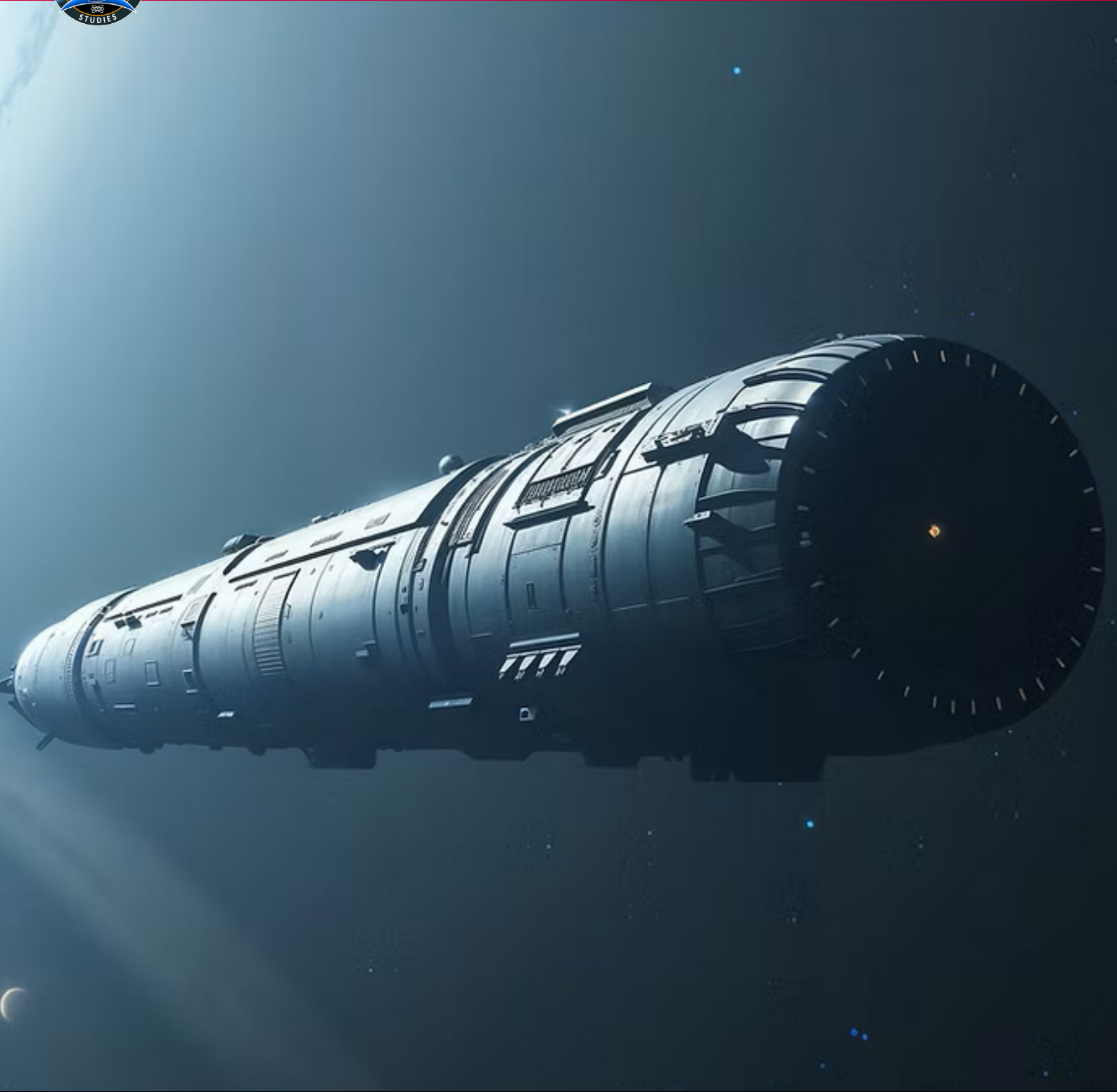




PRINCIPIUM

The Initiative and Institute for Interstellar Studies | Issue 50 | August 2025

SCIENTIA AD SIDERA | KNOWLEDGE TO THE STARS



Lead Feature: BOOK REVIEW: The Ross 248 Project

News Features: The i4is Project Hyperion Competition Results, more on Breakthrough Discuss 2025, Letter to the editor: Where do you look for ET?, Preview International Astronautical Congress IAC25: Announced Interstellar Presentations

