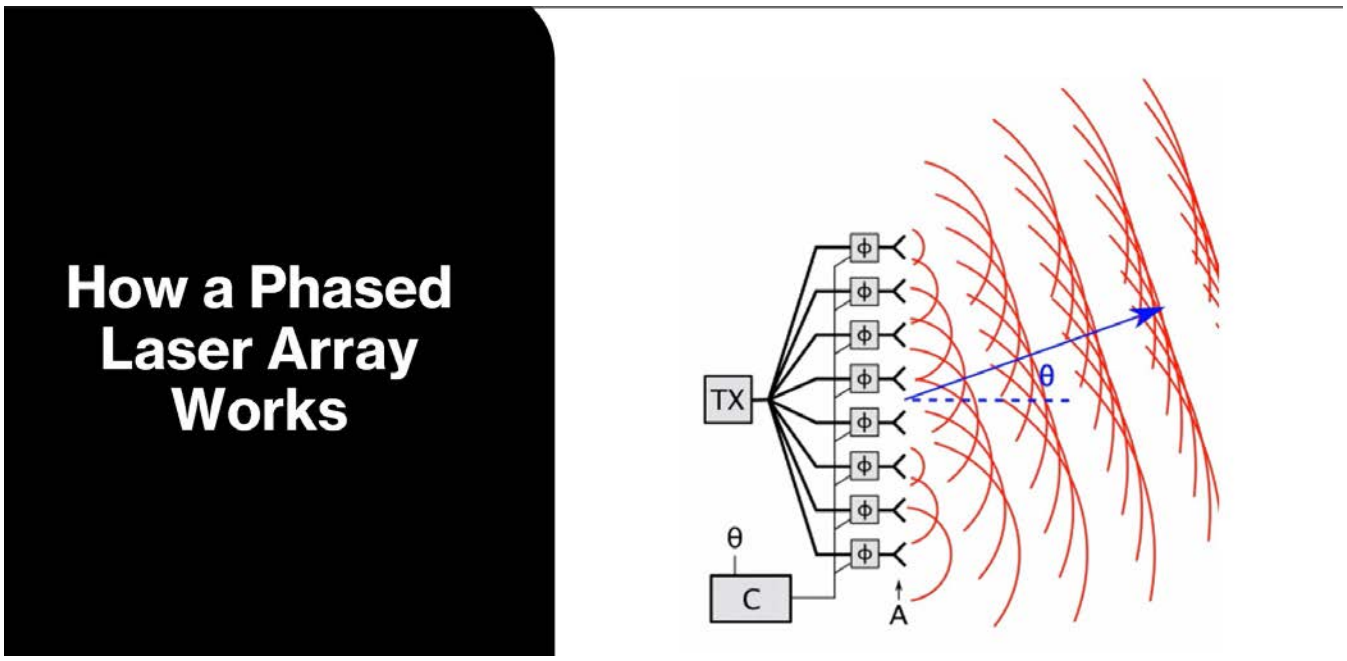
Credit: Tam O'Neill

Our laser propelled probe swarm was introduced at the NASA NIAC conference - with a video at the Con.




Introduction to the NASA NIAC laser probe presentation

Credit: T Marshall Eubanks




A frame from Adam Hibberd's video on Laser Propulsion he explains how the propulsion system maximises the "push" it produces

I think it's fair to say that our splendid suspended space probe attracted a little less attention than its earthly bound DC Comics competitors. However, it's also fair to say that our ultimate ambitions reach far, far beyond our pale blue dot.

We had a wonderful time at WorldCon and extend our gratitude to all the Con organisers.

Thanks are due to the following-
Tam O'Neill (i4is), Patricia Beaulieu (wife of Charles Radley), Simone Caroti (author of *Worldships in SF*), Cassidy Cobbs (i4is), Adam Hibberd (i4is), Ian Norman (i4is), Charles Radley (Blue Origin and Space Initiatives) and Sarah Margree. Also John I Davies (i4is), remote but doing much of the pre-Con juggling, Jesper Stage, for academic input on worldships, and not least Robert Kennedy (i4is-US) – and his fellow creators of the Big Object.

The (almost) whole team on the i4is stand.

In front - Gill Norman, and left to right : Tam O'Neill (i4is), Patricia Beaulieu (wife of Charles Radley), Simone Caroti (author of Worldships in SF), Cassidy Cobbs (i4is), Adam Lear, Ian Norman (i4is), Charles Radley (Blue Origin and Space Initiatives)

Credit: Ian Norman


Our four banners. We'll be using them wherever we present i4is in future.

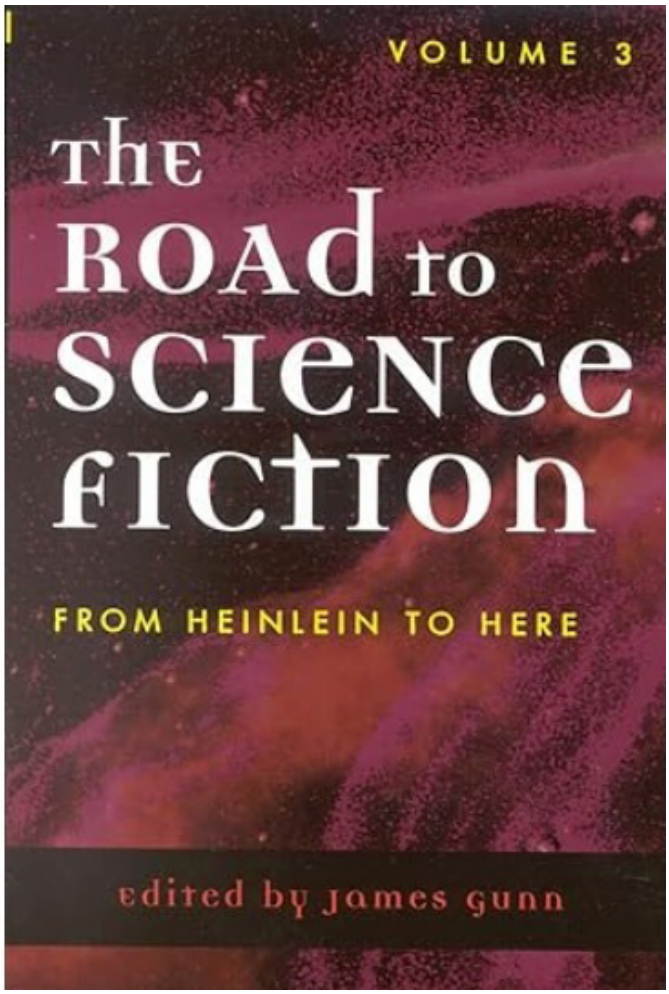
Frome the left they visualise -
An Icarus Firefly fusion probe enroute, Thousands of laser propelled probes passing a target planet, A worldship arrives and links to its predecessor (a Firefly probe) and The worldship interior seen from the propulsion end.
Credit: Michel Lamontagne

# i4is' Science Fiction Anthology and Book Club

## Rob Swinney

The Science Fiction genre has been both inspired by the dream (and, later, the reality) of space travel and inspiring to space technology - notably from the 'Golden Age' of Asimov, Clarke and Heinlein and comic heroes like Buck Rogers and Dan Dare.
We recount our 2024 outreach to the genre at the 2024 SF WorldCon elsewhere in this issue. Here our Deputy Director, Rob Swinney, introduces another way in which we bring together imagination and reality, our upcoming anthology and regular book club.

For more than a year, members and friends of i4is have come together to read and write science fiction (SF). The initial spark for writing came from people volunteering to contribute to a new i4is SF anthology of short stories on the interstellar theme, a collection that will be published in due course (see below for details). Associated writing workshops are run by our very own experts Sarah Margree and Jean Asselin, with two in-person classes already completed, and an ongoing online one. In order to stimulate interest in reading SF, also to show our writers the scope of the genre, Sarah suggested running an online Book Club, which meets regularly on the 3rd Thursday of each month.




We've just finished reading the 36 short stories in *The Road to Science Fiction Vol 3: From Heinlein to Here*, a volume that covers the period from 1940 to 1975, from the 'Golden Age' to the 'New Wave'. Thoughtfully selected by author and scholar James E Gunn, the stories illustrates the different styles of story that evolved over the period, with each text introduced by a very enlightening short essay/preamble that situates the author and story within the SF genre. The consensus by the Club members is that this is a particularly entertaining book.

We've typically been selecting two stories from Volume 3 to read each time, and last month we completed the final story of the volume, 'Tricentennial' by Joe Haldeman. An interesting story published in 1976, it involves an interstellar spacecraft called Daedalus sent to 61 Cygni. This prompted a discussion of whether it had been influenced by the naming of the renowned Daedalus Interstellar Star Probe Study carried out by the British Interplanetary Society between 1973-78. Daedalus and the subsequent Icarus study are close to the hearts of many members of i4is and BIS!

Finally, we are still inviting volunteers to try their hand at writing original SF stories for consideration for the i4is anthology. Science fiction is all about the consequences of introducing changes in the world, such as voyages to stars that have beckoned since the discovery of stellar parallax in the mid-19th century. This is an opportunity to expand the ideas at the heart of i4is' endeavours. To quote Arthur C Clarke, "The only way of discovering the limits of the possible is to venture a little way past them into the impossible".
For more info on the anthology, the writing workshops, or the Book Club, contact info@i4is.org.

# Project Hyperion

## John I Davies

On 1 November 2024 i4is announced the Project Hyperion [1] competition (www.projecthyperion.org). This builds on an earlier project with the same title which we ran at the International Space University, Strasbourg back in 2012. Principium Editor John I Davies outlines the new project.

Worldship interior - from the project briefing

Much has been studied and written about propulsion, power and ultimate goals of an interstellar worldship or generation ship [2] but less about the human aspects for such a long journey. The objective of the competition is to design the habitat of the generation ship, including its architecture and society. Consequently competition teams must be multi-disciplinary and each team must include-

- At least one architectural designer
- At least one engineer
- At least one social scientist (sociologist, anthropologist, etc)

The prizes for successful teams are -

- First $5,000
- Second $3,000
- Third $2,000

The registration fee is $20 and registration closes on 15th December 2024. See the website and briefing for more details.

The organisers are an international, interdisciplinary team with expertise in architecture, engineering, anthropology, and urban planning. They are

Andreas Hein - Aerospace engineer

Yazgı Demirbaş Pech - Architect, Illustrator, Designer

Dan Fries - Aerospace Engineer, Researcher

Cameron Smith - Anthropologist

Michel Lamontagne - Illustrator, Designer

Maciej Rebisz - Concept Artist

Steve Summerford - Landscape Architect

Linda Cortés Satizábal - Architect

More about the Project at www.projecthyperion.org including a link to the project brief www.projecthyperion.org/_files/ugd/91ab16_ce159a8f438b4f529a46df6b70681978.pdf

[1] Hyperion has already received media coverage, *Design an interstellar 'generation ship' to spend decades among the stars with Project Hyperion competition* www.space.com/space-exploration/tech/design-an-interstellar-generation-ship-to-spend-decades-among-the-stars-with-project-hyperion-competition.

[2] Starting with Robert H Goddard in the 1910s, quickly followed by Konstantin Eduardovich Tsiolkovsky and JD Bernal in the 1920s. The latter will be least familiar to most people. His book was *The World, the Flesh and the Devil: an inquiry into the future of the three enemies of the rational soul*.

# Rise of the Serpent-God

## The Apocalypse Plot

## Adam Hibberd

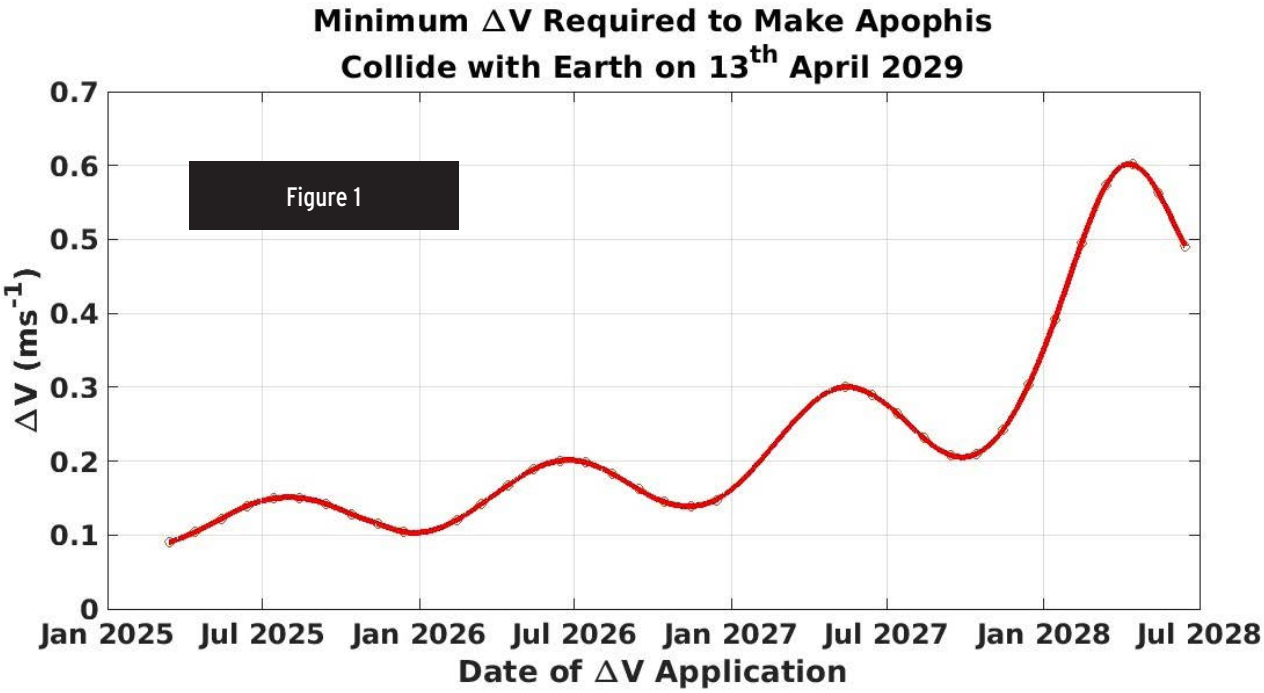
Principium readers will recall Adam's articles on the astrodynamics of intercepting interstellar objects (ISOs), notably 1I/'Oumuamua, our first observed ISO, as part of i4is Project Lyra. Here he deals with a more local object but one of considerable concern. Applying his Optimum Interplanetary Trajectory Software (OITS) he examines how we might deal with a potentially catastrophic encounter with a known near-Earth object (NEO)

Ancient Egyptian art depicting Apohis being warded off by a deity. Tomb of pharaoh Ramses I. Thebes West, near 1307 BC.
Credit (image and caption): Wikimedia Commons

As many are observing, the world seems to be in perilous times at the moment and if one were to believe the New Testament, or at least 2 Timothy Chapter 3, one would presume the cause to be men who are 'lovers of their own selves, covetous, boasters, proud, blasphemers' etc. That seems to be a shockingly accurate prediction, given the upheavals in the Middle East, the calibre of politician coming to prominence in the West, and for that matter around the globe these days.

But it is to a global catastrophe that this piece is dedicated (or at any rate an aversion of it), in the form of the Potentially Hazardous Asteroid (PHA) known as Apophis, named after the serpent-god appearing in Egyptian mythology and considered to be the antithesis to the all-powerful Sun god Ra. Apophis encapsulates total oblivion and for that matter everything the Egyptians feared the most.

Back to the present, the PHA Apophis was discovered in 2004, and it caused consternation and even panic shortly after when initial extrapolations revealed a highish possibility of impact with Earth (~3%) on 2029 April 13th Friday [1]. Subsequently, more accurate predictions indicated the asteroid would in fact miss by a cosmic cat's whisker (~0.00021 au or ~31,000 km from the Earth's surface) on this date, within the orbits of satellites in Geosynchronous Earth Orbit (GEO, ~0.00025 au or ~36,000 km). That puts the close approach of the interstellar object 'Oumuamua to shame (~0.16 au or ~24 million km).
Let us suppose that, perhaps at the bidding of the serpent-god itself, we had the ability to give Apophis a helpful nudge and send it on a collision course with Earth in 2029, what would be the minimum 'change in velocity' or ΔV needed exactly? That may seem instinctively a rather perverse thing to want to do, but there will be method in the madness.
What we find is the plot given in Figure 1, I call this the Apocalypse Plot for obvious reasons.




Now since nominally, Apophis will reach a perigee altitude of only 31,000 km, we must observe that this helpful nudge will by necessity cause Apophis to come closer to Earth such that, ignoring the influences of the atmosphere, Apophis will just make contact with – or graze - the surface of the Earth.
But what IS the aforementioned method in the madness? Well it originates from the observation that if we wished to send Apophis FARTHER away from Earth as effectively as possible, then an impulse must be applied in the opposite direction to this ΔV whose magnitude is provided above.
So let us play out a fun hypothetical. Let us assume that Apophis had actually been on a collision course with Earth, arriving on said date of April 13th 2029.
Might an impactor then sent from Earth be able to deflect it by a sufficient ΔV in this direction to cause it to miss Earth altogether in 2029?
The first thing to note is that the required ΔV magnitude would NOT be that shown in the above Apocalypse Plot. This ΔV shifts the perigee of Apophis in 2029 by 31,000 km towards Earth. However in our hypothetical, Apophis is already targeting Earth and we need to shift it - let's say on the safe side by one Earth Diameter (12,756 km) - so that it misses it by a fairly safe distance.

[1] NASA Apophis science.nasa.gov/solar-system/asteroids/apophis/
[2] CHANG, A F et al Momentum transfer from the DART mission kinetic impact on asteroid Dimorphos. Nature, v 616, n 7957, p 1476-4687, abr. 2023. ISSN doi.org/10.1038/s41586-023-05878-z
[3] Valvano, G et al APOPHIS – effects of the 2029 Earth's encounter on the surface and nearby dynamics. Monthly Notices of the Royal Astronomical Society, v 510, n 1, p 95-109, doi.org/10.1038/s41586-023-05878-z

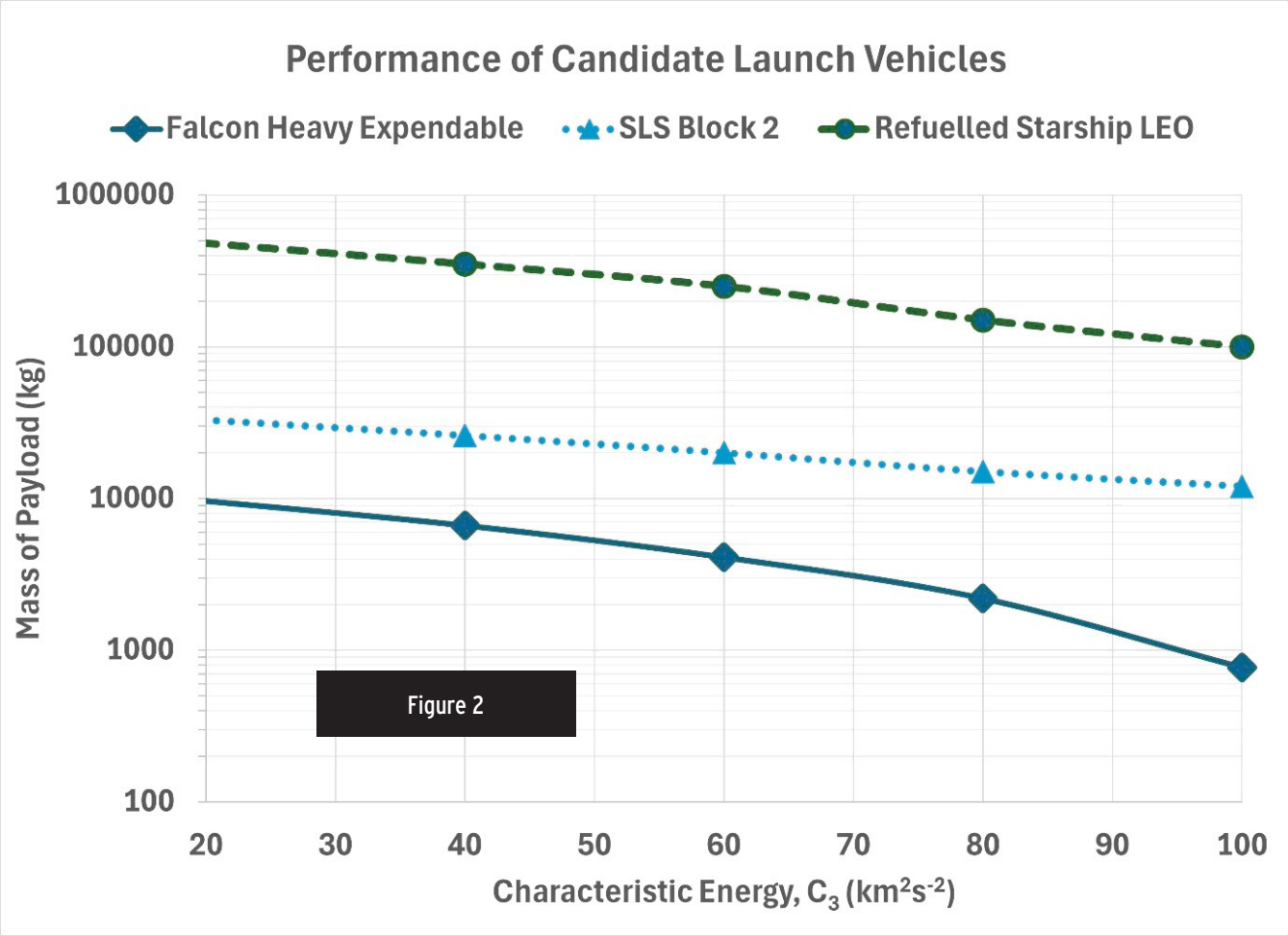



Figure 2

We can observe in the Apocalypse Plot that the minimum possible ΔV required to induce a change of perigee from 31,000 km to 0 km, is equal to 0.1 m/s, and so we can estimate that an impactor arriving at this minimum (in January 2026) would only need to shift Apophis by 0.1*12,756/31,000 = 0.041 m/s, or 4.1 cm/s (to first order) so that it might then be farther away from Earth by an Earth-diameter at encounter perigee. But how do we apply this 0.041 m/s?

At this point in our hypothetical, we reference the DART mission, where the spacecraft managed to shift Dimorphos by 2.7 mm/s (0.0027 m/s or 0.27cm/s) [1]. We need to change Apophis's velocity by at least an order of magnitude higher than DART achieved with Dimorphos and what's more Dimorphos has a mass of only ~5.5 billion kg as opposed to the Apophis's mass of ~27 billion kg [2]. This is also an order of magnitude difference, so we need an impactor with two orders of magnitude higher momentum than the DART mission (579.4 kg at 6.6 km/s. Is this possible? I decided to set out and see.

First, let's assume we have a choice of three candidate launch vehicles, they are, in order of increasing performance, the SpaceX Falcon Heavy Expendable, the NASA Space Launch System (SLS) Block 2 and the SpaceX Starship, the latter fully refuelled and in Low Earth Orbit (LEO). These will be the best performing launchers available to humanity for Earth-escape (hyperbolic) missions, as far as our near future plans are concerned. The relative performances of these are provided in Figure 2. Note that the latter two of the above three launchers are currently unproven, however let us assume an 'alternative reality' scenario where these launchers have been proven, or alternatively view it as though we are using Apophis as a convenient and very real proxy for some future doomsday asteroid, when these launchers WILL be available.

[1] CHANG, AF et al Momentum transfer from the DART mission kinetic impact on asteroid Dimorphos. Nature, v. 616, n. 7957, p. 1476-4687, abr. 2023. ISSN doi.org/10.1038/s41586-023-05878-z
[2] Valvano, G et al APOPHIS – effects of the 2029 Earth's encounter on the surface and nearby dynamics. Monthly Notices of the Royal Astronomical Society, v. 510, n. 1, p. 95-109, doi.org/10.1038/s41586-023-05878-z

Let's further assume that the earliest launch date is 2022 Jan 1st, well over two years ago, and further that the soonest arrival date of an impactor would be 2025 Jan 1st , with the latest arrival date only 3 months before our hypothetical collision.