Interstellar News

**The Journals: JBIS
and Acta Astronautica**

EDITORIAL

Welcome to issue 50 of Principium, the quarterly magazine of i4is, the Initiative and Institute for Interstellar Studies. Our Lead Feature is Patrick Mahon's review of the shared world anthology, *The Ross 248 Project*, edited by Les Johnson and Ken Roy. We include seven pages of Interstellar News. We have News Features: The i4is *Project Hyperion Competition Results*, more on *Breakthrough Discuss 2025*, a letter to the editor: *Where do you look for ET?*, our preview *International Astronautical Congress IAC25: Announced Interstellar Presentations* and our usual, *The Journals*, the regular summary of relevant peer-reviewed papers in *The Journal of the British Interplanetary Society* (JBIS) and *Acta Astronautica*.

Our cover images are of the winner of the i4is Project Hyperion Competition and a visualisation of an intercept of ISO 11/'Oumuamua. 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, P51 in November 2025, will be the first issue edited by Gill Norman. Our new team will be lead by Gill and Commissioning Editor Kajol Mistry.

After 10 years and 41 issues John Davies will be stepping down as Editor after this issue. He is ably succeeded by new Editor, Gill Norman supported by Commissioning Editor, Kajol Mistry and a new team.

Gill Norman with the late Al Worden, command module pilot of Apollo 15, and still the only person to have done an EVA outside low earth orbit (LEO).

MEMBERSHIP OF i4is

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/.

Members have access to:

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- **Principium preprints:** i4is.org/members/preprints
- **Videos:** i4is.org/videos

Please print and display our posters - selected poster variants are listed the Contents and all available at i4is.org/i4is-membership-posters-and-video.



In P51 we will have -

- Our first reports on interstellar related papers from the 2025 International Astronautical Congress.
- The much postponed review of *From Stars to Life A Quantitative Approach to Astrobiology* by Andreas Hein of the new book by Manasvi Lingam, Florida Institute of Technology and Amedeo Balbi, Università degli Studi di Roma 'Tor Vergata'.

We will have other News Features as well as our regular *Interstellar News*. More details on P51 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 13.

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



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Back issues of Principium can be found at-
i4is.org/publications/principium/



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

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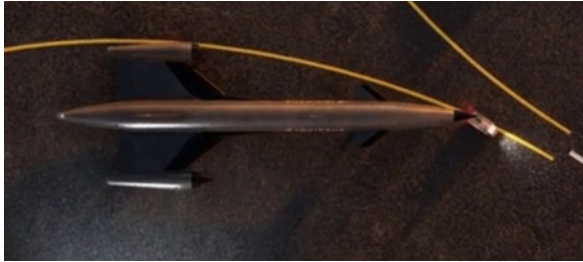
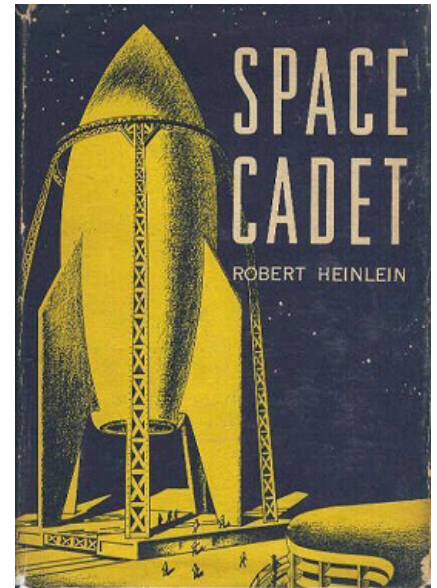
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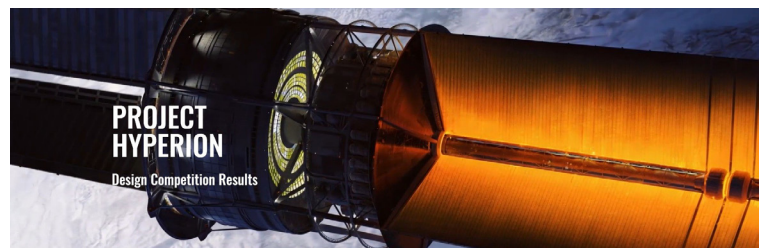
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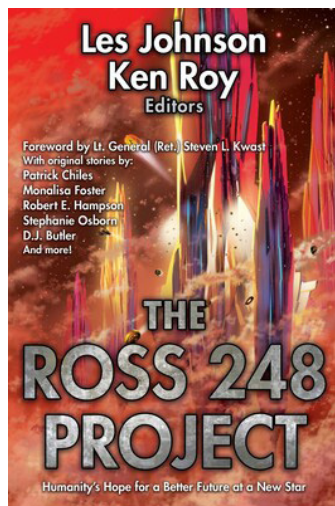
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BOOK REVIEW: *The Ross 248 Project*