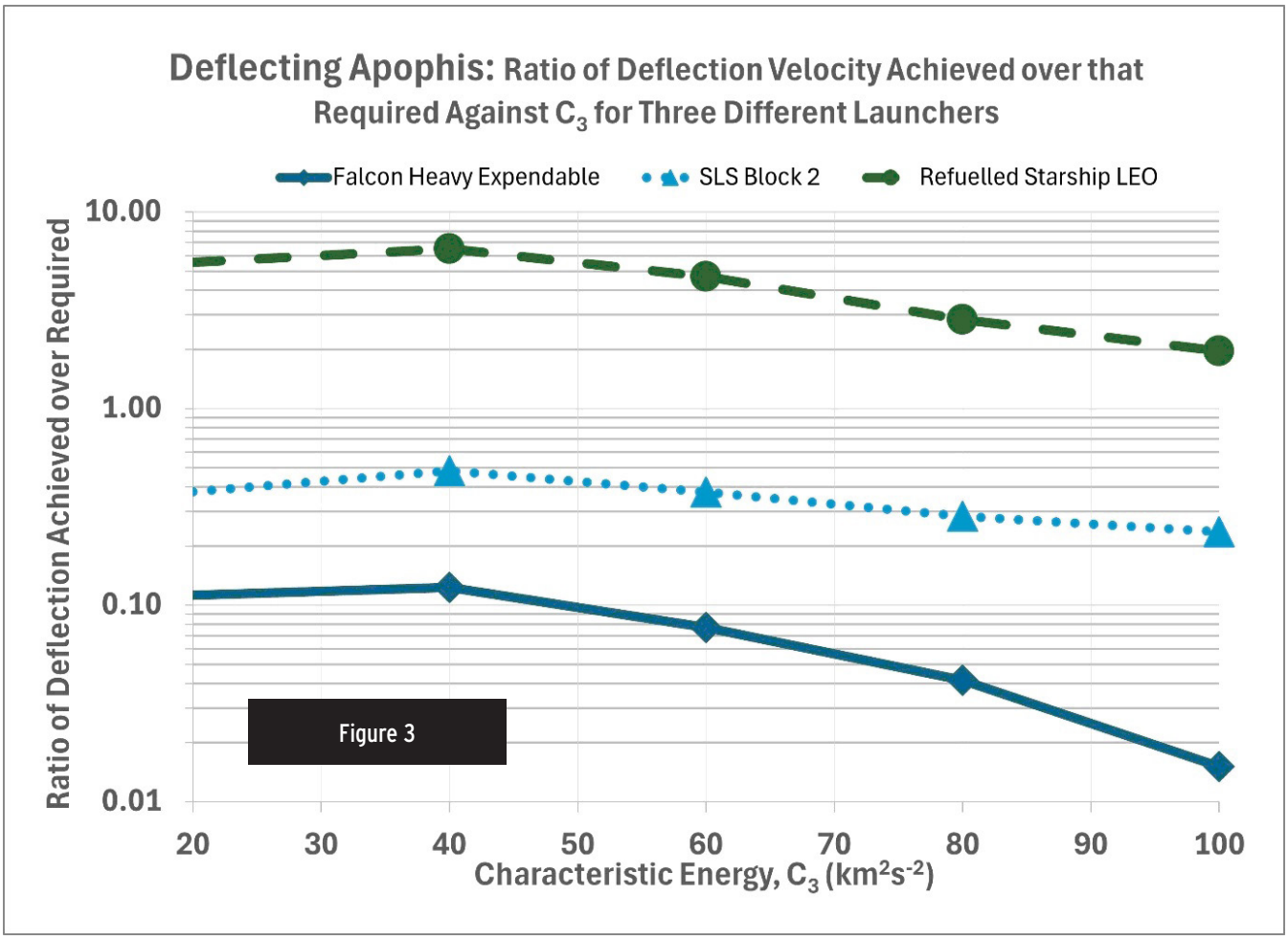



Figure 3

Look at the Figure 3, this is the clincher plot. This shows the ratio of the ΔV generated in the required direction (ie in the reverse direction specified by the three components I calculated to generate the Apocalypse Plot), by an impactor inserted into a direct trajectory to Apophis, over that required to deflect Apophis's perigee by one Earth diameter on the collision date.
What we find is that the Falcon Heavy Expendable can only deliver around 10% of the deflection velocity required; the more powerful SLS Block 2 can achieve 50% of this required deflection; whereas the humongous Starship can deliver a full 6 times this required deflection. Note that these all represent the identical interplanetary orbit (With Earth C3 of 40 $km^2s^{-2}$), and furthermore they all have identical arrival velocities (7.8 km/s- the important deflection component of this being 7.6 km/s).
The difference in momentum between these spacecraft is due to the different payload masses (from Figure 2 these are 6,640 kg, 26,000 kg and 350,000 kg for FHE, SLS and SS respectively).

So a fully refuelled Starship in LEO represents by far the best option for deflecting Apophis, the details of the 'winning' trajectory are shown in Figure 4.
Lo-and-behold! - I may have found a second use for Elon's monster launch vehicle, the other being, of course, Project Lyra! [1].

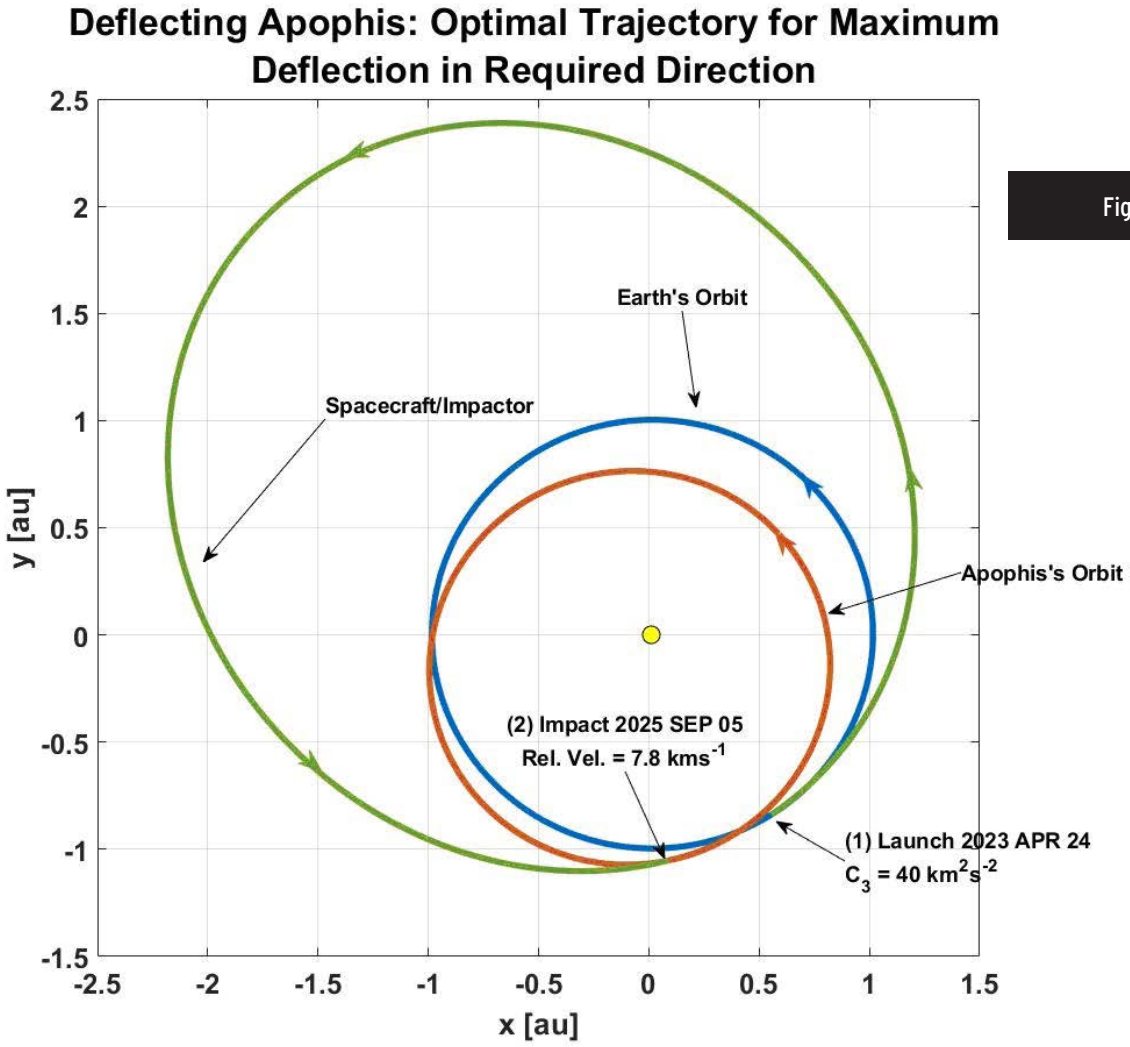



Figure 4

[1] Hein et al *Project Lyra: Sending a spacecraft to 1I/'Oumuamua (former A/2017 U1), the interstellar asteroid* Acta Astronautica, V 161, 2019, p 552-561, doi.org/10.1016/j.actaastro.2018.12.042

**About the author**

Adam spent his first 4 years in Tanzania where his father worked as a lecturer for the University of Dar Es Salaam. After the family returned to Coventry he was educated at his local state school Stoke Park Comprehensive School and Community College, concentrating on STEM subjects, but also gaining proficiency in playing the piano. In the '80s, he studied at Keele University receiving a Joint Honours Degree in Physics and Mathematics. In the '90s he worked as a software engineer on the European launcher program, Ariane 4, where he gained knowledge of Guidance systems for launch vehicles, with particular interest in optimum trajectory ascent to orbit software. Much later in life, after a period of composing and performing for a musical group 'Superheroes Dream', he applied this skill to devise, derive the theory, develop and test a software tool he called 'Optimum Interplanetary Trajectory Software' (OITS). The timing proved to be serendipitous because it was later in that same year when the first interstellar interloper to our solar system 1I/'Oumuamua was discovered, and it seemed natural for him to investigate missions to this object using OITS. He subsequently contacted i4is regarding his findings and ultimately was involved in Project Lyra, authoring, and collaborating on several peer-reviewed scientific papers on the subject.

# The Initiative & Institute for Interstellar Studies


image: ©ALEX STORER

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- **Robert G Kennedy III: President i4is USA - robert.kennedy@i4is.org**
- **Rob Swinney: Education Director - rob.swinney@i4is.org**
- **John I Davies: Editor Principium - john.davies@i4is.org**
- **Tam O'Neill: Manager Membership/Website team - tam.oneill@i4is.org**

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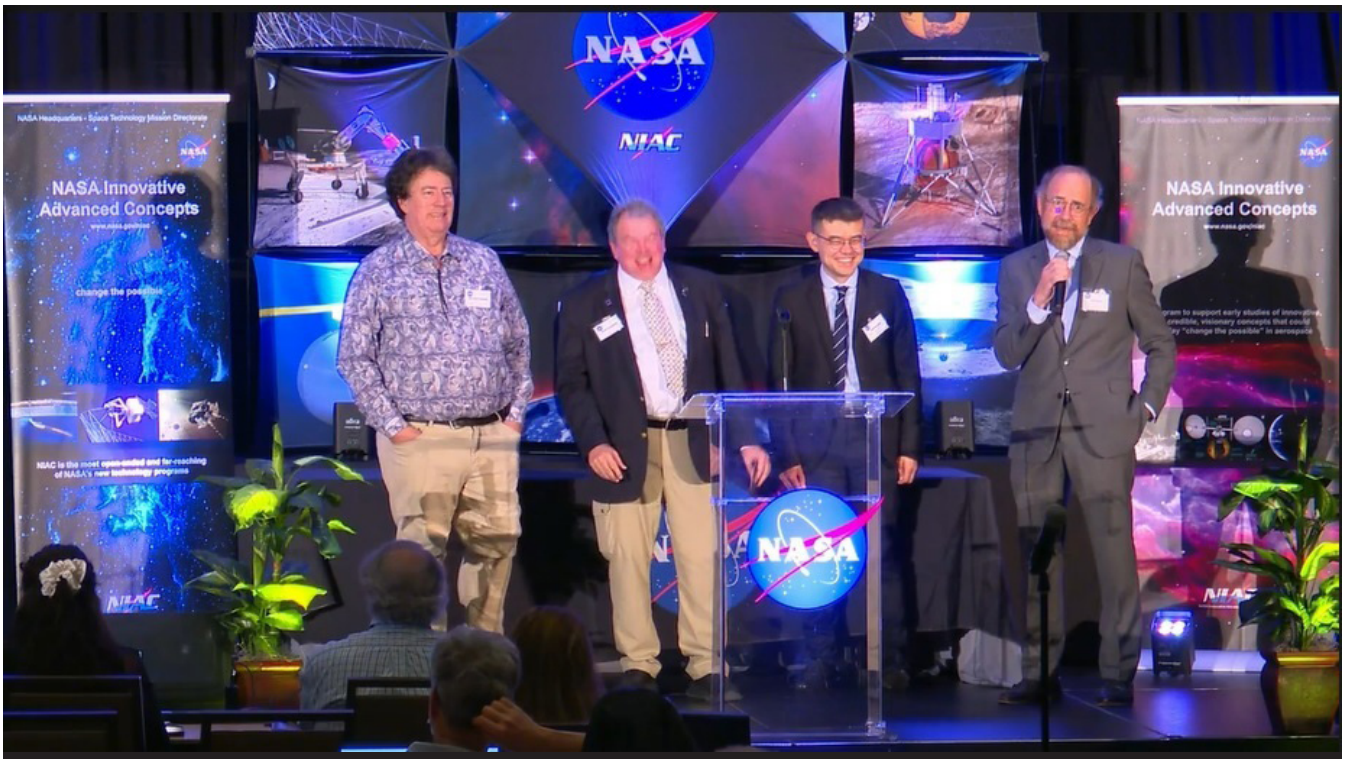
**Parnika Singh reports on recent developments in interstellar studies**

## i4is Presents at NASA NIAC 2024

On 12 September 2024, Marshall Eubanks (Space Initiatives) and the i4is team presented at NASA NIAC 2024 Pasadena on their proposal *Swarming Proxima Centauri: Coherent Picospacecraft Swarms Over Interstellar Distances* which details how tiny, gram-scale spacecraft pushed by laser light are likely to be the only technology capable of reaching another star this century and outlines a representative mission for such an endeavor. The video of the presentation can be seen here: vimeo.com/showcase/10973241?video=1008860866 (go to time 21:00). And check out the following interview with Robert G Kennedy (i4is-US to learn more: www.planetary.org/planetary-radio/2024-niac-part-1 (go to time: 12:00). More in Robert's piece, *Pringles Is A Verb*, elsewhere in this issue.




NASA NIAC 2024 Space Initiatives and i4is team
L to R Marshall Eubanks (Space Initiatives) , Robert G Kennedy (i4is-US), Andreas Hein (i4is), Paul Blase (Space Initiatives).
Credit: NASA NIAC video (vimeo.com)

## NASA Turns Off One of Voyager 2's Science Instruments

The two Voyager spacecraft have been speeding through space since 1977, powered by decaying chunks of plutonium that produce less and less energy every year. With less electricity available, NASA has decided to shut down one experiment on Voyager 2, the plasma science instrument, on 2 October 2024. This device measures the quantity and direction of ionized particles passing the spacecraft. While Voyager 2 still has enough electricity to support its four other operational instruments, it will likely be down to just one by the 2030s. NASA said that over the past several years, engineers for the mission have taken steps to avoid turning off any science instruments for as long as possible since the science data collected by the two Voyager probes is unique. As the first spacecraft to reach interstellar space — the region outside the heliosphere – this is currently our only chance to study this region. However, this particular instrument has been collecting limited data in recent years due to its orientation relative to the direction that plasma is flowing in interstellar space. More information can be found here: www.universetoday.com/168782/nasa-turns-off-one-of-voyager-2s-science-instruments/#more-168782.

## NASA's Search for Alien Life

NASA recently announced that it selected three industry proposals to help develop technologies for future large space telescopes and plan for the agency's Habitable Worlds Observatory mission concept, which could be the first space telescope designed to search for life outside our solar system. The mission would directly image Earth-like planets around stars like our Sun and study their atmospheres for the chemical signatures of life, as well as enable other investigations about our solar system and universe. NASA is currently in the early planning stages for this mission concept, with community-wide working groups exploring its fundamental science goals and how best to pursue them. More information can be found here: www.nasa.gov/news-release/nasa-awards-advance-technologies-for-future-habitable-worlds-mission/

## Navigating Using Pulsars

On 31 May 2024, the University of Padova published a thesis by Samuele Larese De Pasqua titled *Space Navigation with Optical Pulsars*. So far, deep-space navigation has strongly relied on ground segments. However, the positioning accuracy of ground-based navigation systems decreases with the distance from the Earth, significantly increasing the positioning uncertainty for interplanetary missions. Furthermore, ground-based navigation systems require extensive ground operations, and their limited bandwidth could lead to a point of full utilization in the future.
The aim of this thesis is to examine the concept of Space Navigation by Optical Pulsars, a technology that aims at overcoming the limits of ground-based and interplanetary navigation systems [1]. The thesis first presents an introduction to autonomous satellite navigation, highlighting the benefits pulsars could bring. Then, it shows the physical and timing properties of optical pulsars, investigating the timing techniques for reconstructing, processing, and making use of a pulsar signal. Finally, the thesis reports the design for the proposed optical payload and the orbit determination performance of the system, investigating also an on-board optical pulsar-based time synchronization. The full paper can be found here: www.research.unipd.it/handle/11577/3514922.

## The Fermi Paradox: A Social Phenomenon?

Alexander Vladimirovich Shkurko recently published a paper in the International Journal of Astrobiology titled *The social science perspective on the Fermi paradox* (doi.org/10.1017/S1473550424000089). The Fermi paradox points to the apparent contradiction between the idea that the emergence of life and civilization on Earth is an objective process following the general rules of Nature and that there are no visible signs of other civilizations beyond Earth. The Fermi paradox is widely discussed in astronomical, biological, and other natural sciences but almost totally ignored by social sciences, even though more than half of known explanations deal with intentions and behaviors of extraterrestrial civilizations (ETCs) or social aspects of the evolution of technological civilizations. Shkurko analyses the problem and possible solutions to the Fermi paradox from the perspective of social sciences. He argues that the Fermi paradox is primarily a social science problem, and the most plausible solutions have to contain some form of social science explanation. Three types of explanations are discussed, namely, those related to ETCs' intentions, capacities, and the consequences of their decisions and activities. Shkurko argues that attempts to explain the paradox by referring to specific goals and motives of ETCs are the least plausible. Arguments related to the capacities and consequences are more solid but do not convincingly solve the paradox. He concludes that the Fermi paradox is an important problem for social sciences whether ETCs exist or not, and it should attract greater attention from social scientists.

## Frank Drake is Alive!

Elio Quiroga Rodríguez published a paper in the Journal of the British Interplanetary Society titled *Frank Drake is alive! (Rethinking the Drake equation for the search for biological life)* (preprint linked here: www.researchgate.net/publication/384328976_Frank_Drake_is_alive_Rethinking_the_Drake_equation_for_the_search_for_biological_life). Astronomer Frank Drake formulated the Drake Equation as a cornerstone for scientific discourse regarding the prevalence of communicative extraterrestrial civilizations within the Milky Way galaxy. This equation, often referred to as the "Classic Drake Equation", outlines the key factors influencing the number of potential civilizations with which we might establish communication. In this article, Rodriguez dives into the Drake Equation and proposes a simplified version focused on the broader detection of

[1] Using pulsars with known rotation frequencies as a 'galactic GPS' was first discussed in Principium in issue 15, November 2016, *i4is/ISU 2016: Space Environment & Spacecraft Systems Engineering* - https://i4is.org/principium-15

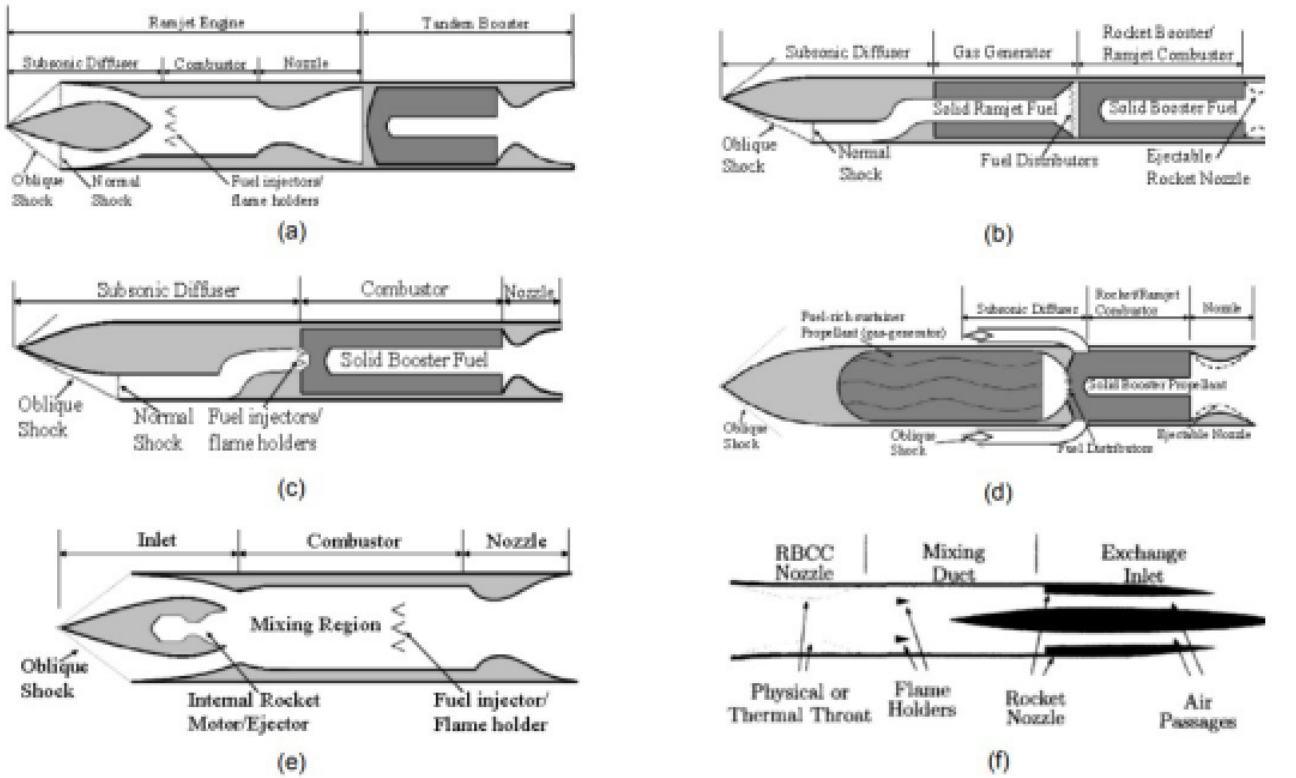
extraterrestrial nonintelligent life. He reexamines the established terms of the equation, such as the rate of stellar formation, the fraction of stars harboring planetary systems, and the probability of such systems containing habitable planets. Additionally, he presents a reevaluation of other factors. Based on this revised framework, Rodriguez then explores various scenarios. He discusses how as our technological capabilities continue to advance, the detection of biosignatures on exoplanets (incorporated into the suggested new version of the equation) is anticipated to offer insights into the search for life beyond Earth.

## Traversable Wormholes

Peter K F Kuhfittig (Milwaukee School of Engineering) published a preprint titled *Macroscopic traversable wormholes: minimum requirements* (arxiv.org/abs/2409.16184). While wormholes are just as good a prediction of Einstein's theory as black holes, they are subject to severe restrictions from quantum field theory. To allow for the possibility of interstellar travel, a macroscopic wormhole would need to maintain sufficiently low radial tidal forces as otherwise, the unfortunate side effect of "spaghettification" occurs. In this paper, Kuhfittig proposes that the assumption of zero tidal forces, ie, the limiting case, is sufficient for overcoming the restrictions from quantum field theory. After reviewing the basic structure of a MorrisThorne wormhole, he discusses the feasibility of this approach by introducing the additional conditions needed to ensure that the radial tidal forces can indeed be sufficiently low and by viewing traversable wormholes as emergent phenomena, thereby increasing the likelihood of their existence. He discusses the properties of the redshift and shape functions.

## Rocket Review

Samarth Mankan et al published a preprint titled *Review on Past, Present and Future Rocket Propulsion Technologies* (www.researchgate.net/publication/384019582) which, as the title suggests, offers a comprehensive exploration of the past, present, and future of rocket propulsion technologies. They begin by tracing the evolution of propulsion systems from their early innovations to the sophisticated systems that have propelled modern aerospace advancements. Through an in-depth review of historical propulsion systems, their design principles, and operational challenges, the authors illuminate the foundational technologies that have shaped contemporary rocket propulsion. This historical perspective provides valuable insights into the ingenuity and persistence of early rocket scientists, highlighting lessons that could inform future innovations. They




Rocket-Based Combined Cycle (RBCC) engines

(a) Tandem solid booster with a canister ramjet; (b) Solid fuel integral-rocket ramjet (IRR); (c) Liquidfuel IRR; (d) Air-ducted rocket; (e) Central ejector RBCC; (f) Annular ejector RBCC[32]

Credit (image and caption): Samarth Mankan, Figure- 1.

then trace and discuss the technologies used in the present era of rocket propulsion. Building on this foundation, the paper delves into emerging technologies and concepts poised to revolutionize space travel. These include the novelty in the use of atmospheric gas as reaction mass to address the mass problem in traditional propulsion, advancements in green oxidizers like nitroform and FOX-7 to reduce environmental impact, and the ambitious concept of antimatter annihilation rocket engines. The potential for faster-than-light travel through warp drives based on quantum field theory is explored, alongside the challenges and potentials of Nuclear Thermal Propulsion (NTP) systems, gel propellants, and pulse laser propulsion. The authors also address the formidable challenge of gravity-controlled propulsion, aiming to provide a holistic view of the technological landscape that could drive the next era of space exploration.

## Spacecraft designed for interstellar travel

Leyan Ouyang (King's College London) has published a paper titled *Spacecraft design for interstellar travel* (doi.org/10.54254/2753-8818/41/20240518) which endeavors to introduce and elucidate potential mechanisms aimed at the development of a spacecraft that is not only sustainable but also optimized for interstellar travel to the Andromeda galaxy, with the primary objective of scouting for potentially habitable exoplanets suitable for human colonization. The conceptual framework encompasses a comprehensive analysis of various critical components essential for the functionality and longevity of the spacecraft, including but not limited to propulsion systems, attitude control mechanisms, and advanced navigation systems. In addition, Ouyang also discusses the search for habitable areas, which are also called Goldilocks' zones and refers to the areas around stars where planetary conditions are conducive to fostering lives. As the existence of liquid water is known as the fundamental prerequisite for supporting life, the basic criteria for a habitable planet is temperature appropriate for water sustaining. Ouyang's final analysis shows that space immigration is a determined consequence of human beings and people should take effective measures to investigate future possible ways of immigrating to another planet.

## Warp Drives

Jilvan Pinheiro published a paper titled *Warp Drive, Dark Energy, and the Manipulation of Extra Dimensions: A Theoretical Exploration* (jilvanpinheiro.com/2024/08/20/warp-drive-dark-energy-and-the-manipulation-of-extra-dimensions-a-theoretical-exploration/). The concept of a warp drive, initially proposed by Miguel Alcubierre, represents a speculative yet theoretically grounded approach to faster-than-light (FTL) travel. Pinheiro explores the feasibility of warp drive technology within the frameworks of general relativity, quantum field theory, and string theory. He examines the energy requirements associated with the Alcubierre metric, the potential role of dark energy as a source of the necessary exotic matter, and the implications of extra-dimensional theories in the context of brane-world scenarios. Pinheiro also discusses the challenges associated with these ideas, including the stability of the warp bubble and the practicalities of manipulating space-time on such scales. He concludes by outlining potential avenues for future research in this fascinating intersection of theoretical physics.

## AI and Aliens

Conor Feehly recently published an article in Space magazine titled *How AI is helping us search the universe for alien technosignatures* (www.space.com/how-ai-is-helping-search-for-alien-technosignatures). Feehly delves into the advancements in the search for extraterrestrial intelligence (SETI), focusing on the recent Breakthrough Discuss conference [1] where leading scientists gathered to explore how AI, astrobiology, and space missions are transforming the field. The conference, held at the University of Oxford, highlighted the critical role of artificial intelligence in analyzing vast amounts of data from telescopes like the Green Bank Telescope and the MeerKAT Array. AI is now able to sift through massive datasets, effectively reducing false positives from human-made signals, which allows scientists to better identify potential technosignatures or signs of alien technology. Feehly also explores the challenges in deciding where to look and what signals to focus on, with some researchers suggesting we need to be open to unexpected anomalies. With upcoming surveys, like the Vera C Rubin Observatory and the Square Kilometer Array, the potential for discovering extraterrestrial life is growing, and technosignature science is gaining credibility as a serious and respected scientific field. The combination of AI, human insights, and powerful telescopes may finally allow us to answer one of humanity's biggest questions: are we alone in the universe?

[1] See *Breakthrough Discuss 2024* in Principium 46 i4is.org/principium-46/

## An Interstellar Precursor Probe

Dr Kevin F Long recently published a paper titled *Development of SunVoyager Interstellar Precursor Probe Driven by Inertial Confinement Fusion Propulsion* (https://arc.aiaa.org/doi/10.2514/1.A36045). Dr Long presents updated calculations for the SunVoyager probe, a spacecraft conceptual design for a mission to the outer solar heliosphere to a distance of 500–1,000 AU, in a trip time of ~6–10 years traveling at speeds of 720 km/s. Such a mission would not only fly by objects in the outer solar system but serve as a precursor to the first interstellar probe. The spacecraft would use nuclear propulsion. Specifically, it would utilize a laser-driven inertial confinement fusion (ICF) engine with a deuterium fuel. This design allows for a greater specific impulse than traditional nuclear propulsion designs – though research is still needed to increase the efficiency of this system. Additionally, the strong lasers needed for such a mission are not yet available – though a laser array could potentially substitute. The spacecraft is designed to carry a 100-ton payload to include large optical telescopes for long-range imaging of nearby exoplanets [1].

## Exocomets, exoasteroids, and exomoons

Paul A Strom (University of Warwick, UK) recently published a preprint titled *Exocomets, exoasteroids, and exomoons* in Cornell's preprint server ARXIV (arxiv.org/abs/2410.06248). Exocomets are comets that exist outside our solar system, orbiting other stars or travelling between them as interstellar objects. These comets, along with exoasteroids, are remnants of the early stages of planetary system formation, providing valuable insight into the conditions during stellar system evolution. They become detectable when they approach a star, causing their nuclei to sublimate and release dust and gas, which form visible tails. The study of exocomets involves spectroscopic observations, where starlight absorbed by exocometary gas provides clues about their composition and dynamics, as well as photometric transits, which measure the light blocked by their dust tails. Various techniques, including the "exocomet curve of growth" method, allow scientists to estimate the size and properties of exocomets. Despite challenges in determining the exact quantities of elements within exocomets, these studies offer important insights into their compositions and behaviors. Strom also discusses how exocomets compare to solar system comets, emphasizing the challenges in making direct comparisons due to differences in observation methods. Additionally, he touches on related topics like debris discs and volatile gas in exoplanetary systems, as well as the ongoing search for exomoons.

## Fission Rocket Development

Sandeep Puri (Texas Tech University) et al recently released a preprint titled *Progress in Fission Fragment Rocket Engine Development and Alpha Particle Detection in High Magnetic Fields* on Cornell's preprint server ARXIV (arxiv.org/abs/2409.15206). The authors present their recent experiments on fission fragment rocket propulsion, and on an innovative new design for an alpha particle detection system that has been inspired by these rocketry results. Their test platform, which operates within high magnetic fields 3 T over a large cross-section (approximately 40 cm in diameter), has been used as a test platform to evaluate the containment and thrust within a future fission-fragment rocket engine (FFRE). This much more efficient nuclear rocket propulsion FFRE design was first proposed in the 1980s with the intent of greatly reducing transit times in long-duration space travel. The authors' objective is to enhance the operational efficiency of this nuclear rocket while gaining deeper insights into the behavior of fuel particles and of the fission-fragment ejecta within strong magnetic fields experimentally. Through a combination of simulations and experimental work, they established a method for the production and detection of alpha particles as a surrogate for fission fragments. To achieve this, they employed Americium-241 sources, which were situated within a cylindrical vacuum chamber positioned in a 3-T Siemens MRI superconducting magnet. By simulating, measuring, and analyzing the emitted alpha particle flux, they've gained valuable information about the distribution and likelihood of escape of fission fragments in a future FFRE design. This approach could potentially achieve both high specific impulse and power density in advanced nuclear propulsion systems, such as the FFRE. More generally, this work provides a powerful new approach for analyzing ion flux and nuclear particle or nuclear reaction fragments from a wide variety of experimental designs.

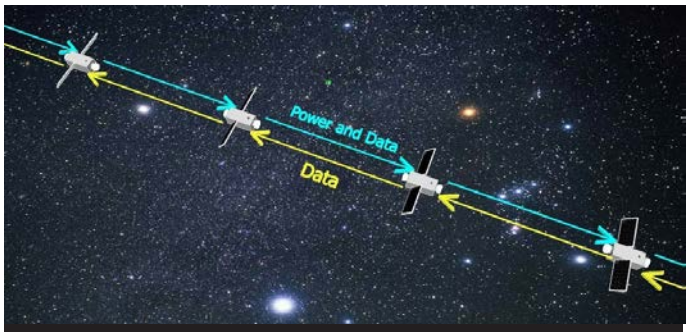
## Lightsail Swarm Mission

Riccardo Dal Maschio of the University of Padua published his thesis titled *Interconnected lightsails for Space Exploration* (thesis.unipd.it/retrieve/40ff8834-dbeb-4d90-adb1-166d2adc517e/Dal%20Maschio_Riccardo.pdf). Maschio explores the possible development of a swarm of interconnected lightsails for efficient and scalable space exploration. He focuses on the comprehensive design and analysis of a nanosatellite architecture that relies on photonic thrusters (lightsail), alongside sophisticated laser communication systems tailored to ensure a

reliable and efficient data transfer. The analysis of different propulsion methods suggests that the best choice for such a mission is the use of the lightsail technology together with a lightweight payload based on the CubeSat architecture. Additionally, Maschio investigates the integration of an optical communication system for long-distance space transmission, based on the existing technologies borrowed from the LCRD (Laser Communication Relay Demonstration) and LLCD (Lunar Laser Communication Demonstration) missions. Referring to these technologies, Maschio examines the available modulation schemes and, via the exploitation of link budget computations, the maximum distances at which the probes have to be set apart are computed. Based on the results obtained, a preferred topology is recommended to ensure reliable communication between the satellites. Given that multiple probes within the swarm may fail during exploration, several redundancies and safeguards have been implemented to maintain the minimal operational performance of the swarm. Moreover, Maschio proposes some future innovations that could be adapted to improve the operations of the swarm and increase the reliability of the communication systems and of the lightsail architecture.

## Morris-Thorne Type Wormholes

Jaydeep Goswami (University of Science and Technology Meghalaya, India) et al published a paper titled *Morris–Thorne-type wormholes with global monopole charge and the energy conditions* (link.springer.com/article/10.1140/epjc/s10052-024-13413-1). In this paper, they investigate Morris–Thorne-type wormholes with global monopole charge using various shape function forms known in the literature. They solve the Einstein field equations incorporating an anisotropic energy-momentum tensor and obtain different physical quantities associated with the matter content. A crucial aspect of this study is the non-exotic matter distribution, examined through the evaluation of energy conditions, and exploring how different shape functions impact these conditions. Additionally, the anisotropy parameter is calculated to quantify the extent of attractive or repulsive behavior. The authors demonstrate that for different types of shape function forms, the energy conditions are influenced by the global monopole parameter. Their findings provide valuable insights for further theoretical explorations of these fascinating hypothetical structures in the realm of general relativity and beyond.




Power and data "hopping" concept for deep space missions.
Credit: (image): Dal Maschio Figure 5.2

## Making Space Lasers Safe

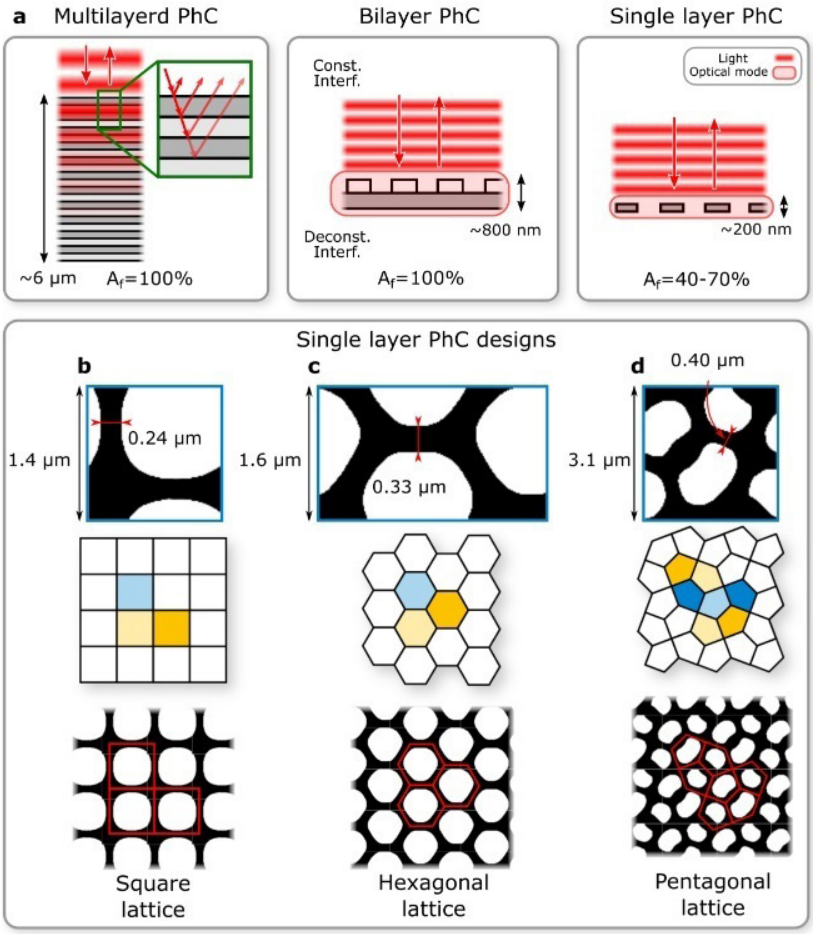
i4is's own Adam Hibberd recently released a preprint titled *Minimum Safe Distances for DE-STAR Space Lasers* on Cornell's preprint server ARXIV (arxiv.org/abs/2409.08873). The prospect of phased laser arrays in space has received considerable attention in recent years, with applications to planetary defense and space exploration. The most detailed investigation conducted into such a design is that of the DE-STAR phased array - a square modular design that exploits the energy created by banks of solar cells in space to generate and amplify the power of a laser beam. With a DE-STAR 4 structure (10 km by 10 km square) capable of generating a laser beam on the order of tens of gigawatts, there is the potential for such an asset to be deployed as a weapon by targeting locations on Earth. This naturally leads to the question of what effective ways can this possible misuse be removed or at least mitigated [1]. One solution explored in the paper would be to locate the DE-STAR far enough away so that the laser flux at Earth would be too low. Results indicate that they should lie 1 au from the Sun, and there are feasible locations for DE-STAR 0-2 arrays where there is no danger to Earth. However, for DE-STAR 4-5, safety measures other than those considered in the paper would have to be adopted.

[1] See also *Hazards of Interstellar Propulsion: Would you want a 100 GW beamer in your back yard or a fusion rocket anywhere close to Earth?* i4is.org/principium-44/

## Nanophotonics for Lightsails

L Norder et al published a paper titled *Pentagonal Photonic Crystal Mirrors: Scalable Lightsails with Enhanced Acceleration via Neural Topology Optimization* on Cornell's preprint server ARXIV centered around the Breakthrough Startshot Initiative (arxiv.org/abs/2407.07896#). The initiative aims to send one-gram microchip probes to Alpha Centauri within 20 years, using gram-scale lightsails propelled by laser-based radiation pressure, reaching velocities nearing a fifth of light speed. This mission requires lightsail materials that challenge the fundamentals of nanotechnology, requiring innovations in optics, material science, and structural engineering. Unlike the microchip payload, which must be minimized in every dimension, such lightsails need meter-scale dimensions with nanoscale thickness and billions of nanoscale holes to enhance reflectivity and reduce mass.

In this study, the authors employ neural topology optimization, revealing a novel pentagonal lattice-based photonic crystal (PhC) reflector. The optimized designs shorten acceleration times, therefore lowering launch costs significantly. Crucially, these designs also enable lightsail material fabrication with orders-of-magnitude reduction in costs. Starshot lightsails will have several stringent requirements but will ultimately be driven by costs to build at scale. The authors highlight challenges and possible solutions in developing lightsail materials - showcasing the potential of scaling nanophotonics for cost-effective next-generation space exploration.




(a) Working principles of different photonic crystal architectures. Multilayered PhC consists of stacked layers with varying refractive indices. The bilayer PhC consists of a repeating PhC pattern on top of a solid membrane. Single layer PhC is a membrane with a repetitive PhC hole pattern. For both the bilayer and single-layer PhC, the incident light creates an optical mode within the material that deconstructively interferes with the transmitted light and constructively with the reflected light. The best optimized single layer PhC design without area constraint for square lattice (b) and hexagonal lattice (c), where black is material and white is vacuum. The square and hexagonal lattice thicknesses are 0.2 μm and 0.3 μm respectively (d), The pentagonal lattice design for an area fraction Af of 55% with a thickness of 0.18 μm.
Credit (image and caption): Miao et al, Fig 2.

## Analyzing Ion Engine Sputtering and Erosion

Long Miao et al (Beijing Institute of Technology) recently published a paper titled *Status analysis on sputtering and erosion evaluation methods of ion optic systems* in the Chinese Journal of Aeronautics (www.sciencedirect.com/science/article/pii/S1000936124003170). In the past few decades, ion engines have been widely used in deep-space propulsion and satellite station-keeping. The aim of extending the thruster lifetime is still one of the most important parts during the design stage of the ion engine. As one of the core components of the ion engine, the grid assembly of ion optic systems may experience long-term ion sputtering in extreme electro-thermal environments, which will eventually lead to its structural and electron-backstreaming failures.

In this paper, the current studies of the grid assembly erosion process are systematically analyzed from the aspects of the sputtering damage process of grid materials, numerical simulations, and measurements of erosion characteristics of grid assembly. The advantages and disadvantages of various erosion prediction models are highlighted, and the key factors and processes affecting the prediction accuracy of grid assembly erosion patterns are analyzed. Three different experimental methods of grid assembly erosion patterns are compared. The analysis in this paper is of great importance for selecting the sputter-resistant grid materials, as well as establishing the erosion models and measurement methods to accurately determine the erosion rate and failure modes of grid assembly. Consequently, the working conditions and structure parameters of ion optic systems could be optimized based on erosion models to promote the ion engine lifetime.

## Combining AI and Deep Space Optical Communication

N Abirami and S Malathy (Karpagam Academy of Higher Education) published a paper in the International Journal of Communications on Applied Nonlinear Analysis titled *Analysis of Revolutionizing Deep Space Optical Communication Networks with AI Advancements* (www.internationalpubls.com/index.php/cana/article/view/1293). Deep Space Optical Communication Networks (DSOCN) represent a transformative frontier within verbal exchange generation. These networks enable data change throughout sizeable interstellar distances, helping area missions and facilitating clinical research past our planet.

The authors explore the intersection of DSOCN with Artificial Intelligence (AI) and its profound implications for the future of deep-area conversation. Incorporating AI technology, such as system learning and neural networks, into DSOCN can revolutionize fact processing, error correction, and signal optimization for long-distance communication. Furthermore, adaptive algorithms powered through AI can dynamically configure optical link parameters, adapting to changing deep-area situations. This responsiveness ensures height reliability and data transfer performance, even across interstellar distances. The authors endeavor to shed light on the potential values of this transformative integration. They also discuss how future work within the area of AI-driven DSOCN ought to address technical demanding situations, ethical considerations, and societal implications holistically.

## Fusion Spacecraft

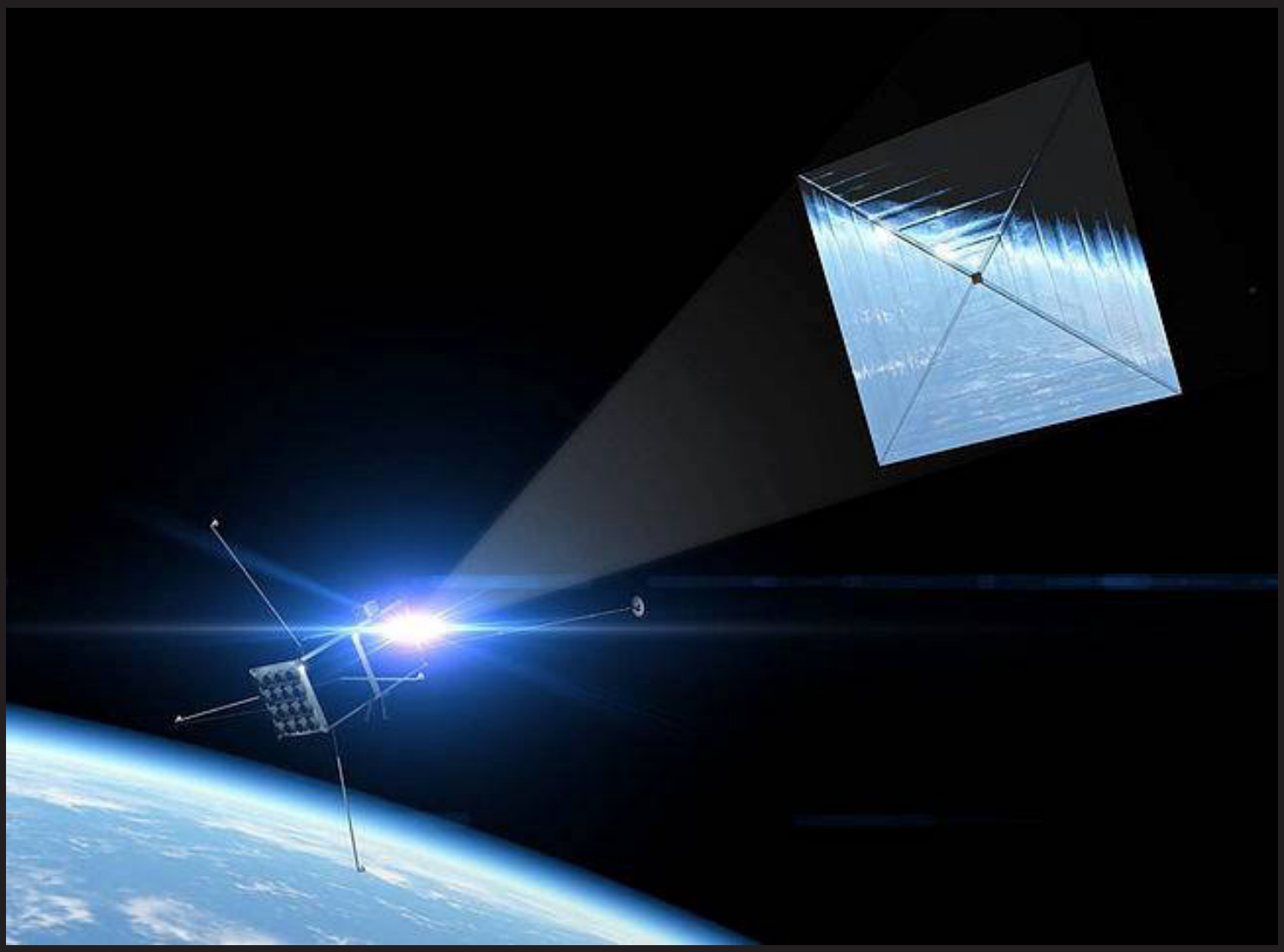
The University of Maryland's Yuca Chen et al published a thesis titled *System Analysis for a Fusion Propelled Spacecraft* (drum.lib.umd.edu/items/7b5622a3-a769-46b3-8ca7-7d05e24e5b8b). The thesis discusses applying nuclear-fusion-based power generation to spacecraft propulsion. The extreme specific impulse achievable with fusion products provides large total momentum changes while using substantially less propellant. Several auxiliary subsystems are required to support the application of fusion-based power to spacecraft propulsion, which are explored in the thesis. These subsystems include one for efficient propellant heating, one for power generation, and one for reactor shielding and structural integrity.

Chen utilizes two centrifugally confined magnetic mirror configurations, one to confine the fusion plasma and one to trap and heat an auxiliary propellant to increase thrust. They estimate propellant mass requirements and derive design constraints on the propellant chamber. Power generation techniques utilizing byproduct radiation from the fusion process are integrated into the reactor structure. Waste heat from neutron power conversion provides preheating of propellant, and a radiator was optimally sized for removing the remaining waste heat. Chen creates models for magnet shielding and determines the rate of neutron absorption and energy deposition for several different shielding materials. A system of heat pipes, magnets, and an enclosing shroud is designed to support reactor functions and prevent damage to system components. The thesis concludes by drawing comparisons between existing propulsion systems and a model fusion system, commenting on the viability of the latter.

# 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.

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- member exclusive posts, videos and advice;
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Discounts for BIS members, seniors & full time students!

# International Astronautical Congress IAC24

## The Interstellar Presentations Part 1

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

Edited by John I Davies

## Introduction

i4is reports on presentations that relate to interstellar travel and communications - and to the Solar System infrastructure which must precede the extension of our species beyond it.
It is the first of two news features following the Congress. The second will follow in P48, February 2025.
All of the programme items listed here are text credited to the International Astronautical Federation (IAF) and are visible via the Programme: iafastro.directory/iac/browse/IAC-24/.

## Contents

These are the presentations and papers we report on in this issue - in order of IAC24 reference -

## The Programme

Here are the reports with IAF identifying codes for the symposium sessions. Shown alphabetically by IAF identifying code under session title, objective, date and time.
Format of programme reports -

| IAF identifying code | Title | Presenter | Institution | Country |
|---|---|---|---|---|
| IAF Abstract: [see also P46 report]<br>IAF Cited Paper:<br>IAF Cited Presentation/Video:<br>Open Paper: if available<br>Reported By: | | | | |

## The Interstellar Programme reports

### 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

| | | | | |
|---|---|---|---|---|
| **A4,2,1,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** | **-** | **Netherlands** |
| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,2,1,x81576.brief.pdf | | | |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,1,x81576.pdf | | | |
| IAF Cited Presentation/ Video: | - | | | |
| Open Paper: if available | None found | | | |
| Reported By: | Simone Caroti | | | |

This paper constitutes a progress report on A Sign in Space (henceforth ASIS), a SETI Institute initiative for the analysis of extraterrestrial signals created and led by media artist Daniela de Paulis [1]. The title of the project comes from Italo Calvino's eponymous short story contained in his 1965 collection Cosmicomics. Another inspiration for ASIS came from a scenario proposed in 2019 by linguist Sheri Wells Jensen and quoted in the paper itself:

> Give it to every adult and every child on the planet who wants it. Toss it to the dolphins and whales. Show it to the other primates. And, we need to encourage people to express that data in all kinds of ways: in strings of 1s and 0s, in grids, using different pitches of sound, with colored lights, played backward, interpreted as instructions for origami, expressed in bead work or knotted threads or in mosaics made of M and Ms.

Essentially, ASIS is an ongoing thought experiment on an open-source approach to the interpretation of signals received from extra-terrestrial civilizations. Launched on 24 May 2023, ASIS started with a simulated message sent to Earth from the Trace Gas Orbiter, an ESA orbiter around Mars. The pretend-alien

[1] De Paulis et al *A sign in space: An interdisciplinary exploration of the potential reception of an extraterrestrial signal*, Acta Astronautica, Volume 212, November 2023 www.sciencedirect.com/science/article/abs/pii/S0094576523004344

signal was received by six arrays, including two in the US and one in Italy, during a live public-domain broadcast sponsored by SETI [1]. Anyone and everyone who wanted to participate was invited to provide their own interpretation of the message's meaning.

By all accounts, the results have been encouraging. Thousands of posts by everyday people – beautifully described throughout the text with the moniker 'citizen scientists' – appeared on Discord over a period of several months, with a concomitant wide variety of interpretive avenues and formatting solutions. Thus, the philosophy behind ASIS – that the interpretation of extraterrestrial signals is best served by the widest possible access to the greatest possible number of interpreters – appears to have a bright future.