edited by Les Johnson & Ken Roy
Baen Books, 2023

Patrick Mahon

Principium, and i4is in general, has always taken science fiction seriously. Much of it, both “outer space” and “inner space”, is relevant to both technical and human concerns which arise from interstellar travel and communication. So an anthology based on a common thread edited by two long-established experts in interstellar related subjects naturally drew the attention of Principium Deputy Editor Patrick Mahon. He opens his review by introducing them.



As Principium readers will be well aware, the team at the Initiative for Interstellar Studies spends a lot of time focused on researching the scientific and engineering challenges of interstellar exploration. However, many of us also find inspiration in artistic responses to the desire to reach for the stars. One such response is the science fiction anthology *The Ross 248 Project*, edited by Les Johnson and Ken Roy, which the American SF publisher Baen Books issued in 2023.

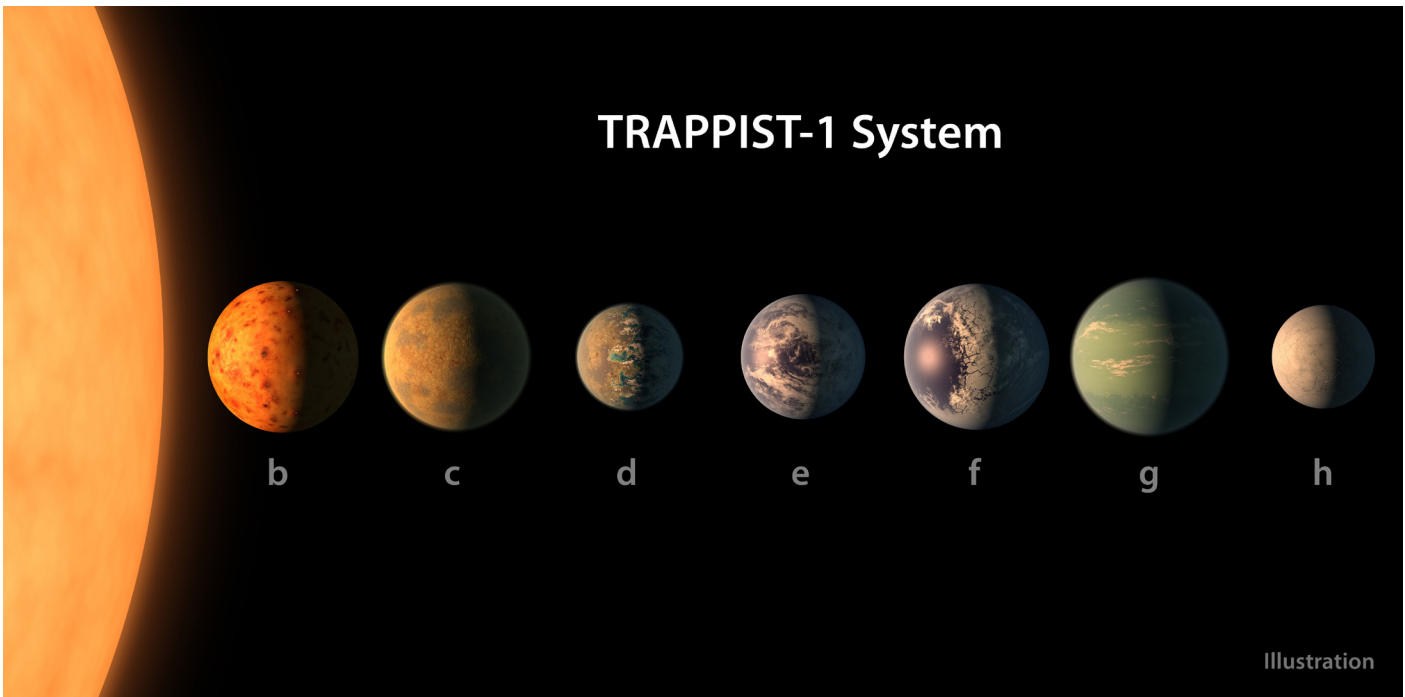
Les Johnson's name will, I'm sure, be familiar to many of you. He's a NASA engineer who has done a lot of work on solar sailing, and he's also an author of numerous books, both non-fiction and fiction. I reviewed his non-fiction book about interstellar exploration, *A Traveler's Guide to the Stars*, in issue 45 of Principium (May 2024, i4is.org/principium-45/).

The name of his co-editor, Ken Roy, may be slightly less familiar, but he's a recently retired American professional engineer who has also published multiple research papers on terraforming and space colonisation. So both editors definitely know what they're talking about.

The anthology contains twelve pieces, in addition to the front matter and the appendices. Ten of them are science fiction short stories, one is a semi-factual alternate history of the past, present and possible future role of the military in space, and the last is an essay on terraforming.

This is a so-called 'shared world' SF anthology, which means that all the stories take place within the same story setting. That setting was developed by Johnson and Roy at the start of the project, and shared with the anthology's authors to ensure a level of consistency between the stories. The editors have helpfully given a summary of it in the book's introduction, with more details provided in three appendices.

I'm sure Principium readers will be interested in these details, to see how realistic the assumptions are. In brief, humanity launches several starships towards Ross 248, a (genuine) red dwarf star which is 10.3 light years from Earth. This destination was chosen as it is relatively close to Earth, and the star is a red dwarf, a type which is statistically more likely to have exoplanets in the habitable zone. Although no such exoplanets have been detected around Ross 248 to date, this doesn't mean there aren't any, since they are on the edge of what current technology can detect.



Illustration

This artist's concept shows what the TRAPPIST-1 planetary system may look like, based on available data about the planets' diameters, masses and distances from the host star. The system has been revealed through observations from NASA's Spitzer Space Telescope and the ground-based TRAPPIST (TRANSiting Planets and Planetesimals Small Telescope) telescope, as well as other ground-based observatories. The system was named for the TRAPPIST telescope.

The seven planets of TRAPPIST-1 are all Earth-sized and terrestrial, according to research published in 2017 in the journal *Nature*. TRAPPIST-1 is an ultra-cool dwarf star in the constellation Aquarius, and its planets orbit very close to it.