The challenges the initiative had to meet in order to be successful were considerable. Spreading the news about ASIS was one such challenge, but the media campaign SETI arranged was effective: in the first week after the initiative's launch, about 145 million people were exposed to it. Another challenge was technical: Discord is not available in China and some other nations, so that a dedicated forum on the initiative's website was devised to allow the citizens of those countries to present their interpretations. Other challenges were linguistic (English was the main language, so fluency in it was necessary to engage in complex conversations) and aptitude-based (not everyone is well-versed in mathematics, say).

Another important effect of ASIS' approach was the self-confidence it generated among its citizen-scientist responders, who accurately felt that their interpretive efforts contributed to the advance of the discipline.

ASIS is still continuing, but its results have already gone a long way toward demonstrating the validity of its open-ended, all-inclusive approach to signal interpretation. Hopefully, we will see more such initiatives in the future.

| Co-authors: Bettina Forget, Claudia Mignone, Irene Fabbri, Gianfranco De Vito |
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| **A4.2.2,x80945** | **Re-examining AI as a "Great Filter" for Advanced Civilizations: The Transition to Post-Biological Life and its Implications for Technosignatures** | **Prof Mike Garrett** | **University of Manchester** | **United Kingdom** |
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replacing

| 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 |
|---|---|---|---|---|

| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,2,2,x80945.brief.pdf |
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| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,2,x80945.pdf |
| IAF Cited Presentation/Video: | - |
| Open Paper: if available | none found |
| Reported By: | Simone Caroti |

This paper constitutes a speculative look at the possibility that the current technological state of the art of our society – which the author describes as "biological civilisation" – might be a universally occurring short-lived phase along the road to the development of ASI, or "Artificial Super Intelligence," an essentially posthuman form of AI that would be completely outside the control of its human designers [2].

The resulting "post-biological civilisation," this paper argues, would probably be under considerable existential threat from its now-independent machine counterparts. Such threats would comprise – but not be limited to – several forms of inter-civilizational or multi-civilizational conflicts as different cadres of AIs and different human factions vied for power either internally within one civilization or externally among several. The postulated universal nature of such a development – biological civilisations across the universe always exist for a short time and always lead to post-biological civilisations – would, if correct, represent a profound paradigm change in our understanding of our future.

[1] I presume the author is referring to the SETI Institute.

[2] 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/

The consequences for SETI's mission statement are equally far-reaching. Even if an ASI civilization were to endure with its biological population intact, the author argues, its now greatly advanced communication and signaling protocols might well prove unintelligible by civilizations still at a biological stage. Essentially, this means that SETI's mission could be fatally crippled by our inability to understand messages coming to Earth from a largely post-biological universe. The "technosignatures" of such advanced societies, which might include "Non-Radiative Communication," "Quantum-Based Computing," and "Nanotechnology Swarms" among others, could be so far ahead of ours that it would be unlikely for us to even understand we have received a communication, let alone interpret or respond to it.

In order to respond to such a scenario, the paper argues, SETI might have to completely rethink its signal-detection parameters to include hitherto unguessed approaches. One such approach could be the opening up of interdisciplinary fields involving disciplines like astrobiology, particle and quantum physics, AI studies, and philosophy to broaden our understanding of what a technosignature is or could be.

| Co-authors: none |
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| **A4,2,3,x89071** | **Causal Impotence and Cosmic Messaging: A Logical Response** | **Dr Chelsea Haramia** | **University of Bonn** | **Germany** |
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| IAF Abstract | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,A4,2,3,x89071.brief.pdf | | | |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/A4/2/manuscripts/IAC-24,A4,2,3,x89071.pdf | | | |
| IAF Cited Presentation/ Video: | - | | | |
| Open Paper if available: | none found | | | |
| Reported By: | John I Davies | | | |
| Dr Haramia aims to refute the "Barn Door" argument against METI [1]. Dr Haramia considers the part of the Barn Door argument which claims that METI transmissions are morally defensible since we have already opened the metaphorical barn door and detectable transmissions have already taken place. First, we don't know that any particular METI transmission will be more or less detectable than all previous unintentional transmissions (causal inefficacy). Second, if both intentional and unintentional messages are received we don't know whether either or both will cause actions by the receiving ETI (causal overdetermination). Third, she argues that arguments for and against the Barn Door argument have been mostly been about interspecies effects (crudely - what they might do to us) but have largely ignored intraspecies effects (what we might do to each other). Finally she argues that there may be a moral justification in stopping intentional METI signals even though we are already signalling the cosmos in other detectable, unintentional ways since human transmissions are, intentionally or unintentionally, purporting to speak for our entire species and planet. | | | | |
| Co-authors: | none | | | |

| **D4,1,3,x83992** | **Artificial Magnetic Field as Active Shield against Cosmic Radiation** | **Dr Alessandro Bartoloni** | **National Institute of Nuclear Physics** | **Italy** |
|---|---|---|---|---|
| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,1,3,x83992.brief.pdf | | | |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/1/manuscripts/IAC-24,D4,1,3,x83992.pdf | | | |
| IAF Presentation / Video: | - | | | |
| Open Paper: | none found. | | | |
| Reported By: | John I Davies | | | |

Space, including the surface of all the rocky planets and satellites is "not a very nice place", as old folk in Lancashire used to say about "abroad". And many advocates of staying at home, including a good proportion of space scientists, maintain that we should leave machines to be the only visitors. But we are an ingenious species and have long looked for ways of making it "nicer". In this paper Dr Alessandro

[1] Messaging to an Extraterrestial Intelligence 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.

Bartoloni and colleagues address the problem of ionizing cosmic radiation. They propose constructing an artificial magnetic shield using a series of electric cables strategically arranged to deflect particles away from inhabited spaces. On other planets we could live underground but the impact on health, both physical and psychological, can be imagined. Candidates for active shielding include electrostatic and magnetic fields. Actively directing high-energy particle beams toward incoming particles is another possible approach.
The team have come up with an Electromagnetic Active Moon Shielding (ELMET) project proposal. The team is drawn from a wide variety of organisations with multiple skills. Their proposal offers a transparent "roof" so the universe including the Earth would be visible to inhabitants. They propose an artificial magnetic field generated by a toroidal structure, half-buried, composed of superconducting electrical cables. The magnetic field lines generated will envelop the inhabited settlement, repelling cosmic rays with the structure itself providing some protection against micro-meteorites.
They see the technology as adaptable to Mars, to in-space vehicles/habitats and even to fusion power generation and space elevators. They outline a series of phases of work to develop their idea.

| Co-authors: Dr Marco Peroni, Marco Peroni Ingegneria – Faenza, Dr Lidia Strigari, Alma Mater Studiorum - University of Bologna |
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| **D4,4,9,x81405** | **Space Arks for the Nearest Stars: a Feasibility Evaluation** | **Prof Giancarlo Genta** | **Politecnico di Torino** | **Italy** |
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| IAF Abstract See also P46 report: | iafastro.directory/iac/proceedings/IAC-24/data/abstract.pdf/IAC-24,D4,4,9,x81405.brief.pdf | | | |
| IAF Cited Paper: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/manuscripts/IAC-24,D4,4,9,x81405.pdf | | | |
| IAF Cited Presentation/Video: | iafastro.directory/iac/proceedings/IAC-24/IAC-24/D4/4/presentations/IAC-24,D4,4,9,x81405.show.pptx | | | |
| Open Paper: | None Found | | | |
| Reported By: | Patrick Mahon | | | |

The aim of this paper is to explore the feasibility of a crewed interstellar mission to Proxima Centauri B, based on a nuclear fusion-powered Space Ark, or Generation Ship, travelling at around 1% of the speed of light, which therefore reaches its destination around 450 years after departure.
Genta starts by defining what he sees as a realistic scenario for a crewed interstellar mission. He rules out Faster-Than-Light (FTL) travel as impossible, discounts as unethical ships carrying embryos or digital emulations of human minds, and also counts out ships carrying humans who hibernate for centuries, and ships travelling near the speed of light, as we don't even vaguely know how to do either. What remains is a mission carrying conscious humans at a speed around 1% the speed of light, so that even reaching the nearest potentially habitable exoplanet, Proxima Centauri B, some 4.3 light years away, would take something like 430 years. Such a mission, taking longer than a single human lifetime, requires a so-called World Ship.
Genta draws on the classification of World Ships in the 2020 paper by i4is Executive Director Andreas Hein and co-workers, published in the ESA house journal Acta Futura. A key issue with such World Ships is that their journeys will necessarily be a one-way affair. As a consequence, they need to carry enough humans to be able to create a self-sustaining colony at their destination. Estimates for the minimum viable size vary in the literature from 100 to 20,000.
The two key spacecraft subsystems that Genta focuses on in this paper are the habitat and the propulsion system, as he views these as most crucial to the success of the stated mission. He considers that the habitat for a centuries-long crewed journey must include artificial gravity, radiation protection, and a fully circular economy that is 100% self-sustaining in terms of materials and energy. Given these constraints, Genta calculates the minimum mass and surface area required for a world ship carrying 250, 500 and 1,000 people. For the rest of the paper, he focuses on the smallest viable mission, carrying 250 people.
Genta then moves on to a consideration of the propulsion system. He sees nuclear fusion as the only feasible option. On the basis of the proposed mission design, he calculates that the optimal solution is for the ship to spend roughly 107 days accelerating to 1% c, and the same time decelerating at the destination. This minimises the overall mass budget, and leads to a world ship with a total mass of 402,000 tonnes. Although this appears huge, Genta notes that the largest sea-going tankers currently in service are more massive than this.
Genta's overall conclusion is that a crewed mission to Proxima Centauri B is potentially feasible, subject to the achievement of high efficiency nuclear fusion propulsion systems, and the solution of such problems as artificial gravity, 100% regenerative life support systems, and radiation and dust protection.

| Co-authors | None |
|---|---|

# Report from the Space Propulsion Conference 2024

## Glasgow, 20-23 May 2024

Nadim Maraqten

**Propulsion is the most prominent technical challenge to the interstellar endeavor and solutions as radical as faster than light (FTL) drives are proposed. However work is progressing on technologies ranging from those requiring radical physics to those at or close to feasibility and here Nadim Maraqten reports on work presented at the 9th Edition of the 3AF (Association Aéronautique et Astronautique de France) *International Conference On Space Propulsion*, 20-23 May 2024 in Glasgow, Scotland (www.3af-spacepropulsion.com). His own paper at the conference was *Reference Missions, Mission Level Needs and Evaluation of Candidate Technologies for High Power Electric Propulsion*. References are at the end of the article.**

I am writing this brief report from the 9th edition of the Space Propulsion Conference (SPC), organized by 3AF and ESA, which took place in Glasgow in May 2024. The bi-annual conference serves as a platform for science and industry to discuss new trends and progress, particularly in chemical and electric propulsion. Please note that this is only a brief and subjective summary of the insights I gained and what I found particularly interesting for the interstellar community. While I aimed to highlight the contributions I found most significant, some details may have been overlooked, so I cannot guarantee full comprehensiveness. To travel to the outer solar system and beyond, with a significant payload mass, and within reasonable time, a very effective propulsion system is needed. Instead of speculating on the discovery of new physical phenomena that can be exploited as a new propulsion system, a more pragmatic approach might be given in using advanced versions of the heritage concepts based on mass variant Newtonian reaction (=propellant based). This was underscored by the keynote of Prof Tajmar "Overview of Breakthrough Propulsion Activities at TU Dresden - Exploring Possible EM-Gravity Interactions", who presented his research on the coupling of EM forces and gravity. The research concluded, "No anomalous forces or torques down to the nano-Newton or nano-Newton-Meter range were found providing new limits many orders of magnitude below previous assessments ruling out claims or theories and providing a basis for future research on the topic." More can be read in a recently published article in nature scientific reports [1]. An overview of the assessed coupling schemes is given in table 1.

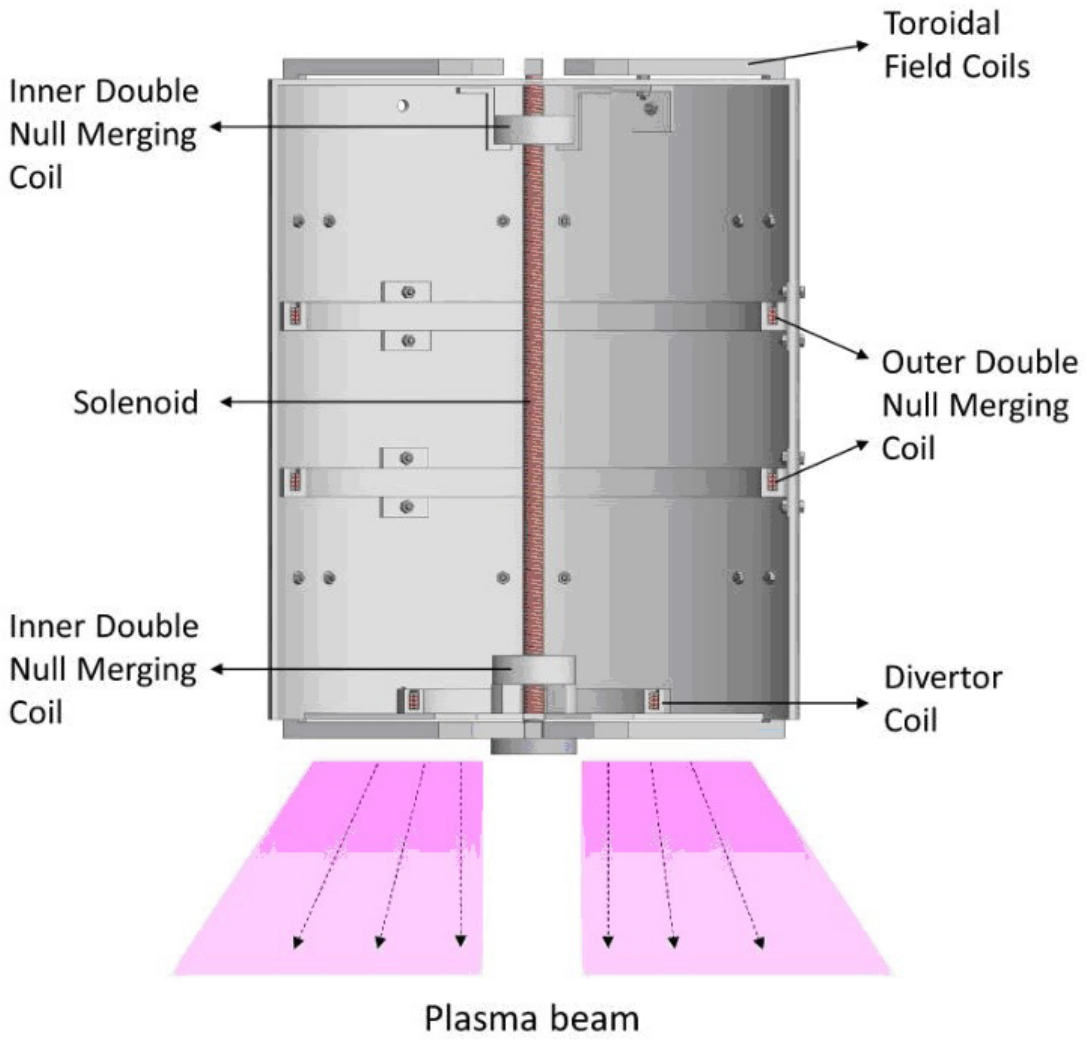
| | Maxwell | | | | | | Non-Maxwell |
|---|---|---|---|---|---|---|---|
| | Electric Field **E** | Magnetic Field **B** | **ExB**, EM-Wave | Charge **q** | Current **I** | Speed of Light **c** Vacuum $\varepsilon_0\mu_0$ | Additional Scalar Field Magnetic Monopoles Born-Infeld EM, ... |
| Gravitational Field **g** | Ivanov Root Gravity* | Ivanov Root Gravity | EMDrive* Feigel Effect and Vacuum MHD | | Superconducting*, Tunneling or Divergent Currents (Biefeld-Brown)* | Vacuum/Casimir Forces | Mbelek-Scalar Force* |
| Mass **m** | Assis-Weber Gravity Model and Electric Polarization* | Alzofon Nuclear Spin Polarization* | | Inertial Mass from Stationary Charges* Saxl-Type, Kaluza-Klein* | | ZPE Mass Models Curie-type Critical Temperature for Spacetime* | |
| *** Experimental results available in literature** | | | | | | | |

Table 1. Coupling-schemes of gravity and electromagnetism including theory and experimental claims (crossed cell marks incompatibility between vector and scalar quantities, yellow areas are assessed in [1]). Credit: Tajmar et al

Thus, near-term interstellar precursors might rather be enabled by advanced versions of current propulsion systems (eg electric propulsion). These need to exhibit high Isps, to transfer convenient amounts of payload masses within reasonable time. High Isps might be achieved by exploiting new electromagnetic or electrostatic acceleration mechansims. One approach for this was presented by Dr Giulia Becatti, who presented an assessment of the "magnetic reconnection based thruster for high specific impulses" [2], on which she works on within a project funded by the EU via a Marie Skłodowska Curie Post Doctoral Fellowship. First estimates indicate the possibility to reach very high specific impulse at high level of thrust.

However, the main bottleneck of electric propulsion systems with high Isps is the specific mass of the power plant ($\alpha$). With current $\alpha$, very high Isps would lead to intolerably low accelerations (thus very long transfer times), because the needed power would result in a heavy electrical power system. To guide the optimization of the Isp, given the system constraints $\alpha$, dv and the transfer time of a mission, R Gabrielli and G Herdrich have presented an extension on the non-dimensional rocket equation [3]. This can help with quantifying the possible Isp and $\alpha$ demands of interstellar missions with energy sources separate to the thruster.

Another and potentially ground-breaking approach for electric space propulsion could be given by using a joint energy source and acceleration system, such as a modified version of a Tokamak, as presented in [4] (see Fig 1). Potential benefits are high levels of power, in combination with a high Isp and thrust. However, the development is still in an early stage.




Tokamak-based electric thruster including main electrical components in development at Imperial College London [4].
Credit: Ali and Knoll. Figure 1

Concluding, given the impressions of the 2024 Space Propulsion Conference it appears to me that near-term interstellar missions are more likely to depend on advanced versions of existing propulsion systems, such as high-Isp electric thrusters. However, key challenges like power-to-mass ratios of the power plant remain. Promising concepts, like Tokamak-based propulsion, are still in their early stages but could offer significant breakthroughs in the future.

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[3] Gabrielli, R and Herdrich, G - *Update on Rocket Equation Analyses for Separately Powered Space Propulsion*, 9th Space Propulsion Conference, Glasgow, Scotland (2024) www.researchgate.net/publication/381199565_UPDATE_ON_ROCKET_EQUATION_ANALYSES_FOR_SEPARATELY_POWERED_SPACE_PROPULSION

[4] Al-Ali, H and Knoll, A - *Power Supplies Design and Characterization for the Spherical Tokamak Thruster: A Novel High-Power Plasma Propulsion System*, 9th Space Propulsion Conference, Glasgow, Scotland (2024)


BELOW: Nadim at the SPC 2024 conference
Credit: Nadim Maraqten


ABOVE: Nadim presenting *Reference Missions, Mission Level Needs, and Evaluation of Candidate Technologies for High Power Electric Propulsion* www.researchgate.net/publication/381229294_Reference_Missions_Mission_Level_Needs_and_Evaluation_of_Candidate_Technologiesfor_High_Power_Electric_Propulsion/references
Credit: Nadim Maraqten

**About the author**
Nadim Maraqten is a postgraduate researcher working on applied-field magnetoplasmadynamic thrusters at the University of Stuttgart. He has been working with i4is since 2022, publishing papers with other i4is propulsion experts including Angelo Genovese and Dr Dan Fries - and contributing articles to Principium since 2022.
Nadim has a first degree in flight and spaceflight technology from the University of Stuttgart and is in the final phase of his MSc in Aerospace, Aeronautical and Astronautical/Space Engineering from the University of Stuttgart and Technical University of Delft.

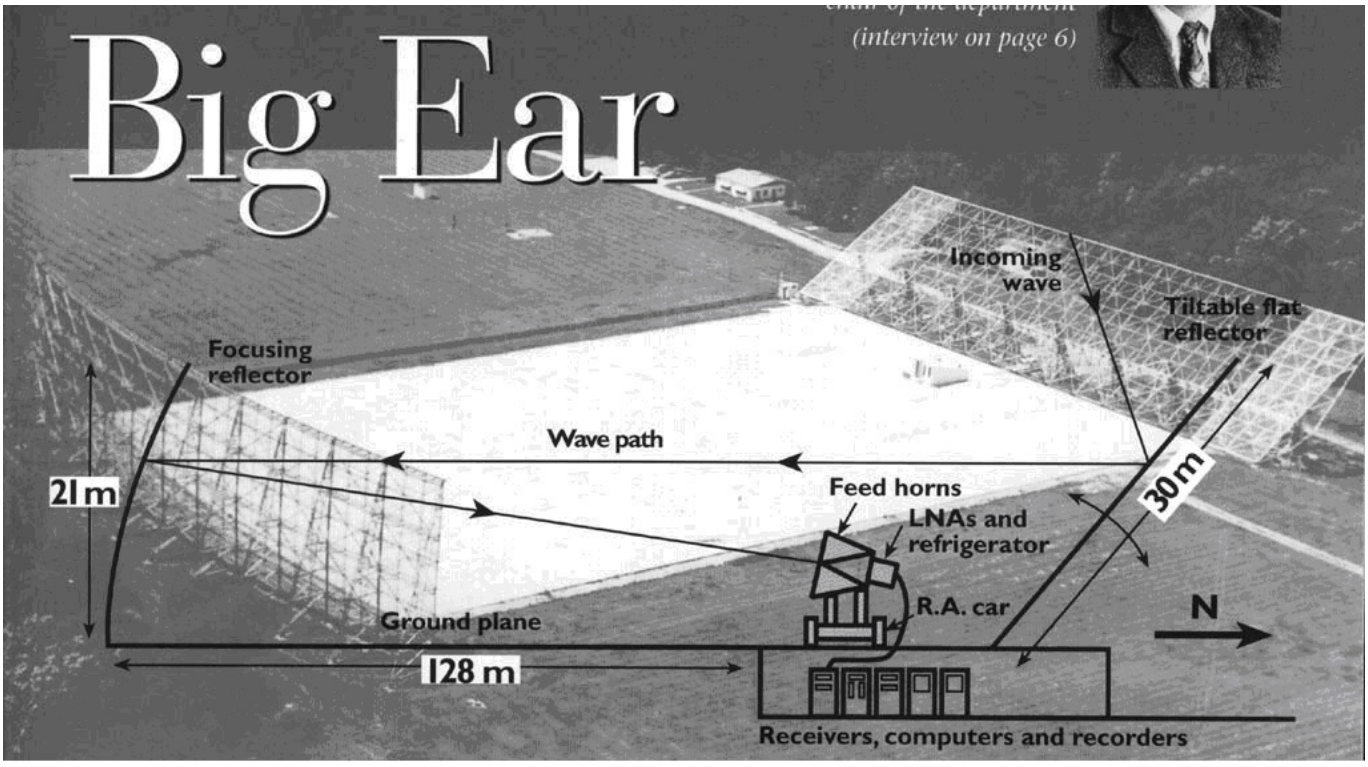
# The Wow! Signal – explained?

## A review of
## *Arecibo Wow! I: An Astrophysical Explanation for the Wow! Signal*

**David F Gahan**

**The Wow! signal was detected by the Big Ear radio telescope of Ohio State University in 1977 - and never observed subsequently. A recent paper by Mendez et al has put forward a new explanation for the signal origin. David Gahan examines the paper in the context of other explanations in the search for extraterrestrial intelligence.**

Modern scientific SETI is the search for technosignatures - and also the search for alternative, natural explanations until the great day when there is no alternative explanation. Great science and ingenuity are involved in both aspects, as when Jocelyn Bell Burnell discovered the first Pulsar and a new branch of astrophysics was born. A similar hunt for natural explanations was launched when, in 1977, a researcher noted an intense narrowband signal on the real-time data print-out from Ohio State University's 'Big Ear' radio astronomy receiver and marked it with the famous, circled 'Wow!' (see Wow! signal - Wikipedia en.wikipedia.org/wiki/Wow!_signal). The radio signature had enough of the features you might hope for from an artificial signal that it excited the interest of SETI pioneers such as Carl Sagan, but also presented the corresponding challenge: what else might have caused it?



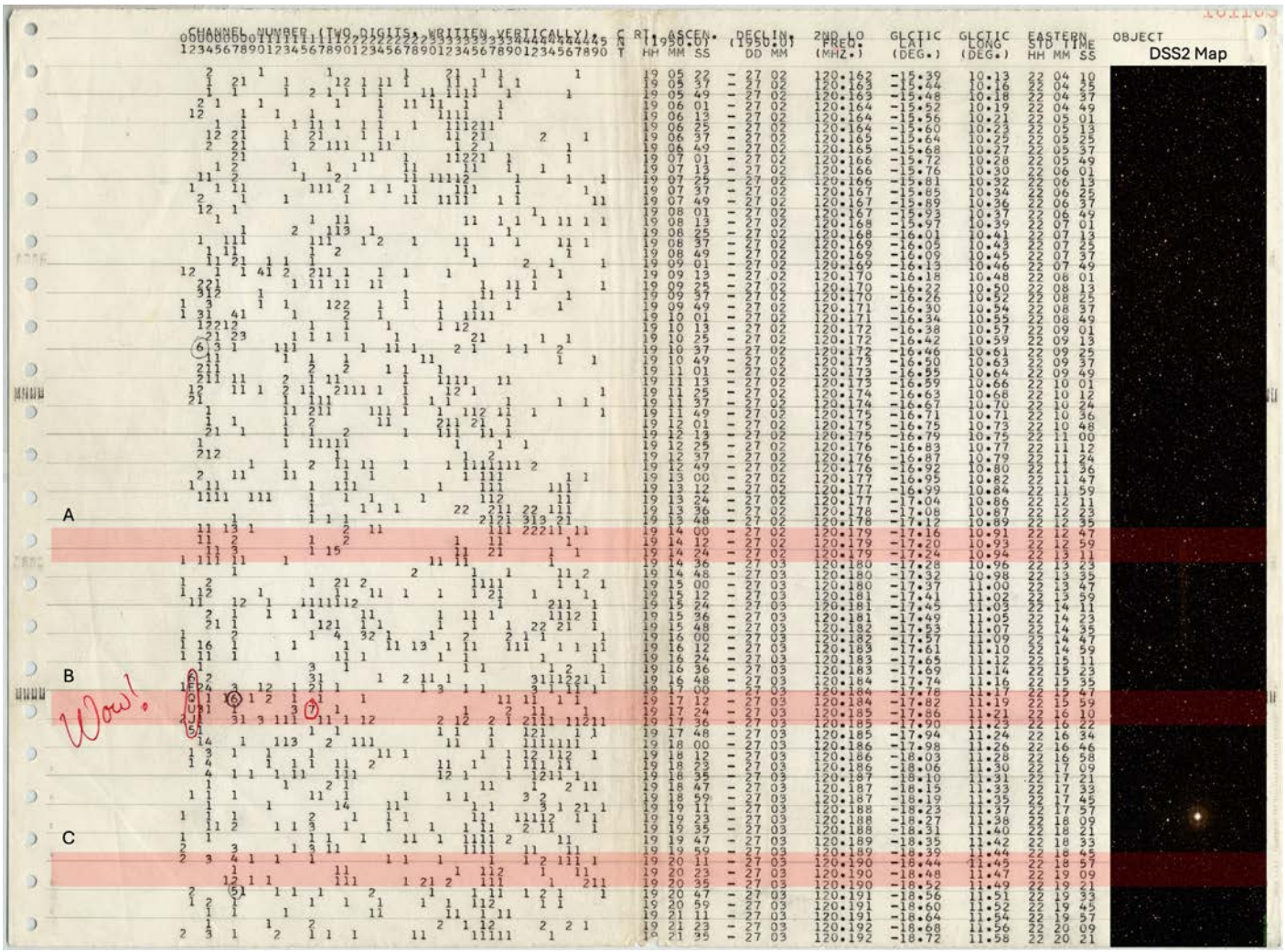

Big Ear Radio Telescope - Aerial View & Diagram of Ray Path

In the summer of 1956 Ohio Wesleyan University (Delaware, Ohio) allowed OSU use of "20 acres more or less" of land near the Perkins Observatory, about 2 miles south of the city of Delaware, on which to build a new radio telescope. Dr John D Kraus's design was for a tiltable flat reflector, a fixed paraboloidal reflector and an aluminum covered ground plane in between. Originally, John had planned for the fixed paraboloidal reflector to be 610 meters (2,000 feet) wide by 61 meters (200 feet) high and the flat reflector to be 610 meters (2,000 feet) wide by 85 meters (280 feet) in slant height. Due to insufficient funding available, the paraboloidal reflector ended up with dimensions of 360 feet by 70 feet, and the flat reflector with dimensions of 340 feet by a slant height of 100 feet. Observations began in 1961. This design became known as a "Kraus-type" radio telescope, and the nickname of "Big Ear" was also linked to this telescope. A telescope of very similar design was built in Nancay, France. Another telescope of a somewhat similar design, called the RATAN 600, was built at Zelenchuckskaya, Russia.

Credit (image and caption): NAAPO (North American AstroPhysical Observatory) www.naapo.org/W8JK/W8JK.htm

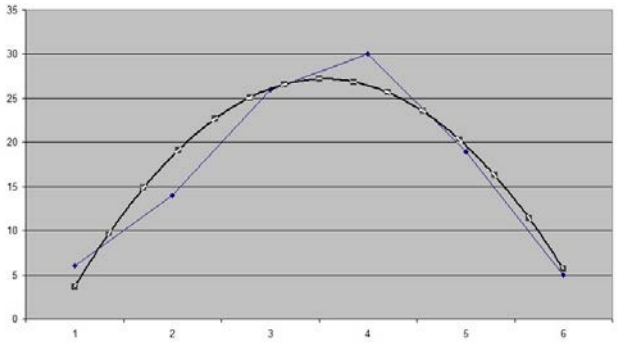
An August 2024 paper *Arecibo Wow! I: An Astrophysical Explanation for the Wow! Signal* (Méndez et al arxiv.org/pdf/2408.08513) seems to provide the most convincing explanation yet. NB despite the title, the Wow! signal was observed in Ohio; the great observatory at Arecibo still does important astronomy despite the destruction of its great dish in 2020 (en.wikipedia.org/wiki/Arecibo_Telescope). Méndez is based there and has 50 years of data available for re-analysis with modern techniques.

There was mystery from the outset. Big Ear, a kind of flat-pack Arecibo with two 'wall-like' reflector panels focusing a portion of sky onto horn antennae, relied on the Earth to do the turning. Two antennae were used in subtraction mode. You were never quite sure exactly which one did the receiving (and hence location, although clearly 'somewhere in Sagittarius') but it was good for signal-to-noise ratio.




Full page of the computer printout with the Wow! Signal labeled in handwritten red ink. The coordinates column corresponds to the location of the positive horn. The signals are calculated from the signal-to-noise ratio (SNR) of the absolute value of the difference between the positive (ON) and negative (OFF) horn, which is 45 arcminutes ahead (3 minutes). Three locations of interest were added to the figure, labeled A, B, and C, and highlighted in red. They have the approximate azimuth size of the Big Ear telescope (8 arcminutes). The actual location of the Wow! Signal is either in B or C. If the signal was present and persistent in B, then the signal would appear in both A and B, but there is nothing in A. If present and persistent in C, then it would appear in both B and C, but there is nothing in C. A Digitized Sky Survey 2 (DSS2) frame was included for reference with the objects in the observed field (right).
Printout credit: The Ohio History Connection Collections. Figure 1 (www.ohiohistory.org/wow/).

That was what really stood out – the sequence of 6EQUJ5 (see the printout and also the sidebar), showing the intensity sequence during the whole 72 seconds the source was in the observational window, reaching an impressive thirty standard deviations above background noise and centred on the 21 cm neutral hydrogen line right where SETI pioneers might have expected.




6EQUJ5 with polynomial trend line).

It was never seen again despite Big Ear's daily passes over the same region of sky so it had to be a transient phenomenon. Later calculations (in Méndez's paper) would reveal that the intensity of the transient (if isotropic and lasting of the order of the minutes/hours) could have been the order of $10^{-8}$ - $10^{-6}$ luminosity of the Sun at that wavelength. Big Ear averaged over 10-second 'buckets' so wouldn't be sensitive to signal modulation faster than this; the 'signal' was therefore assumed to be unmodulated.

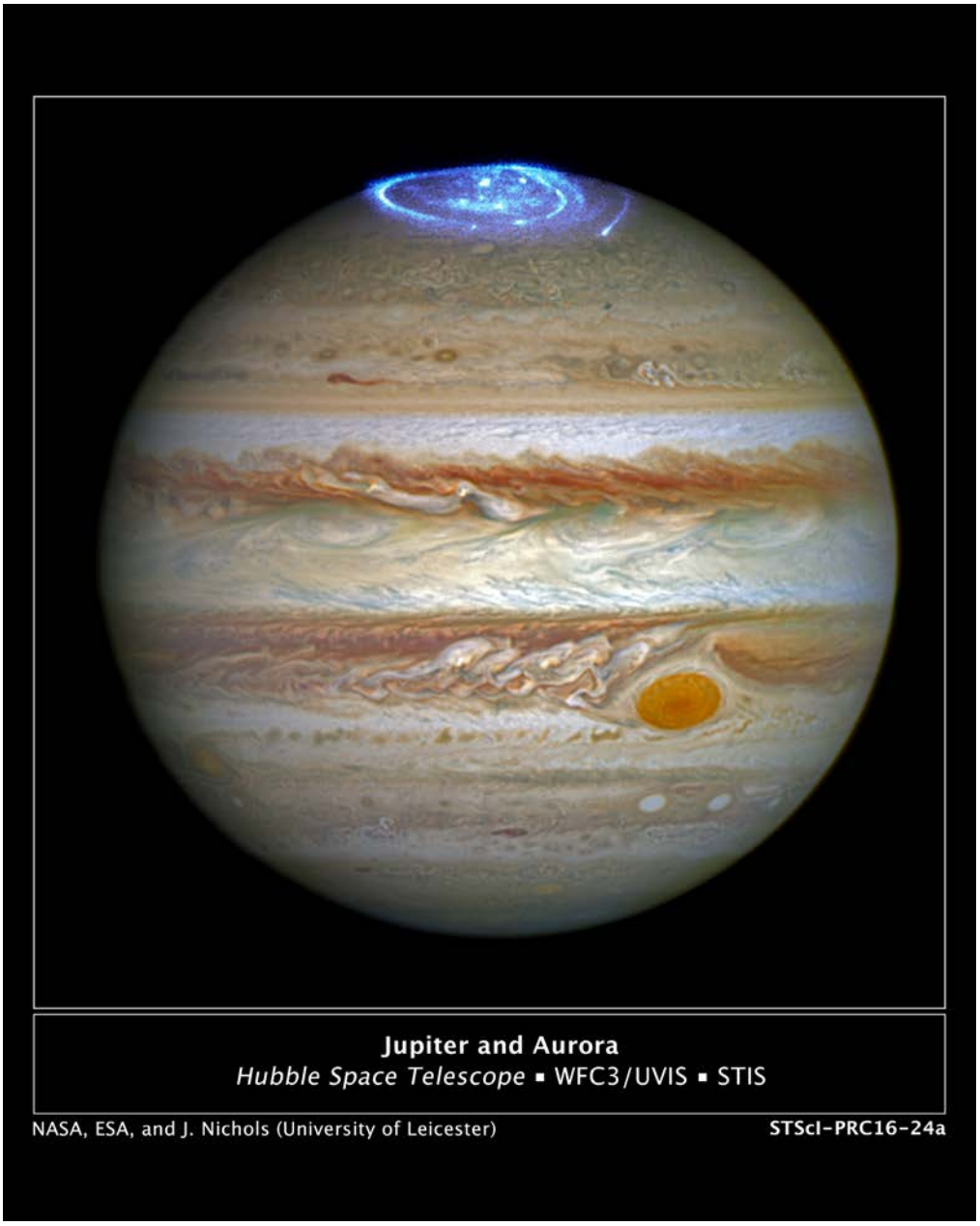
Méndez et al do a good job of examining the best current explanations. Their work on the Arecibo archive led them to see that observational techniques and data formats allowed them to do plenty of read-across. Their data showed similar narrow-linewidth sources (particularly around the pleasantly named 'Teegarden's Star') which they could attribute to clouds of cool, neutral hydrogen. So there was nothing really special about the 10 kHz linewidth (SETI researchers would be more excited about much narrower linewidth sources of a few Hertz) and in fact this points to relatively cold hydrogen without much thermal broadening. The absolute frequency of Wow! - which would be red or blue shifted depending on its rotation rate within the Milk Way - was also consistent with gas clouds between us and the galactic centre and with little Doppler shift either way. But their archival data hasn't show them (yet, although they have 50 years of data to trawl through) anything of the same power as Wow! to within two order of magnitude. So what could cause the faint 21 cm glow of a cloud of cool hydrogen to massively brighten, then quickly fade?

## Interpretation of the Wow! data

Part of the cultural history of the Wow! Signal is the misinterpretation of the format of the data as a message from the stars. One SETI enthusiast asked: "What does the progression 6EQUJ5 actually stand for? A sequence in need of completion? A matrix in need of expanding? A computer malfunction? The ASCII equivalent to a binary code?" (www.setileague.org/articles/calibwow.htm). In fact, you have to take yourself back to the 'steam-punk days of computer print-outs. There was no sophisticated real-time processing of data by complex decision trees with user changeable parameters (eg by Visual Basic), and no spitting out of beautifully graphed intensity charts emailed to your phone. No, you actually had to READ THE PRINT OUT from a chattering printer, maybe with a golf-ball head or daisy wheel. You needed a string of characters that would draw the eye to something unusual, but cover a big dynamic range so as not to lose any information. The researchers came up with an alphanumeric code to represent the integrated signal strength over 10 second buckets (12 seconds including processing time). Specifically, the symbols represent the number of standard deviations by which the received signal exceeded average background noise, on a scale of 0 to 35. So a 0 means no stronger than background noise, 1 is one sigma above noise, 9 means nine sigma above noise, an A would be ten units, and U (the strongest peak of the actual signal) is 30 standard deviations above the mean background noise in the receiver ie 6EQUJ5==6,14,26,30,19,5. If you graph the sequence as amplitude values over time you get roughly a Gaussian distribution, consistent with the antenna 'field of view' pattern of Big Ear in drift-scan mode (ie, as the Earth rotates). The data set depicts signal amplitude over six sample buckets of 12 seconds at the receiver frequency.

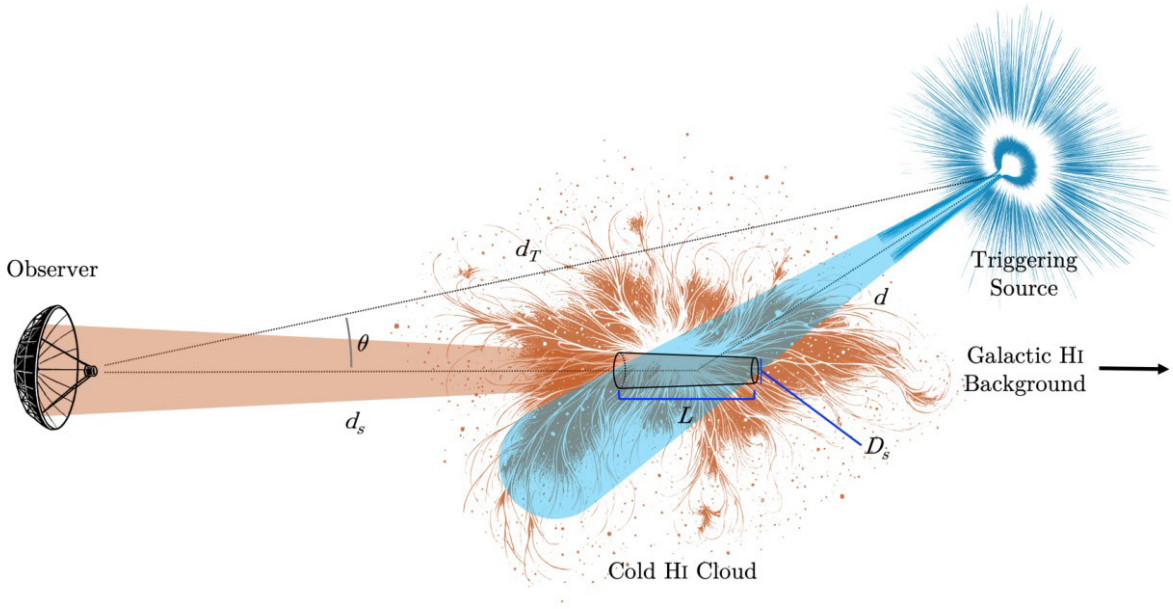
I spent three enjoyable years working with erbium doped fibre amplifiers (EDFAs); every data-packet you receive from California will go though about 200 of these to boost the signal. So I accepted gladly when John asked me to do this review, especially after seeing the word 'MASER' in the paper. Lasers/Masers both depend on having more atoms in the excited state than the ground state, which only happens if they are 'pumped' by an energy transfer mechanism to achieve 'population inversion'. Both lasers and the sort of maser used for frequency reference have feedback cavities (mirrors!) which select a very specific frequency even if the lasing (or 'gain') medium can support a broader range. A simple LED with a short cavity with no feedback (for example) gives a broader spectrum with low coherence versus a solid-state laser.

No feedback cavity but a longer path length (with plenty of population inversion), gives you 'super-radiance' where the signal is boosted as it travels along, with more coherence and a narrower linewidth (the two are mathematically related). This is very like what happens in an EDFA over several meters of erbium doped fibre. (Although Méndez et al try to make a distinction between super-radiance and maser amplification, it's a matter of taste which term you use,)
Astrophysical masers certainly exist (Astrophysical maser en.wikipedia.org/wiki/Astrophysical_maser). Here's a lovely Hubble image of Jupiter with a false-colour image of the permanent, circular aurorae 16 degrees from the magnetic pole. There's plenty of pumping from electron currents flowing in the magnetosphere which give rise to maser amplification. Jupiter is a powerful radio source as a consequence. But the conditions to allow masing in cold, isolated clouds of hydrogen – to achieve population inversion over a large object possibly millions of kilometres long - are much less probable. The Wow! signal looked like a maser emission pumped by a transient energy source (hence the short, unrepeated, duration of the event) but what could be the energy source?




Aurorae on the north pole of Jupiter generate cyclotron masers (Hubble)
Astrophysical maser -en.wikipedia.org/wiki/Astrophysical_maser
Credit: NASA, ESA, and J Nichols (University of Leicester)

Enter the Magnetar. Magnetars (en.wikipedia.org/wiki/Magnetar) are the 'bad boys' of the local neighbourhood. Recently formed neutron stars, they spend a round 10k years in a violent phase. Their magnetic fields are around 1,000x that of a 'normal' neutron star and could wipe your credit card at earth-moon distance. Any hydrogen atom in the vicinity would be massively distorted into a thin cigar shape as its s-orbital would be compressed 200-fold by the field. They are prone to starquakes giving rise to huge flares, of great interest to astrophysicists. Only 30 have been discovered so far but there could be 30 million in the Milky Way. Any flare would have plenty of UV radiation to pump atomic hydrogen to population inversion state and allow masing to begin at the characteristic 21 cm wavelength. Méndez et al do a good job of running through all the relevant numbers and making the case. You still need a long, thinnish cloud of hydrogen pointing more-or-less at us, and a local magnetar to give off one of its flares - but the whole story appears to be plausible, and currently may be the simplest explanation. While searches for sun-like stars (possible homes for ET) has been made, no specific search for candidate hydrogen clouds has yet been made, nor has a magnetar yet been spotted. The imprecision in directional data from Big Ear makes this more work but the effort should be worth it. And Méndez et al still have 50 years-worth of Arecibo data to trawl through for possible similar signals. An ETI origin cannot be ruled out, as the authors say, but the existence of a natural mechanism (if confirmed) for strong signals on the 21 cm line would make this a less favourable choice for ET to choose as their hailing frequency.




The proposed Wow! Signal emission source is a region of a cold $H_I$ ['neutral hydrogen' ie clouds of atomic (not molecular) H.] cloud at a distance $d_s$ that emits a superradiance radio beam along a line of sight L and with a diameter $D_s$. This event is triggered by a strong radiation source, at a distance d from the cloud and $d_T$ from the observer. The trigger beam is not necessarily observed depending on its distance, size, and separation angle Θ. Since the superradiance event also takes a time to build up, the trigger beam if observed always precedes the superradiance event by seconds to hours.
Credit(image and caption): Menendez et al. Figure 6.

**About the Author**
David F Gahan is a regular contributor to Principium and has a special interest in Schelling Points – logical locations and modes of communication that intelligent species might be able to mutually guess. His first article on the subject 'AMiTe Treffpunkt' was published in Principium 32. He is an Imperial College physicist and (relevant to this paper) worked on Optical Amplifiers at Corning Incorporated from 1996-99.

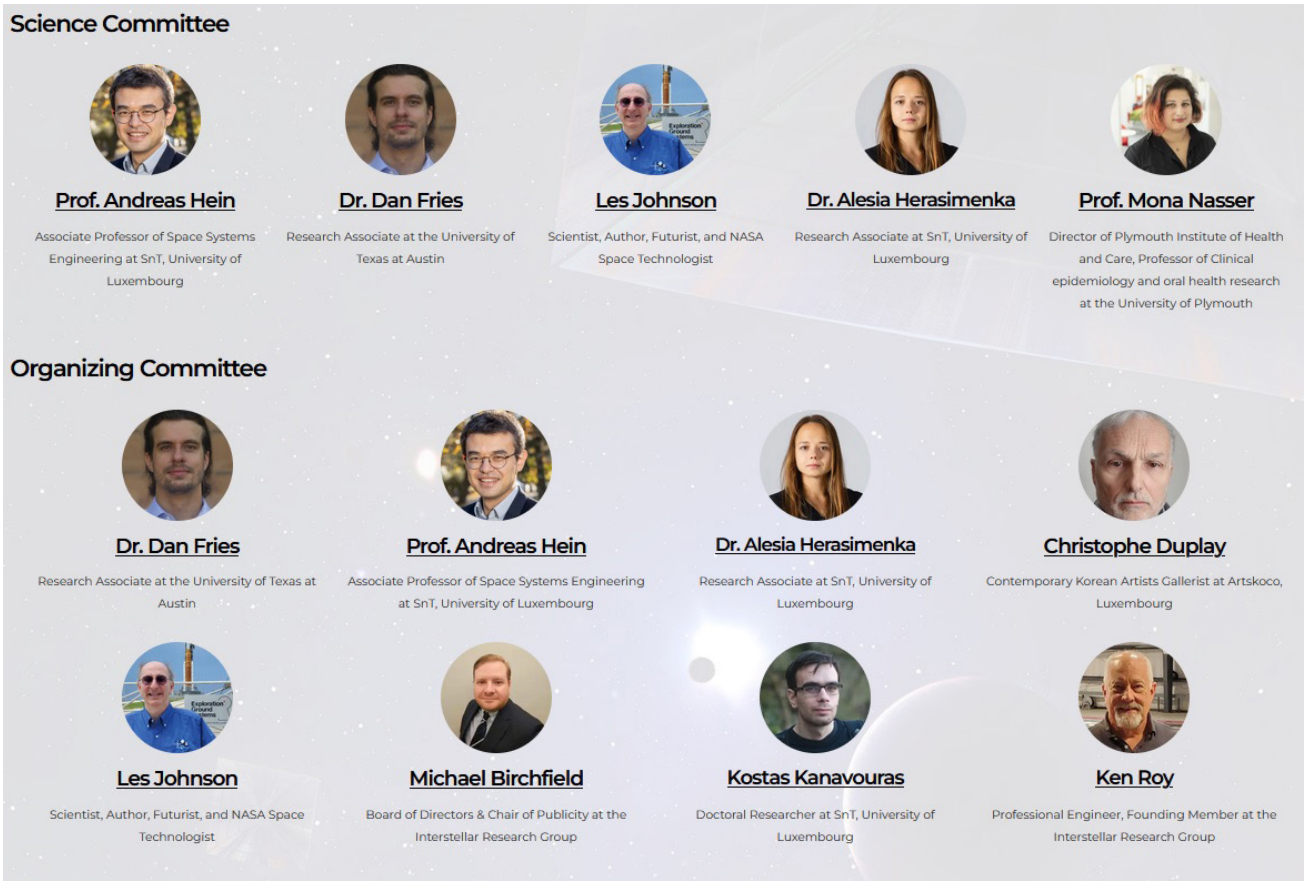
# First European Interstellar Symposium

## The Abstracts

**The First European Interstellar Symposium will be held at the European Convention Center Luxembourg on 2nd – 5th December 2024.**
**The Symposium website is irg.space/first-european-interstellar-symposium**

## OVERALL AGENDA

The Day 1 Pre-conference Monday 02/12/2024, from 09.00 includes Registration and Introductory seminars on various topics related to interstellar travel: interstellar propulsion, environmental life support systems, interstellar communication, space law and an Opening Reception 17:00 – 20:00.
Day 2 Tuesday 03/12/2024 starts at 08.10 for Registration with Symposium main business from 08.40. Lunch 12:30 – 14:00 and concludes with the First Working Track ending at 17.30. There is a Public Outreach Event 20:00 – 21:30.
Day 3 Wednesday 04/12/2024 starts at 08.45 for Registration with Symposium main business from 09.00. Lunch 12:30 – 14:00 and concludes with the Second Working Track ending at 17:50. There is a Gala Dinner and Lightning talks 18.00-20.00 and another public event, a Science Fiction Authors Night, with Les Johnson (NASA, US), Brandon Q Morris, Joshua T Calvert.
Day 4 Thursday 05/12/2024 is the last day. It starts at 08.45 for Registration with Symposium main business from 09.00. Lunch 12:00 – 13:00, the Working Tracks Outbrief concluding 14.30 and an afternoon visit to Luxembourg space companies.
The full agenda can be found at irg.space/first-european-interstellar-symposium/agenda/



## ABSTRACTS

The accepted abstracts are -

*Submission #6: Ultimate Biosphere Survival: Interstellar Migration from the Post-Main Sequence Sun*
In approximately 5 billion years, our Sun will start its post main-sequence evolution. The initial stage of this process, the subgiant phase, has a duration of about 100 million years. The sub-giant Sun will have a luminosity about twice that of the present-day Sun. Its radius will be about 3X the current solar radius. A more suitable phase for interstellar migrations is the horizontal branch of 500 million year duration in which the Sun's luminosity will have increased by a factor of about 100X and its radius by about 10X. At intervals of 500,000 years or less, Sun-like stars approach within one light year of the solar system. This paper investigates the feasibility of using large space habitats accelerated by graphene solar-photon sails to enable interstellar migrations of ~1,000 year duration.
**Author:** Gregory Matloff (Physics Dept., New York City College of Technology, CUNY)
**Presenter:** Gregory Matloff
Oral Presentation
**Topics**
* Life Support Systems and Habitats
* Potential Destinations and Astrophysics
* Propulsion