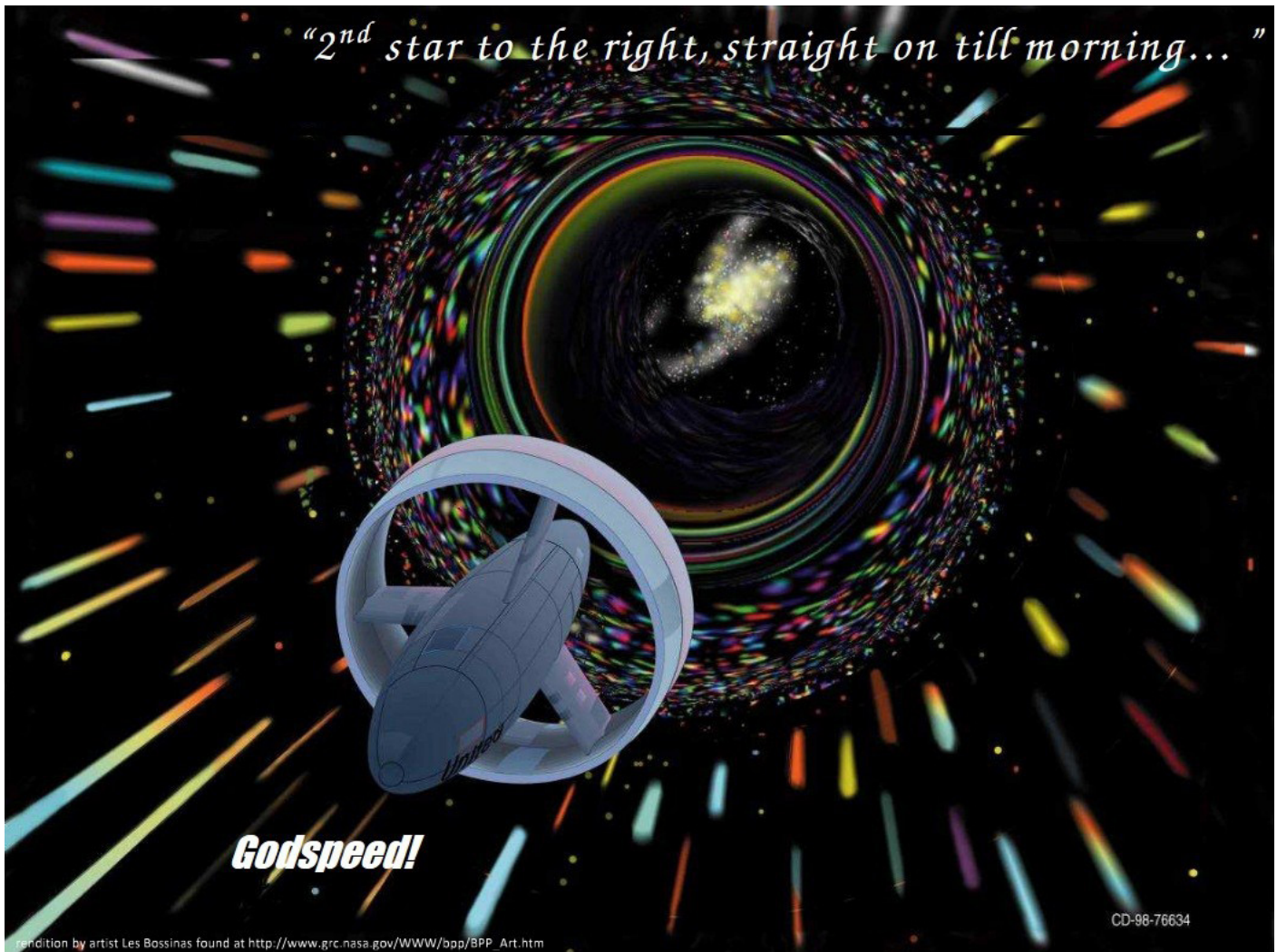
They are likely all tidally locked, meaning the same face of the planet is always pointed at the star, as the same side of our moon is always pointed at Earth. This creates a perpetual night side and perpetual day side on each planet.

TRAPPIST-1b and c receive the most light from the star and would be the warmest. TRAPPIST-1e, f and g all orbit in the habitable zone, the area where liquid water is most likely to be detected. But any of the planets could potentially harbor liquid water, depending on their compositions.

In the imagined planets shown here, TRAPPIST-1b is shown as a larger analogue to Jupiter's moon Io. TRAPPIST-1d is depicted with a narrow band of water near the terminator, the divide between a hot, dry day and an ice-covered night side. TRAPPIST-1e and TRAPPIST-1f are both shown covered in water, but with progressively larger ice caps on the night side. TRAPPIST-1g is portrayed with an atmosphere like Neptune's, although it is still a rocky world. TRAPPIST-1h, the farthest from the star, would be the coldest. It is portrayed here as an icy world, similar to Jupiter's moon Europa, but the least is known about it.

Credit (image and caption): NASA/JPL-Caltech/R Hurt, T Pyle (IPAC)

The editors have made the creative assumption that Ross 248 has multiple exoplanets orbiting it, in a system resembling the 7 exoplanets discovered by NASA to be orbiting the red dwarf Trappist-1 in 2017. Using propulsion technology based on the Alcubierre warp drive, three large starships travel from our solar system, at one-tenth of the speed of light, taking around 110 years to reach their destination. The use of an Alcubierre drive definitely puts the assumed technology into the speculative end of things, but they have been completely open and honest about this, explaining the rationale for their choice in Appendix III to the book. Brownie points for that.



Warp Drive in action from Warp Field Mechanics 101 Dr Harold "Sonny" White ntrs.nasa.gov/api/citations/20110015936/downloads/20110015936.pdf The quotation at the top "second star to the right, and straight on till morning." is in the 1953 Disney version of J M Barrie's play, Peter Pan. The original omitted "star". The connection here is the final line of the film Star Trek 6, where it is Captain Kirk's order to the helm at the end of the film

After a brief foreword and introduction, the anthology opens with 'Garden of Serpents', by Patrick Chiles. This is set in the year 2583 AD - which is renumbered as 0 AA ('After Arrival') - which is when the fleet of ships arrive in the Ross 248 system. A detachment of troops from the Space Patrol ship *Guardian E* are transported down to the surface of the fourth exoplanet in the system. This has been named 'Eden', as it has an oxygen-containing atmosphere and a living biosphere, so the hope is that it will be relatively easy to colonise. The soldiers' mission is to construct research stations for the use of the scientists who will follow them down. However, the alien flora and fauna on the surface of Eden view the troops as unwelcome contaminants of their environment, and react accordingly. Chaos ensues!