*Submission #7: A Filipina Space Ethos*
One of my grandparents migrated to the US from the Philippines in 1947, assimilated quickly, had children who assimilated fully, and died during my primary school years. Pinay: Culture Bearers of the Filipino Diaspora, edited by V Chattergy and P Nieva (Filipino Association of University Women, 2017) left me astonished by the adaptive skills of Filipina migrants. Are these the same adaptive skills needed for community resilience in space? It is not the colonialist's myth of the rugged pioneer, but the experiential knowledge of the displaced islander that will usefully guide human space exploration and expansion.
**Authors:** Jayme Johnson (Wichita State University (resigned), James Schwartz (Wichita State University
**Presenters:** Jayme Johnson
Oral Presentation
**Topics**
* Communications
* Ethics
* Life Support Systems and Habitats
* Potential Destinations and Astrophysics
* Psychology, Anthropology and Crew Health
Special Session

*Submission #8: Relativistic Interstellar Flight Communications by virtue of the KLT*
Nowadays the whole world uses the Fast Fourier Transform (FFT) to extract signals out of background noise, but FFT uses just sines and cosines as orthonormal time functions to, and that is an oversimplified situation. Since the discovery of the Hilbert space around 1900, however, a number of orthonormal bases in Hilbert space were used by advanced mathematicians to extract signals out of noise. During the years around World War Two, men like American Harold Hotelling, Finn Kari Karhunen, French Michel Loève and Indian Damodar Kosambi independently came up with the idea of decomposing the incoming stochastic process as an infinite sum of static random variables multiplied by orthonormal time functions. Having so done, the input autocorrelation matrix is diagonalized and the eigenvalues are the elements of the main diagonal, while each eigenfunction is corresponding to just one eigenvalue only (no degeneracy). In quantum physics that is called the eigenvalue equation of the autocorrelation operator. Thus, finding the KLT of a given stochastic process means solving the integral equation whose kernel is the autocorrelation. This author worked on the KLT while doing his PhD in mathematics at King's College London (UK) in the 1970s. He then discovered that the KLT eigenfunctions of Brownian Motion are Bessel functions J(t) and

the corresponding eigenvalues are the zeros of some derivatives of the Bessel functions. He then found that these results perfectly apply to noisy signals emitted by a special-relativistic spaceship (like StarShot).
In fact, in his first book "Telecommunications, KLT and Relativity" (1994, IPI Press, Colorado Springs, USA, website https://bis-space.com/shop/product/telecommunications-klt-relativity/) he analytically worked out several KLTs of interest to space flights and genetics aboard spaceships.
Though these mathematical calculations were published in journals like Acta Astronautica and similar journals, the topic of relativistic interstellar flight was much too ahead of time in the 1990s, and the mathematics were simply too lengthy for immediate computer implementation.
Hopefully the situation is improving now in 2024. Please, kindly read this summarizing paper:
Claudio Maccone, Relativistic Interstellar Flight Communication Theorems, Acta Astronautica, Vol. 26, No. 2, pp. 105-117, 1992.
**Author:** Claudio Maccone (International Academy of Astronautics (IAA, Paris, France) and INAF in Italy)
**Presenter:** Claudio Maccone
**Oral Presentation**
**Topics**
* Communications
Special Session

*Submission #9: Antimatter Versus Fusion Deceleration Concepts for Exoplanet Exploration*
Flyby probes are often used for a first glimpse, but robust exploration of exoplanets will inevitably require a propulsion system capable of deceleration into orbit around a nearby star and/or an exoplanet. Given the vast distances between stars, spacecraft cruise velocities of at least a few percent of the speed of light will need to be achieved. Deceleration from such velocities requires a propulsion system with particle exhaust velocities corresponding to kinetic energies of at least 1 MeV/nucleon. Conventional fission reactors are too heavy, and their architecture is incompatible with the emission of such energetic exhaust particles. This paper contrasts two propulsion concepts, one utilizing antimatter to induce uranium-238 fission and the other an architecture based on nuclear fusion. In both cases particles emanating from the actual nuclear reactions are focused and transmitted into space. While antimatter-based propulsion concepts have been proposed for several decades, the limited production of antimatter and its storage difficulties have retarded their development. The antimatter concept has been the subject of two past studies funded by the NASA Innovative Advanced Concepts (NIAC) program. With the exception of thermonuclear warheads, fusion reactors that output more energy than the energy input to achieve ignition have not yet been demonstrated. In this paper the suitability of several nuclear fusion channels (reactant combinations) are assessed, Onboard power systems for both concepts are also discussed. For example, a mission to the habitable planet Proxima b should have at least 100 kW for data communication back to Earth, AI-level computing, and a LIDAR system capable of studying Oort Cloud objects from both our solar system and the Centauri AB binary system. This paper describes the current state of these concepts in the context of both manned and unmanned missions to the exoplanet Proxima b. It contrasts the strengths and weaknesses of these approach in order to provide guidance to future studies.
**Author:** Gerald Jackson (Hbar Technologies, LLC)
**Presenter:** Gerald Jackson
**Oral Presentation**
**Topics**
* Power Systems
* Propulsion

*Submission #10: INDUSTRIALISING EXTRASOLAR ASTEROIDS TO BUILD OUR HOME AMONG THE STARS*
Background: A spectrum of interstellar exploration strategies will be essential to yield high benefits to capitalise on their high costs. To minimise costs, initial explorations will be cursory and data-limited. It is envisaged that human colony missions are the ultimate goal but such missions must be preceded by thorough robotic surveys. Furthermore, human life support will be required both in transit and at the destination. We suggest that interim missions for robotic surveys and for robotic pre-colonisation require an obvious evolution from in-transit self-repair to in-situ resource utilisation at the destination.
Objective: We examine the feasibility of building pre-colonisation assets within extrasolar systems using local resources.
Methods & Results: We have previously suggested that interstellar spacecraft will require substantial onboard self-repair to ensure their survival in-transit. Such interstellar spacecraft must be supplied with a finite range of feedstocks together with a FabLab-type manufacturing capability to build components and parts on-demand. The core of such a FabLab capability is a 3D printing facility supported by milling stations and other kinematic machines. We have demonstrated that electric motors – highly complex, multi-material components – can be 3D printed implying that the FabLabs are themselves self-repairing. To perform in-situ resource utilisation at the extrasolar system destination, further capabilities are required to generate a range of feedstocks. An industrial ecology is required to support an industrialisation process necessary for the construction of assets required for human colonists. O'Neill colonies are a fits-all solution to human habitability in extrasolar systems. This will require physical and chemical processing of local asteroidal resources. We have demonstrated the extraction of aluminium metal feedstock from anorthite minerals. Aluminium is a highly versatile multifunctional material. We expect that aluminium will be the dominant material required for constructing an O'Neill colony.
Conclusions: The payload of our ISRU-functional interstellar spacecraft constitutes a self-replicating machine. The implications for SETI are profound. Given the lack of evidence of technosignatures (in this case, evidence of artificial processing of our own asteroid objects such as extensive clay deposits), the Copernican principle forces us to the conclusion that extraterrestrial intelligence with technological means do not exist.
**Author:** Alex Ellery (Carleton University)
**Presenter:** Alex Ellery
Oral Presentation
**Topic**
* Advanced Materials

*Submission #11: REMOTE CONTROL OF SELF-REPLICATING STARSHIPS*
Background: Self-replicating starships are an inevitable evolution from interstellar starships that can self-repair in-transit. They offer the most economic means through which to explore our Galaxy at a capital cost of launching a single or a few starships. Tipler suggested that any technologically-competent extraterrestrial intelligence (ETI) would inevitable adopt this strategy. We further suggest that this strategy is logical for global defence – it provides both intelligence about potential threats in our Galactic environment and security regarding the location of our home world. Sagan suggested that no responsible ETI will adopt self-replicating starships as they are potentially uncontrollable because of their evolvability.
Objective: We propose that prevention of evolutionary change in the self-replicating starship's genetic information is feasible.
Methods: We review error detection and correction coding (EDAC) methods utilised extensively in spacecraft onboard memories to combat incident radiation. Evolutionary mutation can be prevented to any arbitrary degree through channel coding which ensures the fidelity of information through a communications channel – in this case, a vertical evolutionary channel. Biological genetic fidelity is limited by the energy cost of physical repair mechanisms but spacecraft memory-encoded binary information repair involves only bit flipping. There are two major types of EDAC and variations thereof - block coding and convolutional coding – which add redundant information. Interleaved Reed-Solomon block coding with convolutional coding is commonly implemented for reliable interplanetary data transmission, eg Voyager. Turbo coding approaches the maximum encoding efficiency dictated by Shannon's theorem. For a self-

replicating probe to spread through the Galaxy requires copying fidelity over only 24 vertical generations. We might employ deeper encoding depth at critical genetic instructions such as number of offspring and telomeric counters.
Results: Efficient channel coding can prevent mutations generated by copying errors in the genetic code of the self-replicating starship thereby preventing it from evolving.
Conclusions: The Sagan-Tipler debate regarding the existence or non-existence of ETI revolved around their deployment of self-replicating probes to permeate the Galaxy within astronomically short timescales. Sagan's retort is unfounded. Fearfulness of technology has never been much of a deterrent for humans so its application to ETI contravenes the Copernican principle.
**Author:** Alex Ellery (Carleton University)
**Presenter:** Alex Ellery
Oral Presentation
**Topic**
* Communications

*Submission #17: Seeding life with an interstellar probe. Technical and ethical considerations*
Claudius Gros, a theoretical physicist from the Institute for Theoretical Physics at Goethe University Frankfurt, proposed an idea of how robotic missions equipped with cryogenic pods with genes could be used to distribute microbial life to planets capable of supporting life but not likely to give rise to it on their own.
These kinds of interstellar robotic missions are beyond our current and near-future technological capabilities. However, there are proposals for using laser sails to send microscale probes to nearby stars within the near future. Could these kinds of microprobes be used to seed life to other worlds? Should we do this if it is technically feasible? Clearly, there are many technical problems: How do you identify suitable target planets? What organisms should we use? How do you preserve them during the long interstellar journey? How do you securely deploy organisms during the very limited time of the fly-by, and so on? Here I will make a literature review of what kind of ethical and technical problems this kind of seeding will raise.
**Author:** Pauli Laine (Finnish Astronautical Society)
**Presenter:** Pauli Laine
**Oral Presentation**
**Topics**
* Autonomous Spacecrafts
* Communications
* Ethics
* Miniaturisation and Technology Development
* Potential Destinations and Astrophysics
* Power Systems

*Submission #18: To Seed or Not to Seed: The Ethical Implications of Directed Panspermia*
Background - Directed panspermia involves the deliberate spread of life between planets by intelligent actors. While it was originally proposed to explain the origins of life on Earth, recent advancements in space and bio-technology suggest that humans could soon attempt this over interstellar distances – and perhaps even succeed.
Objective - Analysing the ethical impact of humans undertaking directed panspermia.
Methods - Analytic philosophy and evolutionary biology. The paper uses two of the most opposing ethical views to bracket the field of ethical theories.
Results - Panspermia is different from deliberate settlement in that humans cannot directly intervene once it is underway. Biocentric ethical theories support attempting this project to secure life's continued existence and increase its cosmic abundance. However, given its vast effects and irreversibility, directed panspermia also carries serious moral risks: if what matters is protecting and promoting the welfare of sentient beings, then attempting this project could create astronomical levels of suffering in the long-term future.

Conclusions - Taking into account normative uncertainty, the cost of waiting, and the "unilateralist curse", we argue that both views can agree on a temporary moratorium on directed panspermia.
**Authors:** Anders Sandberg (Institute of Futures Studies), Asher Soryl (University of Otago)
**Presenter:** Anders Sandberg
**Oral Presentation**
**Topics**
* Ethics
* Space Law

*Submission #19: Traversable Wormholes powered by Casimir Energy with Temperature and Charge*
Traversable Wormholes (TW) are solutions of the Einstein Field Equations. Even if they are not yet discovered, they represent an interesting research line especially after the discovery of Gravitational Waves. Indeed, there are proposals which consider TW as sources for Gravitational Waves. In addition to this remarkable research field, TW are also interesting because they have peculiar properties that other astrophysical objects do not have, namely they can create short-cuts between distant regions of the space-time. This amazing property can be satisfied at the price of introducing a particular kind of source dubbed as Exotic matter. We know that such a matter has not yet been discovered, however one can invoke the Casimir energy which behaves like the Exotic matter. The physics of the Casimir energy has a large plethora of applications. In this talk, we would like to propose such an energy source as a possible source powering a TW. This idea has been proposed for the first time in two pioneering papers: MS Morris and KS Thorne, Am JPhys 56, 395 (1988), "Wormholes in space-time and their use for interstellar travel: A tool for teaching general relativity" and MS Morris, KS Thorne and U Yurtsever, Phys. Rev. Lett. 61, 1446 (1988), "Wormholes, Time Machines, and the Weak Energy Condition". Also the book of M Visser, Lorentzian Wormholes: From Einstein to Hawking (American Institute of Physics, New York), 1995 is an excellent example about the physics of TW. However, we have to wait for 2019 when the candidate speaker of this talk proposed to search which kind of TW could be associated with a Casimir source. The result was published in Eur.Phys.J.C 79} (2019) 11, 951 under the title "Casimir Wormholes". A discrete degree of curiosity has been arised by such a publication (98 citations on Spires). In this talk we would like to show how some modifications on Casimir Wormholes can take the paradigm "traversable in principle" a little bit more closer to the possibility of being "traversable in practice".
**Author:** Remo Garattini (University of Bergamo)
**Presenter:** Remo Garattini
**Oral Presentation**
**Topics**
* Potential Destinations and Astrophysics
* Propulsion

*Submission #20: Feasibility study of reducing interstellar travel times with groups of co-operating fuel-carrying rockets*
Background
Previous rocket concepts for interstellar missions using such propulsion, which the mankind might be able to develop during the next 100 years, like projects Orion, Daedalus and Longshot have suggested travel times around 50-100 years to our nearest star systems. For example Project Daedalus had 2-stage rocket using inertial confinement fusion, which managed to reach 50-year travel time to the Barnard's star for a flyby-mission.
Objective
This feasibility study evaluates the concept of using groups of co-operating fuel-carrying rockets for reducing travel times. The payload rocket doesn't have to carry all the fuel it needs for the mission. Instead it shall meet other fuel-carrying rockets at crucial points along the way. These fuel-carrying rockets shall likewise meet other fuel-carrying rockets and use their fuel. Vessels of similar speed, direction and place can rendezvous and exchange fuel. This is especially useful for the deceleration phase of the journey, because all the fuel for deceleration don't have to be costly accelerated to very high speeds.

Methods
Using performance metrics of Project Daedalus like similar fuel / empty mass ratios of rockets and the same effective exhaust velocity some example configurations of fuel and payload carrying rockets are created. Travel times and resource requirements for a mission to Alpha Centauri system are calculated for different configurations using established science like the ideal rocket equation.
Results
With the example rocket configurations used travel time for a one-way, decelerating mission to the nearest star system is reduced from 50 - 100 years to 10 - 20 years. The resource requirements are huge, 500 - 300 000 expendable fuel carrying rockets with total masses 12,000,000 - 6,000,000,000 tons. However, the resource requirements are related to travel time: the quicker we want to go the more resources we need. Rockets needed for deceleration require tens of years of lead time before payload rocket.
Conclusions
Using the described methodology a human colonization mission to our nearest star system is possible without sleeper or freezer or hibernation ships or generation arks.
**Author:** Aapo Puhakka (Finnish Astronautical Society)
**Presenter:** Aapo Puhakka
**Oral Presentation**
**Topics**
* Autonomous Spacecrafts
* Propulsion

*Submission #21: Simplified Evolutionary Neurocontrol for Lower Bound Payload Estimates of Low Thrust Solar Oberth Maneuvers to the Heliopause*
Despite decades of space exploration, the very outer regions of the solar system remain largely uncharted, leaving open questions about the interaction of heliosphere and interstellar medium. One promising interstellar precursor mission architecture which can provide the challenging delta-v needed involves a Solar Oberth Maneuver (SOM) using solar electric propulsion, followed by a Jupiter gravity assist.
Devising an effective steering strategy for such a mission is challenging. Using evolutionary neurocontrol, previous research demonstrated the feasibility of flight times under 25 years (Loeb et al, 2011); yet, with the necessity of including a further Radioisotope Electric Propulsion (REP) stage. However, advancements in high-temperature solar cells might allow for SOMs even closer than 0.7 AU, and NASA's Space Launch System (SLS) for higher payload capabilities.
Previous implementations of evolutionary neurocontrollers are often sophisticated, involving artificial neural networks (ANNs) with high-dimensional inputs (up to 28 parameters) and 30-40 nodes in the hidden layer. While this allows for more optimization potential, the large input and parameter space complicates the optimization process.
The work at hand has two main objectives: i) developing a simpler evolutionary neurocontrol architecture for optimizing SOM steering strategies to achieve lower bound payload estimates and ii) using it to evaluate payload capabilities of a SOM to the heliopause with a perihelion distance of 0.3 AU, assuming a SLS launch and an advanced electric thruster with specific impulse of 6,000s and 75% thrust efficiency.
A mutation-driven evolutionary algorithm is used to optimize the steering strategy given by a neurocontroller that transforms the current spacecraft state into steering control commands.
It is shown that a neurocontroller with 4 input parameters, 10 hidden nodes and 2 output nodes suffices for lower bound assessments of payload capabilities to 200 AU within 25 years. An estimated lower bound payload of above 1,000 kg represents a significant increase in payload mass.
On the condition of sufficient maturity of the high-temperature solar cells, these results suggest feasibility of a mid-term heliopause mission without the necessity for a REP stage, thus allowing for a mission of decreased complexity and higher scientific payback.
**Authors:** Nadim Maraqten (Initiative for Interstellar Studies), Angelo Genovese (Initiative for Interstellar Studies), Willem van Lynden (Alma Propulsion Laboratory, University of Bologna)

**Presenter:** Nadim Maraqten
Oral Presentation
**Topics**
* Propulsion

*Submission #22: Advancing Interstellar Exploration: Integrating Technological, Ethical, and Socio-political Dimensions*
Background: Interstellar exploration necessitates a convergence of technical innovation and profound ethical inquiry. This work synthesizes advancements in propulsion systems, sustainable habitats, and life support alongside the ethical, sociopolitical, and philosophical questions that arise as humanity extends its reach beyond the solar system.
Objective: To present a multidisciplinary framework that integrates technological advancements with ethical and sociopolitical considerations, ensuring that humanity's expansion into the cosmos is guided by foresight, equity, and collective well-being.
Methods: This study draws from three key research areas: (1) advancements in propulsion technologies and sustainable Mars settlement strategies, and (2) the development of closed-loop life support systems and habitat construction using in-situ resources, and (3) ethical frameworks for responsible exploration, addressing the moral, legal, and governance challenges of interstellar travel.
Results: The integration of MFPD and sustainable habitat technologies promises significant reductions in travel times and resource dependency, making interstellar travel feasible within our lifetime. Closed-loop life support systems, incorporating bioregenerative processes, ensure sustainable human presence in space. Ethical frameworks emphasize the preservation of extraterrestrial ecosystems and the rights of potential extraterrestrial life forms, advocating for an inclusive and equitable approach to space exploration.
Conclusions: Interstellar exploration is not merely a technical challenge but a philosophical journey. This synthesis of science and ethics offers a blueprint for navigating the unknowns of space with wisdom and integrity, ensuring that humanity's interstellar aspirations reflect the best of human values. This talk aims to lay the foundation for a responsible and sustainable future among the stars by fostering a multidisciplinary dialogue.
**Author:** Florian Neukart (University of Leiden; Terra Quantum AG)
**Presenter:** Florian Neukart
**Oral Presentation**
**Topics**
* Ethics
* Life Support Systems and Habitats
* Power Systems
* Propulsion
* Psychology, Anthropology and Crew Health

*Submission #26: A top-down instructed bottom-up production method for space exploration utilising in-situ resources*
Current astronomical and remote sensing methods are fundamentally limited in their capacity to obtain comprehensive information from other star systems. Direct visits are necessary to gather detailed data, but interstellar travel to the object of interest, constrained by relativistic effects, is prohibitively energy-expensive when carrying mass over durations feasible within a human lifespan. Our understanding of other star systems remains superficial, confined to remotely sensed observations.
Given these constraints, one way to overcome them is to build the information observation and communication system on-site with the resources at hand. While technological components for self-assembling and in-situ resource utilization (ISRU) systems exist, integrating these parts to find the adjacent possible is lacking.
This approach involves encoding and inscribing matter with construction instructions, enabling the self-assembly of complex structures using locally available resources.
Our study aims to assess the feasibility and implications of this bottom-up production method in the context of interstellar missions.

We employ a multidisciplinary systems engineering methodology to integrate existing technologies and processes. Our approach models the self-assembly process, starting from the creation of a "seed" that contains the necessary instructions. This seed autonomously initiates the construction process, using local materials and energy sources available within the interstellar environment. We aim to quantify the potential savings in energy, mass, and time compared to traditional top-down methods and the direct transportation of finished products.
Our preliminary findings suggest that the bottom-up construction method may significantly reduce the energy and mass required for interstellar missions. By enabling on-site production, this approach could offer a more efficient alternative to current methods. We also explore the feasibility of encoding complex construction plans into the seed and the practical challenges of sourcing and utilizing local materials in an extraterrestrial environment.
This research demonstrates the potential of a top-down instructed bottom-up production method for space exploration. Future research could focus on applying the approach to other, perhaps terrestrial, use case.
**Authors:** Matthias Frenzl (Complex Structures Research Collaboration), Abhimanyu Shanbhag (Complex Structures Research Collaboration)
**Presenters:** Abhimanyu Shanbhag, Matthias Frenzl
**Oral Presentation**
**Topics**
* Advanced Materials
* Autonomous Spacecrafts
* Miniaturisation and Technology Development
Special Session

*Submission #27: From Interplanetary to Interstellar: Current Status of Exploration using Space Sails And Required Developments*
Background
Following the symposium "Large area structures & light" by the Deep Space Exploration Program at the University of Tokyo and the Breakthrough Initiatives in September 2023, an international working group was established. It focuses on identifying synergies among space sail technologies as a pathway towards practical interplanetary and interstellar missions.
Objective
The objective of this study is to answer two questions. Firstly, how big is the technological gap between present state-of-the-art space sailing and future proposed interstellar missions? Secondly, what are the major risk areas, and how can eventual bottlenecks be overcome?
Methods
These questions are addressed through a focus on three planned missions with different Technology Readiness Levels, different types of stakeholders and different destinations: Solar Cruiser, Project Svarog and Breakthrough Starshot. Gaps between these missions and currently achievable technologies on subsystem- and system-levels are assessed using the Advancement Degree of Difficulty (AD2) scale, and potential ways forward are proposed. A database of parameters achievable with present technologies is obtained from prior work by the authors.
Results
When comparing mission requirements with the current state-of-the-art, the maximum scaling of key parameters such as total sail loading and deployed area required by Solar Cruiser, Project Svarog and Breakthrough Starshot are generally found to be factors of 3, 10 and 600 respectively. It is however noted that the amount of risk of advancing the technology to the required level grows significantly when stepping from Solar Cruiser to Project Svarog and to Breakthrough Starshot. Key risk areas for each mission are mapped out, with attitude control, sail material, shape accuracy and subsystem integration being identified as major risk areas. Alternatives to technologies in these high-risk areas are summarized.
Conclusions
It is concluded that although linear extrapolation predicts that the outlined missions should be feasible

with development of current technology, bottlenecks may arise in areas of high risk. It is highlighted that testing of high-risk components in intended environments is essential for lowering the AD2 levels. Moreover, cross-sectoral collaboration and cross-pollination between different types of space sails as well as other technologies is highlighted as a key to finding alternatives to high-risk technologies.
**Authors:** Debdut Sengupta (Imperial College London), Maximilien Berthet (University of Tokyo), Onur Çelik (Delft University of Technology), Andreas M Hein (University of Luxembourg), Ken Fujino (University of Tokyo), Koki Tanaka (University of Tokyo)
**Presenter:** Debdut Sengupta
**Oral Presentation**
**Topics**
* Advanced Materials
* Autonomous Spacecrafts
* Communications
* Miniaturisation and Technology Development
* Potential Destinations and Astrophysics
* Power Systems
* Propulsion

*Submission #29: Interstellar communications among future human colonies*
This study evaluates the feasibility and crucial importance of establishing interstellar communication among future human colonies dispersed across approximately 60 stellar systems, using an approach based on numerical calculation. We specifically focus on the reciprocal exchanges of communications, employing gravitational lensing to amplify signals across vast distances. We assess several critical parameters necessary for effective communication, including antenna gain, signal-to-noise ratio (SNR), bit error rate (BER), and channel capacity at both microwave and optical frequencies. Additionally, we examine the challenges posed by stellar corona noise.
Our analysis includes a comprehensive exploration of different communication configurations. We conclude that dual gravitational lenses offer the most effective strategy for microwave transmissions, providing optimal signal amplification. For optical transmissions, the effectiveness of using two gravitational lenses is comparable to that of a single lens.
Furthermore, we have evaluated potential data compression algorithms suitable for these long-range communications to optimize bandwidth and reduce transmission times.
To add a practical dimension to our theoretical study, we analyze and derive the optimal sequence of stellar colonization, which could guide future expansion strategies.
Our findings highlight the significant advantages of advanced gravitational lensing-based communication systems in maintaining a shared culture, ensuring technological progress, and fostering mutual enrichment between Earth and its interstellar colonies. Despite the inevitable time delays and potential for cultural divergence over huge distances, these communication strategies hold the promise of keeping both civilizations connected and advancing in unison.
**Authors:** Nicolò Antonietti, PhD (INAF), Claudio Maccone, PhD (IAA), Luca Derosa, PhD (iMEX.A), MEng Domenico Caliendo (iMEX.A)
**Presenter:** Nicolò Antonietti, PhD
Oral Presentation
**Topic**
* Communications

*Submission #31: Interstellar Precursor Missions with Advanced FEEP Ion Thrusters*

One of the most challenging technologies needed to make interstellar precursor missions practicable is the propulsion system. Several "breakthrough propulsion" concepts have been proposed, but no conclusive results offering a near-term solution to the problem have so far emerged. It is therefore realistic to assume that such solutions, if any, are probably decades away from implementation. It is thus prudent to consider outer-solar system missions employing extensions of existing technologies.