I had mixed views about the opening piece. Although this action-focused military-SF story provides a dramatic start to the book, pulling the reader in, it also sets an unwelcome tone, for me at least. The soldiers are to be followed down by research scientists, we are told. Yet when they encounter herds of animals that resemble half-scale Tyrannosaurus Rexes, we hear that the soldiers 'had to kill hundreds of the monsters before they learned to leave us alone'. No attempt at distraction or deterrence. No consultation with the research scientists, who might want to study these large alien creatures. Just shoot first and ask questions later. Although this story is set over 550 years into our future, it would appear that we've learned nothing in that time.

Next up is 'And A Child Shall Lead Them', by Stephanie Osborn. Set one year after 'Garden of Serpents', this story introduces us to two new species who have travelled from our solar system to Ross 248. The first are the Cerites: tall and thin humanoids who have evolved from the humans who settled the main belt asteroid Ceres in order to mine it. The Cerites have deliberately genetically engineered themselves to be more resilient to the low gravity, high radiation environment in the asteroid belt. The second species are sentient AIs.

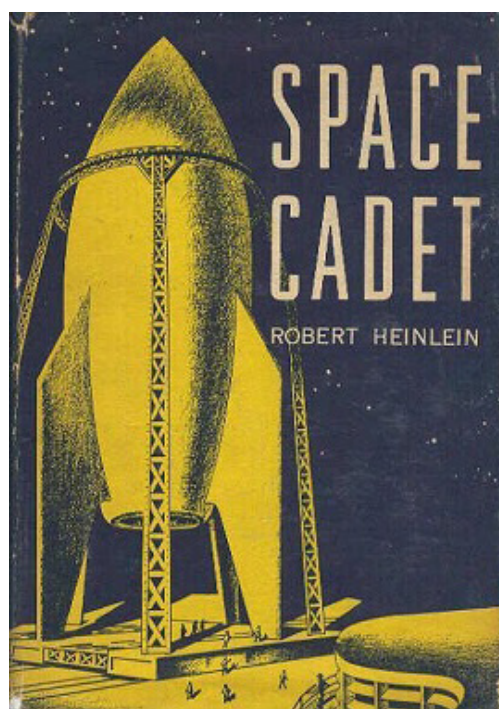
A mixed crew of Cerites and sentient AIs travelled from Earth in a second starship, *Ceres' Chariot*. This has gone into orbit around Liber, an airless moon of the seventh exoplanet in the Ross 248 system.

When a young but precociously intelligent female Cerite called Arinna realises that the red dwarf at the centre of the system is a flare star, which is just emerging from a century-long period of quiescence, she warns the adults. While most of them assess her data, recognise that she's correct, and agree on emergency actions to minimise the radiation risks they will face when the red dwarf flares, not all do.

The Cerite commanding *Ceres' Chariot*, Captain C'Bakab, is unimpressed by warnings from what he sees as a frightened young girl, and orders his crew to maintain their current orbit, putting the ship at huge risk if they are in direct line of sight of the star when it flares. C'Bakab's Executive Officer, a sentient AI whose formal name is 34-of-Foxtrot, but who is known as Harry, is left in a quandary. Should he obey the direct orders of his Cerite commanding officer? Or, having used his advanced AI brain to confirm that Arinna's warnings are accurate, should Harry take evasive action while the Captain is off shift and asleep, and deal with the personal risk of a court-martial, and the wider risk of conflict between Cerites and sentient AIs, later on?

I'm glad to say that 'And A Child Shall Lead Them' put my concerns about the first story to bed. Here we encounter two new races, each very different from each other and from 'ordinary' humans, yet they are (mostly) able to work together successfully. Most importantly, the story is about the use of science to make important predictions about the future, and to take rational action based on those predictions. This is the type of future for space exploration that I want, personally.

The third piece in the anthology is not a story, but an alternate history of the Space Patrol, a utopian military organisation which featured in 'Garden of Serpents', and whose wider role is to guarantee a peaceful future for humanity in space. Drawing on such sources as Thomas Hobbes' *Leviathan* (1651), HG Wells' 1914 novel *The World Set Free*, and Robert A Heinlein's 1948 juvenile novel *Space Cadet*, as well as the actual history of US military and nuclear activities in air and space, up to the creation of the US Space Force in late 2019, Brent Ziarnick produces a fascinating and thought-provoking essay which asks some very pertinent questions about how humanity might be able to secure a peaceful future in space when we're still so bad at avoiding armed conflict here on Earth.



First Edition cover of Robert A Heinlein's 1948 juvenile novel *Space Cadet*.
Source: Wikipedia

◀ Next up is 'Somebody's World', by Laura Montgomery, a practicing US space lawyer. Three years on from 'And A Child Shall Lead Them', the third starship to travel to the Ross 248 system, *Copernicus*, has diverted from its original target of Eden, which has been declared off-limits for colonisation following the events of 'Garden of Serpents'. It is now in orbit around Liber and while surveying the 7th planet in the system, which the moon Liber orbits around, they see artificial features, suggesting that the planet was once inhabited by intelligent beings.

When they fly down to the surface and explore, they find what seem to be buildings which show evidence of having contained equipment that has been taken away. This raises a huge legal question: have the planet and its moon been abandoned by its former alien residents, in which case the humans and sentient AIs on the *Copernicus* can colonise it, and mine the planet's resources as they would like to? Or is the legal position that the planet and moon still belong to the absent aliens, like ships lost at sea under the laws of salvage, so that mining will have to be prohibited? What initially sounds like rather arcane legal niceties has huge implications for the success of the entire mission to Ross 248, which Laura Montgomery dramatises very effectively.

My only reservation about this story, as a non-lawyer, is that the range of legal options considered by the lawyers in the story seem pretty limited. Given that they have no information about the nature of the intelligent aliens that appear to have left the planet, but may return in future, it seems odd to assume that legal principles developed in the modern, capitalist societies of Europe and America are the only possibilities. It would have been nice, for example, to see some reference made to the recent legal disputes between indigenous peoples in Australia and New Zealand and their governments, to see an alternate model for exploring these legal questions which does not assume that both parties share a common philosophy about capitalism and land rights.

The father and son team of Daniel M Hoyt and E Marshall Hoyt set their story, 'Kraken Rising', some 60 years after arrival at Ross 248. All the 'normal', non-Cerite humans are still living on board the orbiting starship *Copernicus*, or down in a rather cramped sub-section of 'Toe Hold', the mostly Cerite base on Liber, the moon of the seventh planet which featured in 'And A Child Shall Lead Them'. Neither solution is particularly attractive, but the poor living conditions in Toe Hold have led to the rise of an anticolonial movement which is becoming increasingly radicalised and violent.

In response, the leaders of the human faction have been exploring the possibilities for terraforming the third planet in the system, a water world known informally as Poseidon's World.

Sabrina and Adam are scientists who have been friends for decades. They are both on the research team on Poseidon's World, whose five-year mission is to gather the data that will enable a decision on whether it is suitable for terraforming, or not. But while Sabrina is a disciplined and methodical environmental scientist, Adam is a disorganised genius who has a track record of coming up with brilliant ideas, half of which work perfectly, while the other half's results vary between disappointing and disastrous. When Sabrina is tasked with investigating a series of increasingly violent storms that have suddenly started popping up all over the planet, she reluctantly concludes that Adam may be responsible for them. But she's been sending him her data, which shows that they are a direct threat to successful terraforming. Surely Adam isn't in league with the anticolonials?

I loved this story. It's an almost perfect mix of engaging characters, a fascinating science-based plot, and a dramatic setting. For entirely understandable reasons, many space-based SF stories default to one of two settings: rocky alien planet, or spaceship interior. It's refreshing to have a story set on a water world, particularly when it is depicted in as visceral and exciting a way as is the case here.

Following on neatly from the Hoyts' story, space journalist Matthew Williams has contributed 'Terraforming Planets Under a Red Sun', a non-fiction article about the opportunities and challenges of terraforming planets, whether within our own solar system or elsewhere. This is a detailed and engaging essay by a science writer who clearly knows his stuff, and will I'm sure be of great interest to all readers of Principium.