A key propulsion parameter to enable interstellar precursor exploration is the specific impulse; in order to reduce the propellant mass, and consequently the spacecraft mass, to reasonable values, the specific impulse must be much higher than the maximum specific impulse presently achieved by the most efficient ion thrusters.

Field Emission Electric Propulsion (FEEP) offers several unique features: very high specific impulse (> 7,000 s), the most efficient way of carrying propellant (namely in solid state as Indium melts at ~ 157°C), very low thermal losses as the emitter electrode is kept just above 157°C.

Over the past two decades, Fotec GmbH and Enpulsion GmbH have developed and refined FEEP technology based on porous tungsten emitter crowns, elevating it to a well-established space propulsion solution. More than 150 thrusters have been successfully deployed and are currently operational in space. Ground tests have demonstrated that these thrusters can operate for over 50,000 hours with minimal performance degradation. This remarkable lifetime is a critical attribute for the success of interstellar precursor missions.

Recent advancements have led to the successful fabrication and operation of a 2D array of emission points with a single extractor. This achievement is an important stepping stone towards the feasibility of the concept proposed in our previous work (Genovese et al, JBIS, 68, 2015), paving the way for the development of advanced FEEP ion thrusters with high thrust density and ultra-high specific impulse as high as 30,000s.

Furthermore, a short-term interstellar precursor mission based on the present FEEP technology is proposed. Finally, a more challenging mid-term mission could be enabled by the advanced FEEP concept described in this work.

**Authors:** Nembo Buldrini (FOTEC Forschungs- und Technologietransfer GmbH, Viktor Kaplan-Strasse, Wiener Neustadt, 2700 Austria), Angelo Genovese (Initiative for Interstellar Studies i4is Germany)
**Presenters:** Nembo Buldrini, Angelo Genovese

Oral Presentation

**Topic**

* Propulsion

*Submission #32: Deployment strategies for 3D interstellar solar sails*

In order to send solar sails beyond the outer solar system, significant improvements regarding the sail velocity must be achieved. To improve the velocity, the total spacecraft mass needs to be reduced. A first step is to implement aerographite (density of 0.18 kg m^-3), a new type of sail material, proposed by Heller in 2020. The next step would be to improve the deployment system. Until now, conventional motor driven metal booms unfold the sails. By removing the booms and motors, the velocity improves. Without the stabilizing booms the sail collapses under the photon pressure in the close vicinity of the sun (preceding simulations). Yet, a low solar orbit is necessary for maximum sail performance. Therefore, an alternative stabilizing strategy is required.

First, the sail will not have a conventional two-dimensional shape, but rather a three-dimensional rotational body shape. This gives the sail a self-stabilizing geometry under the influence of solar radiation and wind. The shapes can be eg semi-spheres, cone-like, funnel- or horn-like. These shapes are to be tested initially in a smaller scale in a vacuum, whilst being irradiated by a solar simulator and being exposed to a neutral plasma stream to simulate the solar wind.

Secondly, alternative deployment mechanisms are required to unfold the sail and stabilize it. So far, we investigate the use of shape memory alloys (SMA), embedded in the sail material, as well as the integration of unipolar electrets to use the Coulomb forces between them for unfolding. The SMA can be activated either passively by solar radiation or actively by Joule-heating. We test multiple methods to embed the SMA, eg weaving the SMA into the material. Furthermore, by using infrared radiation heating under vacuum conditions, the passive deployment can be tested. The active deployment can be tested by applying a voltage to the SMA. The electrets are produced by shielding free charges on a metal core with a dielectric sheath against the environment. This process is validated by measuring the surface potential of the electret.
Future strategies will include the investigation of the interaction between the aerographite and the space environment.
**Authors:** Julius Karlapp (Dresden University of Technology), Martin Tajmar (Dresden University of Technology)
**Presenters:** Julius Karlapp, Martin Tajmar
Poster
**Topics**
* Advanced Materials
* Propulsion

*Submission #33: Interstellar Precursor Missions by Combining Laser-Powered Electric Propulsion with an Oberth Maneuver*
Interstellar precursor missions require advanced propulsion systems with very high specific impulses in order to reduce the propellant mass to acceptable values and consequently being able to reach the high delta-v needed. Electric propulsion technology can be scaled up to very high specific impulses (Isp » 5.000s). However the power needed for the same thrust is also increasing together with the mass of the power source, which puts a limit to the maximum delta-v achievable with a certain Isp.
A breakthrough in power source specific mass is needed in order to enable missions with very high Isp (< 1 kg/kW); this breakthrough could be realized having the power source not on-board, as with Laser-powered Electric Propulsion (LEP), where the needed power is beamed to the spacecraft from an external laser source. In this case the on-board power source is limited to a light-weight photovoltaic receiver/converter. However, the laser source must be very large in order to accelerate the spacecraft long enough to reach the needed final speed, as the laser spot size on the spacecraft is inversely proportional to the laser aperture and directly proportional to the increasing distance.
In order to avoid laser sources with a km-size aperture, the laser-powered spacecraft acceleration could be imparted during a close sun powered fly-by by a relatively small laser array placed near the sun. Furthermore, this mission architecture would take advantage of the so-called Oberth-effect, as adding $\Delta v$ within the sun's gravitational well increases the gain in final spacecraft kinetic energy.
This paper gives an assessment on the feasibility of the described propulsion architecture and proposes a preliminary design for an interstellar precursor mission.
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**Presenter:** Angelo Genovese
Oral Presentation
**Topic**
* Propulsion

*Submission #34: Biological and mechanical reproduction strategies for interstellar exploration and settlement*

Crewed interstellar flight requires bioregenerative life support for several reasons. The limited resources that can be brought on board at departure make continuous recycling imperative. To maintain the crew's health, a diet that includes at least some fresh food is indispensable. Biological organisms, being regenerative by nature, can be easily regrown in case of failure, unlike mechanical systems that depend on spare parts and repairs. A major key to the success of bioregenerative life support is effective in situ biological reproduction (ISBR). Organisms must properly reproduce in space conditions to sustain the functionality of the entire bioregenerative system. It can be argued that technological self-reproduction is another imperative for interstellar flight. Because of the limited knowledge of the interstellar medium and its long-term impact on terrestrial biology and technology, interstellar flight is highly uncertain. This uncertainty calls for an adaptable, self-organizing spacecraft architecture that can dynamically respond to unforeseen challenges.

The Evolving Asteroid Starships (E|A|S) project is a theoretical study exploring the gradual transformation of an asteroid into an interstellar craft using asteroid mining and in-space manufacturing, facilitated by swarm robotics with self-replicating capabilities. This project addresses the challenges of bioregenerative life support and self-organizing spacecraft architecture through a complex adaptive systems approach and computer modelling. Two models have been developed: an agent-based model (ABM) for the bioregenerative life support system and a discrete event simulation (DEVS) for the self-organizing spacecraft architecture. These models allow for the investigation of long-term system behavior and the testing of different space travel scenarios. Both systems exhibit chaotic behavior, where small differences in stochastic parameters, such as bioreactor efficiencies or module lifetimes, lead to divergent outcomes. The challenge is to design strategies that can mitigate potential catastrophic deviations by eg, integrating redundancies and applying distributed decision-making. Such strategies can help to maintain system stability, avoid chaotic attractors, and support multigenerational growth.

**Authors:** Angelo Vermeulen (Delft University of Technology), Arpi Derm (SEADS), Alvaro Papic, Igor Nikolic (Delft University of Technology), Frances Brazier (Delft University of Technology)

**Presenter:** Angelo Vermeulen

Oral Presentation

**Topics**

* Autonomous Spacecrafts
* Life Support Systems and Habitats

*Submission #39: Pentagonal Photonic Crystal Mirrors: Scalable Lightsails with Enhanced Acceleration via Neural Topology Optimization*

The Starshot Breakthrough Initiative aims to send one-gram microchip probes to Alpha Centauri within 20 years, using gram-scale lightsails propelled by laser-based radiation pressure, reaching velocities nearing a fifth of light speed. This mission requires lightsail materials that challenge the fundamentals of nanotechnology, requiring innovations in optics, material science and structural engineering. Unlike the microchip payload, which must be minimized in every dimension, such lightsails need meter-scale dimensions with nanoscale thickness and billions of nanoscale holes to enhance reflectivity and reduce mass.

Our study employs neural topology optimization, revealing a novel pentagonal lattice-based photonic crystal (PhC) reflector. The optimized designs shorten acceleration times, therefore lowering launch costs significantly. Crucially, these designs also enable lightsail material fabrication with orders-of-magnitude reduction in costs.

We have fabricated a 60 x60 mm2, 200 nm thick, single-layer reflector perforated with over a billion nanoscale features; the highest aspect-ratio nanophotonic element to date. We achieve this with nearly 9,000 times cost reduction per m2. Starshot lightsails will have several stringent requirements but will ultimately be driven by costs to build at scale. Here we highlight challenges and possible solutions in developing lightsail materials - showcasing the potential of scaling nanophotonics for cost-effective next-generation space exploration.
**Authors:** L Norder (Delft University of Technology), S Yin (Brown University), MHJ de Jong (Delft University of Technology), H Aydogmus (Delft University of Technology), F Stallone (Delft University of Technology), PM Sberna (Delft University of Technology), MA Bessa (Brown University), RA Norte (Delft University of Technology)
**Presenter:** L Norder
**Oral Presentation**
**Topics**
* Advanced Materials
* Miniaturisation and Technology Development
* Propulsion

*Submission #40: Towards optical levitation of centimeter scale photonic crystal lightsails*
The quest for interstellar travel presents one of the most formidable challenges in modern science and engineering, primarily due to the need for propulsion systems capable of achieving relativistic speeds. Traditional chemical and nuclear propulsion methods are inadequate for these requirements, prompting exploration into alternative technologies such as laser propulsion. This approach leverages photon pressure to accelerate spacecraft to significant fractions of the speed of light, necessitating the development of ultra-lightweight, highly reflective structures. Due to required radiation pressure, achieving levitation at macro scale poses important challenges in the fields of optomechanics and nanofabrication, as these structures have to be optimized both for their mass and optical properties, generally resulting in designs with extreme aspect ratios with almost perfect reflectivity.
Here, we demonstrate our initial results and roadmap for achieving macroscopic scale optical levitation as a critical step towards the realization of laser-propelled spacecraft for interstellar travel. The focus is on the development, optimization and characterization of high aspect ratio photonic crystal membranes designed for stability and efficiency under high-intensity laser illumination.
Using cutting-edge nanofabrication techniques, we fabricate SiN photonic crystal lightsail membranes with extreme aspect ratios (1 cm/200 nm) optimized via neural network algorithms. Our novel fabrication-measurement scheme ensures these membranes are released and measured within an Inductively Coupled Plasma - Reactive Ion Etching (ICP-RIE) system, avoiding exposure to atmospheric pressure and external forces that could compromise their integrity. The photonic crystal lightsail membranes are subsequently subjected to continuous strong radiation pressure (400 W - 1,070 nm) to assess their mechanical integrity and dynamic stability.
We present our progress on achieving and characterizing the macroscale optical levitation and share our future plans with the goal of demonstrating the feasibility of stable levitation of macroscopic structures using a single laser, paving the path for this previously unexplored regime of optomechanics. These results will be essential for realizing the dream of interstellar travel, providing a feasible pathway to propel spacecraft beyond our solar system within human lifetimes.
**Authors:** Ata Keşkekler (TU Delft), Lucas Norder (TU Delft), Richard Norte (TU Delft)
**Presenter:** Ata Keşkekler
Poster
**Topics**
* Advanced Materials
* Autonomous Spacecrafts
* Miniaturisation and Technology Development
* Propulsion

*Submission #41: Should Military Issues be Incorporated in Interstellar Missions?*
Is there a need to think about military issues in relation to interstellar travel? I argue yes, based on a couple of primary lines of historical and current research.
First, all indications we have are that the universe is a 'life form eat life form' place. Predator-prey relations exist not just in the natural world but also in the realm of state politics. It is not just about resources either, conflict can and does arise over ego, fear, markets and many other reasons. The net is that based on our one-planet dataset, war is ubiquitous and thus countries must defend themselves (in some way or another).
Closely related to existential competitiveness is the question of an extraterrestrial's disposition. We have zero evidence that more advanced civilizations will be peaceful or benign. For that matter researchers also frequently assume monolithic ETs that speak and act with one voice, again without evidence. This implies that there could be a lack of civilizational agreement on how to treat humanity if encountered.
Second, there is no such thing as an unarmed interstellar-capable ship. At a minimum, from sheer kinetic energy, to main drive systems to electromagnetic communication systems powerful enough to work over interstellar distances, a starship can be a weapon. The unintentional mis-use of these systems or the energy of a starship might be interpreted as hostile acts. Avoiding these situations must be a paramount part of any mission.
For reasons cited it would thus be negligent not to think, plan for and incorporate some level of military practice into any interstellar ships including not just human or AI-crewed ships, but microprobes as well.
**Author:** Ken Wisian (University of Texas at Austin)
**Presenter:** Ken Wisian
**Oral Presentation**
**Topics**
* Autonomous Spacecrafts
* Ethics
* Space Law

*Submission #42: Optimal Solar Sail Trajectories for Fast Deep Space Missions*
Solar sail missions hold considerable promise for expeditions to the outer reaches of the solar system and interstellar travel due to their propellantless character. One approach to achieving high velocities involves utilizing a solar flyby (gravity and photonic assist) to accelerate the sail away from the solar system. Recent attention has focused on aerographene, an ultra-lightweight material with a density of 0.16 kg/m3, offering significantly improved performance potential compared to conventional materials like mylar or kapton. However, aerographene's complete absorptive nature poses challenges for controllability of the sail, eg the ability to arbitrarily change its trajectory.
In this study, we propose an optimal control approach to find a trajectory maximizing the excess velocity of a solar sail towards the farthest regions of the solar system, leveraging a solar flyby. We address the challenge of temperature constraints, crucial for preventing material degradation near the Sun. This involves incorporating constraints on both the state variable (distance from the Sun) and control variable (orientation of the sail) to manage surface temperature fluctuations. Specifically, while proximity to the Sun may be necessary for gravitational and photonic assists, it also risks excessive heating, necessitating adjustments to sail orientation to mitigate temperature effects.
To solve this optimal control problem with combined constraints, we employ a multiple shooting method with a constrained arc. We derive optimality conditions using Pontryagin's principle and analyse the Hamiltonian dynamics to formulate an optimal control problem tailored to ideal, ie perfectly reflective, solar sails.
Furthermore, continuation techniques are employed to assess the impact of degraded sail performance (with a less reflectivity coefficient) on trajectory variations. This exploration aims to determine the feasibility of interstellar missions solely with aerographene sails.
This comprehensive study offers insights into optimizing solar sail trajectories, addressing key challenges for ambitious deep space exploration missions. By integrating theoretical analysis, numerical simulations, and innovative design concepts, we advance our understanding of solar sail dynamics, laying the groundwork for future interstellar exploration endeavours.

**Authors:** Alesia Herasimenka (University of Luxembourg), Lamberto Dell'Elce (Centre Inria de l'Université Côte d'Azur), Andreas Hein (University of Luxembourg)
**Presenter:** Alesia HERASIMENKA
**Oral Presentation**
**Topics**
* Advanced Materials
* Propulsion

*Submission #43: Astrosociological design of protocols for encounters with extraterrestrial life*
Background
The paper attempts to lay the ground work for safe and trustworthy encounters with alien civilisations through simple protocols that AIs are trained to execute and offers three new 'laws of robotics' derived from them with which to inculcate artificial sentience and replace other efforts in that direction, for example, the notorious three laws of robotics first suggested by the fiction writer Isaac Asimov.
Objective
The paper considers how a sociobiologically determined set of bioethics can be fashioned into a set of universal protocols with which encounters with extraterrestrial life may be managed. These protocols will be simplified into an alphanumeric formula to capture the essential levels of trust for useful communications and suggest how the incorporation of AI into communications will overcome the prejudices likely to be present in exchanges with ETIs and to provide a basis for expecting an alien counterparty to possess similar ethical protocols to generate trust.
Methods
It examines three bioethics and within each considers a hierarchy of dynamical trust parameters. The three bioethical principles are derived from the concept of strangeness in the visual cognitive dimension to inclusive fitness, from environmental logic and from an initial neutral communication protocol designed to avoid revealing too much about Humanity. A simple alphanumeric code is generated to annotate the degree of trust present in an encounter with an ETI. From a hierarchy of trust levels it can be shown how interactions may proceed for Humans during encounters with all life, microbial or intelligent, organic or artificial.
Results
With the trust levels within the three bioethics the necessity for a deceitful presentation of Human nature becomes clear.  An agnostic protocol of first interaction is derived in which generative language text models can replace other mathematical and logical astrolinguistic proposals for extra terrestrial communications like LINCOS and can be applied to communication even under potential risks in untrustworthy alien encounters.
Conclusions
Communication with ETIs must begin with a known level of deceit in order to build trust.  Developing common mathematical or science languages will be the least productive way of communicating with ETIs.
**Authors:** Andrew Kennedy (Project Chronolith), Stella Grania Kennedy Kennedy-Whitaker (none)
**Presenter:** Andrew Kennedy
**Oral Presentation**
**Topics**
* Communications
* Ethics

*Submission #45: The use of Textiles as a processing form for space applications*
Since the dawn of human history, we have sought a fundamental necessity for survival: the hut or the cave as a form of protection. This fundamental aspect of human existence has remained constant throughout history, but the way we think about living has evolved. The resumption of space travel, has made the prospect of living in space become a tangible possibility, revolutionizing the way we think of life. If the house meets the needs of the occupants on Earth the habitat does so in space. This challenge addresses various factors that must be considered when building in an extreme environment. This factor represents a significant challenge for the selection of materials that are optimal for use in space. The use of in situ materials will be a necessity for the construction of habitats on a planetary surface, given that regolith is the most abundant material on it but it is also necessary to consider the use of textiles.
The behaviour of the textile as a form of processing will provide a variety of solutions to the space challenges. One example is the possibility of creating moon fibre from regolith, which could be used as a building material in future lunar bases. The selection of materials for use in space is a crucial decision, but equally important is the manner in which these materials are employed. The choice may fall upon hard or solid structures or alternatively, flexible or mouldable materials. The choice of the most suitable solution is contingent upon the specific applications or requirements, which may include the facilitation of communication, the transport, the production of components, or the construction of habitats. For this ongoing research, a series of experiments will be conducted to assess the applicability of different textiles for the use of outer space habitats.
This approach will lead to a more comprehensive understanding of the potential for construction in space. Whether used alone, in combination with other materials such as regolith or as a form of processing textiles offer a multitude of properties that are essential for a space-based operations.
**Authors:** 1. MSc Linda Cortes Satizabal (Institut für Textiltechnik der RWTH Aachen University), Dr.-Ing. Kira Heins (Institut für Textiltechnik der RWTH Aachen University), Dr.-Ing. Christian Boltersdorf (Institut für Textiltechnik der RWTH Aachen University), Univ.-Prof. Prof hc Dr-Ing Dipl.-Wirt.-Ing. Thomas Gries (Institut für Textiltechnik der RWTH Aachen University)
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Poster
**Topics**
* Advanced Materials
* Life Support Systems and Habitats
Special Session

*Submission #47: Project Hyperion: Systems Architecting of an Interstellar Generation Ship*
Background
Project Hyperion is a conceptual study of a hypothetical interstellar generation ship. Since 2023, the Hyperion team has been working on organizing an interdisciplinary design competition on the habitat of the generation ship. Design competitions have proven to be an effective means of generating a variety of designs to explore a novel design space. The highly interdisciplinary nature of generation ship habitats, spanning architecture, engineering, and social sciences makes it a particularly challenging design problem.
Objective
This talk presents the system architecting process to define the Project Hyperion competition, which includes the steps of defining the context, system boundaries, system and sub-system-level requirements and constraints.
Methods
We use concepts from architecture (functional spaces), social sciences (cultural invariants), and engineering (habitat geometries, bioregenerative life support systems) to combine them into an integrated socio-technical framework, where the focus is on the interdependencies between the features of the habitat and the society's structure.

Results
We present the first results from the competition and where the designs are situated in the design space. Designs with unusual positioning are also presented.
Conclusions
We conclude that an iterative approach to define competitions and an analysis of the resulting designs may efficiently steer the process of converging towards a baseline architecture for a generation ship habitat.
**Authors:** Andreas M Hein (Initiative for Interstellar Studies), Yazgi Demirbas Pech (Initiative for Interstellar Studies), Cameron Smith (University of Arizona), Dan Fries (Initiative for Interstellar Studies), Claas Olthoff (University of Stuttgart), Steve Summerford, Maciej Rebisz (Independent)
**Presenter:** Andreas M Hein
**Oral Presentation**
**Topics**
* Life Support Systems and Habitats
* Miniaturisation and Technology Development
* Psychology, Anthropology and Crew Health

*Submission #48: Project Lyra: Opening up the space between the stars - Missions to Interstellar Objects and Nomadic Worlds*
Background
It is frequently believed that the space between the stars is empty. The interstellar community is firmly grounded in this belief and is predominantly focused on missions to other star systems. Today, we know that the space between the stars is not empty but is populated by a plethora of objects. While interstellar dust has been known for many decades, more recently, larger objects have been discovered, such as interstellar objects and nomadic worlds.
Objective
We present a variety of mission architectures to interstellar objects and nomadic worlds and thereby explore propulsion technology – trip time limits over a variety of distance requirements.
Methods
We use the Optimum Interplanetary Trajectory Software (OITS) to find optimal trajectories for various interstellar objects alone. Furthermore, we use Technology Readiness Levels (TRL) for comparing propulsion system performance with maturity.
Results
We find that chemical propulsion in combination with a solar Oberth manoeuvre and/or flybys (in particular the Passive Jupiter Gravity Assist (PJGA)) reaches its limits at a distance of roughly 500 AU, if the maximum trip time is set at about 80 years. For reaching nomadic worlds, which may have average distances of 10^3 to 10^4 AU, precursor versions of interstellar-capable propulsion systems are needed, such as laser sails and fusion propulsion.
Conclusions
We conclude that existing propulsion systems, combined with flyby maneuvers are viable for reaching interstellar objects up to hundreds of AU distance, which is in a similar range as the putative Planet Nine. However, nomadic worlds (hundreds of km in diameter) are likely only reachable via interstellar-capable propulsion systems. The presented results have important implications for future propulsion system roadmaps, which should also focus on the development of interstellar-capable propulsion systems.
**Authors:** Andreas M Hein (Initiative for Interstellar Studies), Adam Hibberd (Initiative for Interstellar Studies), Manasvi Lingam (Florida Institute of Technology), Marshall Eubanks (Space Initiatives), Dan Fries (Initiative for Interstellar Studies), Robert Kennedy (Institute for Interstellar Studies), Jean Schneider (Paris Observatory)

**Presenter:** Andreas M Hein
**Oral Presentation**
**Topics**
* Miniaturisation and Technology Development
* Potential Destinations and Astrophysics
* Power Systems
* Propulsion
Special Session

*Submission #50: Integrating Interstellar Research and STEM Education: Pioneering the Future of Space Travel*
Background
The Limitless Space Institute (LSI) is at the forefront of pioneering advancements in interstellar research and education. Through the funding of groundbreaking research through the LSI Grants and Fellowship program, significant advancements have been made in the power and propulsion of spacecraft, and our comprehensive STEM education and outreach programs, we are committed to inspiring and educating the next generation of explorers and the workforce that will establish our home among the stars.
Objective
Our primary objective is to present the latest advancements in interstellar research funded by LSI and to showcase our robust STEM education initiatives. We aim to illustrate how integrating interstellar concepts into classrooms worldwide can inspire and educate the future workforce necessary for achieving interstellar travel. By participating in the European Interstellar Symposium, we seek to highlight the importance of early exposure to interstellar travel concepts to foster a generation capable of realizing these ambitious goals.
Methods
Research Initiatives:
• Target Population: Research teams and institutions focused on interstellar travel.
• Program Content: Funding and support for innovative research projects, including theoretical and experimental approaches to propulsion, power generation, and autonomous systems.
• Evaluation Method: Regular progress reviews, peer-reviewed publications, and collaborative workshops to assess the impact and feasibility of the research.
STEM Education and Outreach:
• Target Population: Global citizens passionate about inspiring the next generation of explorers who will "go incredibly fast".
• Program Content: Development of curriculum and educational materials that integrate interstellar travel concepts, hands-on activities, virtual experiences and in person trainings both in the host country and Houston, Texas.
• Evaluation Method: Surveys, feedback forms, and performance metrics from participating schools and educational institutions to measure engagement and learning outcomes.
Results
Through the LSI Grants and Fellowship program, funded research around the world has yielded significant advancements in spacecraft power and propulsion technologies. Our support on the educational front, our programs have reached thousands of students globally, igniting interest in STEM fields and providing them with a foundational understanding of interstellar travel. Feedback from educators indicates a high level of engagement and enthusiasm among students, with many expressing a newfound interest in pursuing careers in space exploration and related fields.

Conclusions
The findings from our research and educational initiatives demonstrate the vital role of early exposure to interstellar concepts in inspiring the next generation. Integrating these concepts into K-12 education not only fosters a deeper interest in STEM but also prepares a skilled workforce capable of tackling the challenges of interstellar travel. Our participation in the European Interstellar Symposium aims to further these efforts by fostering collaboration and knowledge exchange among the multi-disciplinary community dedicated to building our home among the stars.
By bridging the gap between current research and education, the Limitless Space Institute is paving the way for a future where interstellar travel is not just a dream but a reality.
**Author:** Kaci Heins (Limitless Space Institute)
**Presenter:** Kaci Heins, Executive Director
Oral Presentation
**Topic**
* Propulsion

*Submission #56: Interstellar Astrometric Navigation*
Background
Interstellar spacecraft need to know their position and velocity at various points in their mission in order to make course corrections, and to switch on/off propulsion, instruments, or communications. Given their large distances from Earth, spacecraft must be able to navigate autonomously.
Objective
I develop a model to determine the 3D position and 3D velocity of a spacecraft using measurements of the angular separations of stars.
Methods
The Gaia survey has provided accurate stellar positions and velocities relative to the solar system barycentre (SSB). A spacecraft at some other arbitrary position and velocity can observe the same stars, but at different angular positions due to parallax, aberration, and proper motion. This can be inverted: By measuring the relative angular positions of the stars, the 3D position and 3D velocity of the spacecraft relative to the SSB can be inferred, here using a Monte Carlo approach. The model requires measurements of only the angular separations between pairs of stars (no absolute measurements), as done historically with a sextant. The model takes into account special relativity and light travel time. An accurate onboard clock is not required as the approximate SSB time is also inferred. Stellar radial velocity measurements may be used in addition or instead to achieve similar results. I demonstrate the performance using simulated spacecraft data together with real astrometric data.
Results
Using 20 bright, nearby stars and assuming an angular measurement accuracy of 10 mas (milliarcseconds), the position of a spacecraft can be determined to within 0.03 au and its velocity to 20 m/s.
The accuracy improves linearly with the accuracy of the angular separation measurements. Increasing the number of stars or taking multiple measurements over time improves the determination further.
Conclusions
While not as accurate as pulsar navigation in the solar vicinity, the astrometric method works in deep space many parsecs from the Sun, where pulsar navigation would also have to accommodate parallaxes. Astrometric navigation can also be used for initialization, combined with pulsar navigation, or used as a backup system.
This work builds on that published by the author in [PASP 133:074502 (2021)](https://iopscience.iop.org/article/10.1088/1538-3873/ac0774).

**Author:** Coryn Bailer-Jones (Max Planck Institute for Astronomy)
**Presenter:** Coryn Bailer-Jones
**Oral Presentation**
**Topics**
* Autonomous Spacecrafts
* Miniaturisation and Technology Development

*Submission #57: Macro-Environmental and Technology Readiness Assessment for Interstellar Travel Infrastructure*

Background

Habitats on Earth are part of a larger macroenvironment that provides infrastructure, supplies, and services, alongside the microenvironment within each habitat. When designing for human space travel, all macro and micro aspects are considered. Deep space design includes everything from the transportation to the buildings, devices, and breathable air. Therefore, the concept of the macroenvironment includes infrastructure systems beyond individual mission requirement. Given the limited human space travel experience, further ventures into space require increased involvement. What does an infrastructure plan on the Moon look like, and how does that compare to supporting deeper missions in the solar system and interstellar travel? Answering such questions aids in designing for extended space travel and envisioning long-term infrastructure and maintenance strategies.

Objective

This paper outlines and assess the (i) main survival and functional elements needed for sustainable space travel across various destinations and mission types, from cislunar to interstellar, (ii) quantities and interconnected requirements, (iii) the technology status, and (iv) the anticipated timeline for achieving the technology readiness.

Methods

The tables and matrices present basic elements including space and terrain routes, energy systems, and supplies like food, water, and gases, comparing their use for single missions versus their role as infrastructure for multi-missions. The assessment charts the requirements and technology readiness for cislunar, planetary, and interstellar trips. The evaluation involves referencing previous studies related to the sequence and technological requirements for both achieved and anticipated travel such as ISP and Road Map to the Stars. Additionally recent documented advancements in space travel since 2015 are used for comparison and to project the future pace of space exploration utilizing aggregated design items such as Starship Gliina System.

Results & Conclusion

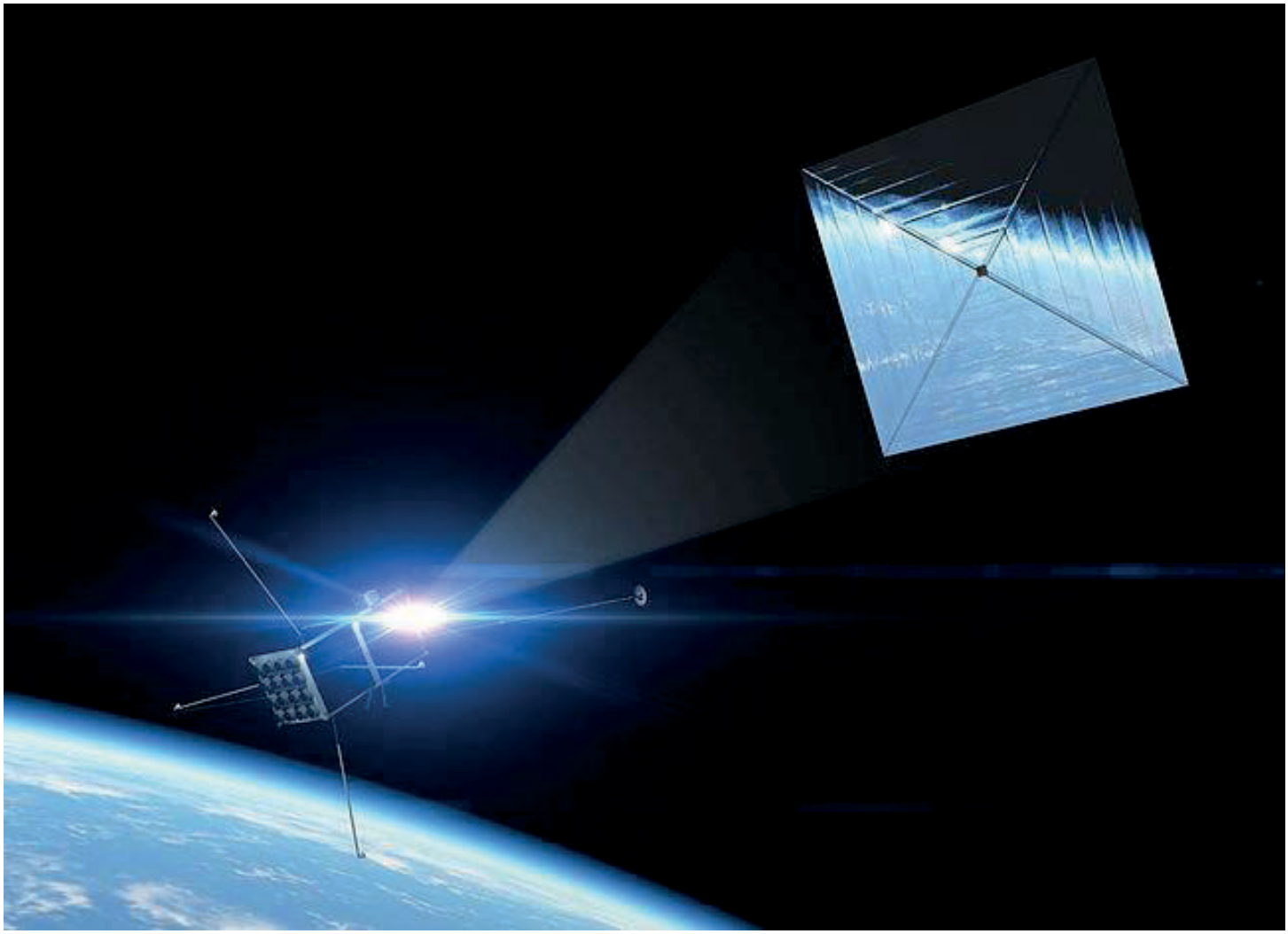
In extended space travel, the complexity of designing macroenvironmental and infrastructural requirements grows significantly. The assessment of the components' requirements shows an exponential increase in magnitude as travel distances and intervals expand. That aligns with the trajectory of technological readiness capability timelines. Such realistic guidelines enhance the design of infrastructure and maintenance components, improving resilience, longevity, maintainability, and maintenance protocols while decreasing the burden of involving several macroenvironment elements in each mission.

**Author:** Antoine G Faddoul (Tony Sky Designs Group)
**Presenter:** Antoine G Faddoul
Oral Presentation
**Topic**
* Life Support Systems and Habitats

# 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, February, March and April 2024 have appeared since the report in our last issue. P46. The April issue is in print but not yet online. The entries below are scanned from the print issue.

| **JBIS VOLUME 77 #4 APRIL 2024 Interstellar Issue** | | |
|---|---|---|
| **Faster-than-Light Travel from Dark Energy Inflation** | **J A Morgan** | **USA** |
| The mass-energy content of the present-day universe is dominated by an exotic component known as dark energy. In its earliest stages, a similar dominant component drove the exponential growth of cosmological inflation. This note explores how a sufficiently advanced civilisation might manipulate dark energy for faster that-light travel. An exact solution of the Einstein gravitational field equations that experiences highly anisotropic inflation serves as a toy model to illustrate the principles. A sample calculation exhibits highly superluminal motion while imposing negligible stress on a spacecraft hull. | | |

| **JBIS VOLUME 77 #4 APRIL 2024 Interstellar Issue** | | |
|---|---|---|
| **Frank Drake is Alive! (Rethinking the Drake Equation For the Search For Biological Life)** | **Elio Quiroga Rodriguez** | **Universidad del Atlantico Medio, Spain** |
| In 1961, astronomer Frank Drake formulated the Drake Equation as a cornerstone for scientific discourse regarding the prevalence of communicative extraterrestrial civilizations within the Milky Way galaxy. This equation, often referred to as the "Classic Drake Equation' outlines the key factors influencing the number of potential civilizations with which we might establish communication. This article submerges into the Drake Equation and proposes a simplified version focused on the broader detection of extraterrestrial non-intelligent life. The established terms of the equation, such as the rate of stellar formation, the fraction of stars harboring planetary systems, and the probability of such systems containing habitable planets, are re-examined and discussed. Additionally, a re-evaluation of other factors is presented. Based on this revised framework, various scenarios are explored. As our technological capabilities continue to advance, the detection of biosignatures on exoplanets (incorporated into the suggested new version of the equation) is anticipated to offer insights into the search for life beyond Earth. | | |

| JBIS VOLUME 77 #4 APRIL 2024 Interstellar Issue | | |
|---|---|---|
| **Inertial Confinement Fusion Propulsion for the Massive Ra World Ship Model — Part 2** | **Kelvin F Long** | **Interstellar Research Centre, UK** |
| A strategy for sending humans around other stars will be to acquire the ability to construct large World Ships which are of order ~$10^{11}$-$10^{12}$ tons in mass, ~100 km in length and host large populations of millions of people over many generations of lifetime. This paper presents such a concept but driven by inertial confinement fusion engines utilising very large pellets of order 230 g in mass augmented with 4.85 kg/pellet of expellant propellant for increased mass flow rate and thrust generation. A mission architecture is constructed for a 1 million population carrying capacity growing to 10 million, based on an original 1984 published model which achieved a cruise speed of 1,500 km/s or 0.5% c for a 1,000 year trip time. Calculations show that propulsion of such a vast construction will require hundreds of engines operating in parallel thrust mode and at moderately high pulse frequency for an elongated burn time of order half a century. The purpose of this study was to examine whether it was possible to drive an interstellar world ship using ICF engines using similar assumptions to a 1984 study for a Mk2A design. The conclusion of this study is that although an architecture does appear to be possible, there are practical reasons why it may be better to pursue alternative propulsion methods for this specific application such as via external nuclear pulse propulsion as adopted for the original studies. This paper is a follow-up to an earlier one which discussed some of the assumptions of the study. | | |

## Acta Astronautica

Acta Astronautica papers are published online before print. These issues with relevant papers have appeared since our last issue, Principium P46.

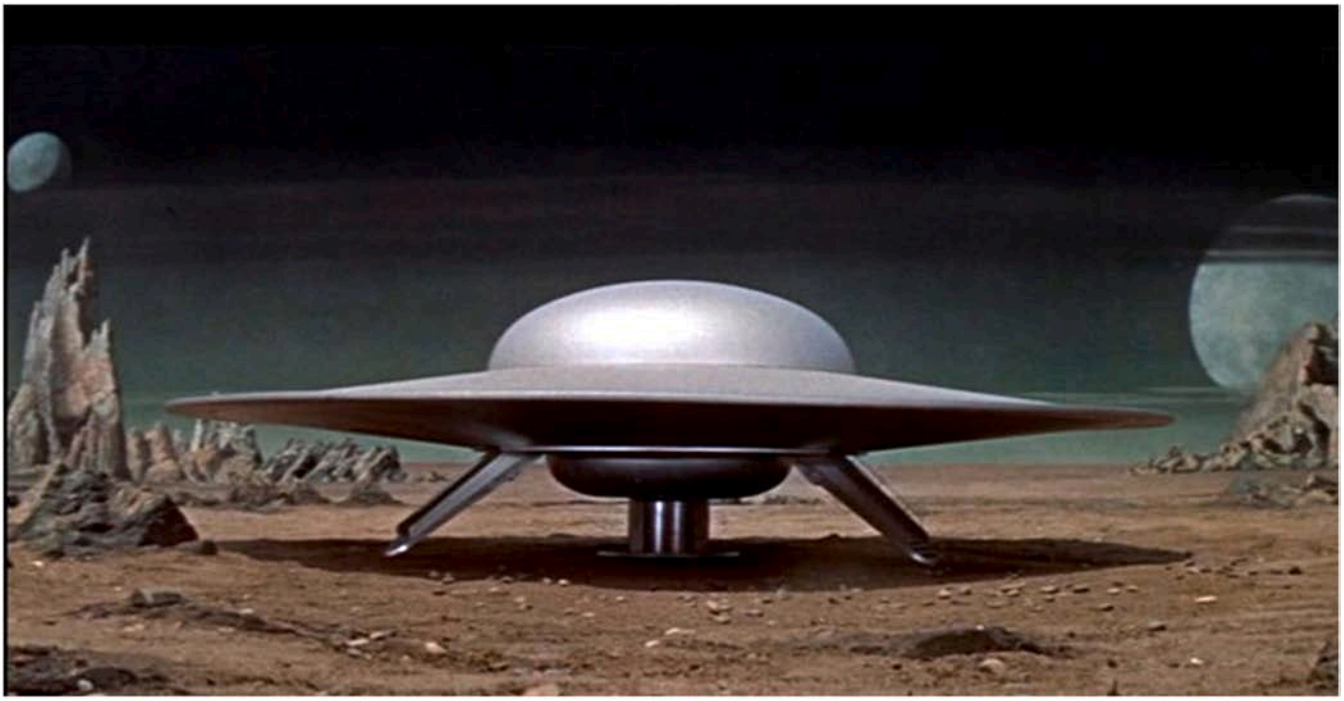
| **SETI in 2022** | **Volume 225 December 2024** | **Jason T Wright et al** |
|---|---|---|
| In this third installment of SETI in 20xx, we very briefly and subjectively review developments in SETI in 2022. Our primary focus is 80 papers and books published or made public in 2022, which we sort into six broad categories: results from actual searches, new search methods and instrumentation, target and frequency selection, the development of technosignatures, theory of ETIs, and social aspects of SETI. | | |

| **Bremsstrahlung power conversion for fusion power and propulsion in space** | **Volume 220 July 2024** | **Thomas Bone, Raymond Sedwick** |
|---|---|---|
| Centrifugally confined Direct Fusion Drive propulsion has the capability of greatly advancing humanity's ability to traverse and explore the solar system. p-11B is a promising fusion fuel to use in such a system because the reaction is aneutronic. However, a large amount of bremsstrahlung radiation is produced and must be converted into electricity to power the electric field used to help confine the fusion plasma. This work details an idealized analytical model to determine the viability of using a thermionic energy converter for this purpose. The model finds a maximum power density of $10^5$ W/m$^2$ with a Carnot efficiency of 30%. The required electric and magnetic fields to produce net positive fusion power are > 350 MV/m and ~ 30 T respectively. This data is then used to discuss the feasibility of using p-11B as a fusion fuel for Direct Fusion Drive. | | |

| Interstellar exploration: From science fiction to actual technology | Volume 222 September 2024 | Giancarlo Genta |
|---|---|---|

The technology for even the most advanced missions in the solar system doesn't need advances in basic science. Travelling through the solar system can be described through what is called 'hard science fiction', ie science fiction strictly based on scientific knowledge. Interstellar exploration is a completely different matter. Robotic flyby missions to the nearest stars using nanoprobes can be performed using technologies based on known science, while anything beyond this requires advances which we don't know how to implement, or even we are not sure whether they are possible at all. The point applies not only to the technological aspects but even the scientific bases on which the relevant technologies may rest. The missions requiring less scientific-technological advances, are slow missions, like space arks (generation ships) or missions based on hibernation with travel times up to hundred years. To implement both, the uncertainties are more related to the advances in space medicine and biology than in propulsion and physics. The fastest travels allowed by the current interpretations of the relativity theory are relativistic missions in which the time contraction at speeds closing the speed of light is exploited to decrease the travel time for the astronauts, although the travel time seen by those who remain on Earth is close, in years, to the distance traveled expressed in light years. However, the energy required for this type of missions is large and grows drastically with the increase of time contraction.

Faster than light travel, which seems to be possible following some interpretations of relativity involving either wormholes or some sort of warp drive, requires substantial advances in fundamental physics. A symptom of this is that the novels dealing with interstellar travels belong more to the space opera – which doesn't follow strict scientific credibility – than to the hard science fiction subgenre. No novel of this kind explains details about how the relevant machinery works, and even less scientifically realistic are the movies, TV series, and video-games of this kind. Moreover, to achieve a travel time allowing to reach distant star systems in reasonable times using warp drives, the authors of Star Trek had to resort to the Warp Factor which is essentially a nonlinear scale. This makes the requirements for FTL travel even more difficult to achieve.



**The star cruiser C57D landed on Planet Altair 4 in the movie Forbidden Planet (1956). It was the first high-budget SF movie dealing with an interstellar journey performed at FTL speed. The original trailer recited: "Today. Man prepares to take his first steps outward into space – Tomorrow he will explore the stars. MGM's great technical staff brings you a magnificent picture of the distant tomorrow".**
**Note that this was the year before the launch of the first satellite, Sputnik 1. It was a great success.**

**Credit (image and caption): Giancarlo Genta Fig 1.**

# BECOME AN i4is MEMBER

## Curious about the mysteries beyond our solar system?
## Passionate about advancing humanity's journey to the stars?
## Fascinated by the potential of interstellar missions?
## If so....
## BECOME AN i4is MEMBER!

**Parnika Singh**

The Initiative for Interstellar Studies (i4is) invites you to be part of a groundbreaking movement. We are a nonprofit organization driven by a singular vision—to unlock the stars and take humanity beyond the boundaries of the known cosmos. By becoming a member, you'll help transform what once seemed like science fiction into reality.

As an i4is member, you won't just be following the journey—you'll be a vital part of it. From theoretical research to hands-on development, our projects are paving the way for interstellar exploration and inspiring new generations of scientists, engineers, and dreamers who dare to imagine a future among the stars. Imagine a world where you can play a direct role in humanity's most audacious endeavor—reaching other star systems. With your support, i4is is not only advancing research but also igniting the passion for interstellar exploration in schools and universities worldwide.

Here's what membership offers:

Δ Exclusive Access: Be the first to explore select articles from Principium before they're publicly released.

Δ Insider Updates: Stay in the loop with member-only newsletters, revealing the latest breakthroughs in interstellar research.

Δ Engaging Content: Delve into our ever-expanding library of videos, designed to inspire and educate.

Δ Special Events: Participate in live streams of i4is events and engage in discussions with leading experts from around the globe.

Δ Annual Insight: Download and immerse yourself in our annual report, a comprehensive look at how we're turning dreams of travelling to the stars into actionable progress.

**Joining i4is is more than just supporting a cause—it's a commitment to expanding humanity's horizon, a step toward a future where the stars are within our grasp. Whether you're a student or seasoned space enthusiast, our doors are open to all those who believe in the possibility of an interstellar future.**

**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 Principium preprints.

Interior of a worldship, a generation starship, from the Project Brief for i4is Project Hyperion. See the article on Project Hyperion, elsewhere in this issue. Project Hyperion presents a team competition to design such a vehicle, concentrating on the systems required to ensure the survival, health and happiness of its multi-generational travellers.

## Recent member newsletters

There have been three member newsletters (August, September and October) since P46, our last issue. All member newsletters are emailed to members and also available from the members-only area on the website - i4is.org/members.

The most recent, October 2024, included the month's Interstellar News and these preprints of P47 articles -

- News Feature, abstracts from JBIS and Acta Astronautica
- Report from the Space Propulsion Conference 2024 Glasgow, 20-23 May 2024, 9th 3AF (Association Aéronautique et Astronautique de France) International Conference On Space Propulsion
- *Rise of the Serpent-God: The Apocalypse Plot*, dealing with a potentially catastrophic encounter with a known near-Earth object
- First European Interstellar Symposium, The Abstracts, first European Interstellar Symposium, European Convention Center Luxembourg on 2nd – 5th Dec 2024

- and the P47 Interstellar News

## Getting more actively involved

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

## Writing for Principium

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

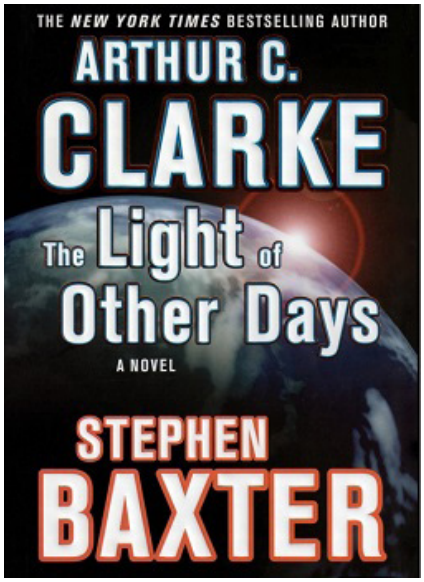
*"Earth is the cradle of humanity but one cannot live in a cradle forever."*

*K E Tsiolkovsky*

# NEXT ISSUE


**Next time, in P48 - February 2024**

Arya Gonullu will present a follow up to her P46 piece *The Cosmic Challenge: Why Quantum Entanglement Won't Deliver The Ansible*, connecting it to black holes being used in quantum error-correction, and relating that to quantum computing and thence to the "ansible" idea of Ursula K LeGuin.




**Front cover of *The Light of Other Days* (2000) by Stephen Baxter from an idea by Arthur C Clarke. Tiny wormholes allow virtually instantaneous communication - a more recent variant of the ansible idea.**
**Credit: Tor Books (publisher)**


A report on the IRG/i4is European Interstellar Symposium

Progress report on i4is Project Hyperion worldship design competition

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

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

# COVER IMAGES

Our cover images for this issue show a worldship interior envisaged as part of i4is Project Hyperion and differing images of the familiar star Vega, from space telescopes developed many years apart but both very much alive.

## FRONT COVER

Project Hyperion Worldship interior
Credit: i4is Project Hyperion

i4is Project Hyperion is a design competition launched in November 2024 and based on work from 2011 by i4is at the International Space University, Strasbourg. More about the project in *Project Hyperion* in this issue.

## BACK COVER

**Back cover**
Hubble vs JWST images of Vega
Credit: NASA Hubblesite (hubblesite.org), Space Telescope Science Institute (www.stsci.edu)


After 34 years in space the Hubble Space Telescope is still delivering stunning results but it operates in a different but overlapping spectrum than its younger sibling the James Webb Space Telescope (JWST) launched on Christmas Day (25 December) 2021 [1]. TOP: A Hubble Space Telescope false-colour view of a 1,000 astronomical units (AU) wide disc of dust around Vega. Hubble detects reflected light from dust the size of smoke particles on the edge of the disk. The black spot at the centre blocks out the glow of the star. BOTTOM: The James Webb Space Telescope resolves the glow of warm dust in a disk halo, at 250 AU out. The outer disk (analogous to the solar system's Kuiper Belt) extends from 75 AU to 160 AU. The black spot at the centre is due to lack of data from saturation. Caption adapted from NASA Hubblesite [2].

[1] The JWST mirror is 6.5 metres in diameter and the Hubble mirror is 2.4 metres so the crude light gathering capacity of the younger telescope in $6.5^2 / 2.4^2 = 42.25/5.76 = 7.34$ times greater than its predecessor.
[2] Full Credits: NASA, ESA, CSA, Space Telescope Science Institute (STScI), S Wolff (University of Arizona), K Su (University of Arizona), A Gáspár (University of Arizona) hubblesite.org/contents/media/ges/2024/030/01JBF20FGYTRR4E0QVBWY516R1

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

Webb

Front cover: Project Hyperion Worldship interior
Credit: i4is Project Hyperion

Back cover: Hubble vs JWST images of Vega
Credit: NASA Hubblesite (hubblesite.org)

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.

**I4IS.ORG**