'Dim Carcosa', by DJ Butler, is set just four years after the previous story. In it, we meet Prashanth Satyadeva, a former member of the Space Patrol who retired on medical grounds. He now lives down on Toe Hold and just about makes a living as a private detective. When he is contacted by a woman called Victoria Tan, who is rich enough to still be living on the starship *Copernicus*, he can suddenly see a brighter future for himself. Tan wants him to find her 21-year old daughter, Chao-xing, a fashion model who has been missing for 2 days. He starts looking, but every clue he finds points uselessly at a surreal 19th century short story about the 'Dim Carcosa' of the title. Can he solve the case before he goes mad?

I must admit, I'm still confused by this piece, despite having read it multiple times. Even so, the framing as a noir private detective story sets it apart from the rest of the anthology, and I enjoyed the style and energy a great deal, even if I didn't understand the plot fully.

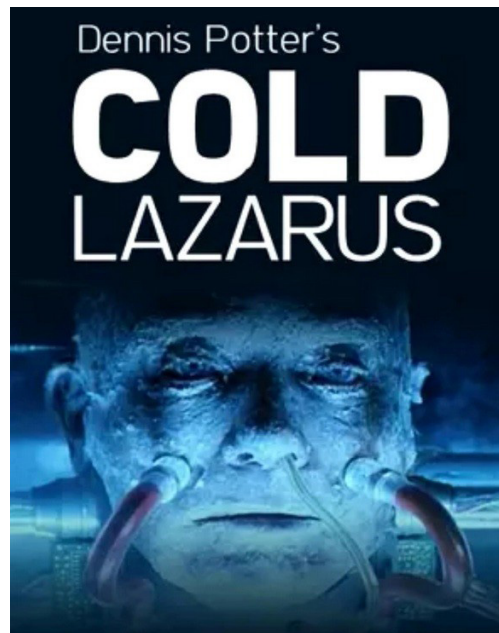
Robert E Hampson's 'Echoes of a Beating Heart' is set nearly two decades after 'Dim Carcosa', in the year 83 AA. 'Davey' is an adolescent sentient AI, growing up with human parents who are doing scientific research on Eden, the biologically active world we first met in 'Garden of Serpents'. Experience has demonstrated that sentient AIs that are to work successfully alongside humans or Cerites need to go through something similar to a human childhood, in order to develop their own personality and purpose.

There aren't any other adolescents on Eden, and Davey gets increasingly lonely as time goes on. That is, until the research group's current doctor goes back up to the orbiting starship *Copernicus*, his term in the field over. His replacement is a human husband-and-wife team who bring their sixteen year old daughter, Betsy, with them. Davey and Betsy become friends, so when Betsy decides that she wants to explore the area surrounding their hab-domes, he goes with her. Almost inevitably, this gets them into serious trouble... This is a multi-layered story, packing several distinct ideas into a limited number of pages, and I thought it was extremely effective. I loved the concept of sentient AIs going through a human-like adolescence in order to socialise them and enable them to develop their own individual sense of purpose. And the friendship between Davey, an AI, and Betsy, a human teenager, had enough ups and downs to feel authentic.

One thing in this story did disturb me, though. In a historical interlude, early in the story, we're told that soon after the discovery of Eden and its vibrant biosphere, 'a heated debate arose' between those who wanted to kill off all the native lifeforms and then terraform Eden, and those who wanted to protect the existing biota. Thankfully the argument was eventually settled in favour of planetary protection. But the story implies that this decision was entirely within the gift of the arriving colonists. It seems inconceivable to me that the possibility of such a scenario would not have been foreseen by those planning the mission, back on Earth, and that a set of mission rules would not have been created ahead of launch, prohibiting the willful destruction of entire living ecosystems found at the destination. Surely one of the main reasons for exploration of other star systems would be to study any alien lifeforms that we encountered, not simply to wipe them out in order to make colonisation easier. There are rather uncomfortable echoes here of the history of the Western colonisation of the Americas and Australasia, and the fate of those who already lived there.

In an interesting departure, the next story is set back in our own solar system. Monalisa Foster's '1-of-Antonia' takes place 3 years after 'Echoes of a Beating Heart', and is set on Pluto. The dwarf planet is owned and operated by the Sentient AI Network (SAIN), and amongst other things, SAIN runs virtual reality systems and a cryogenics industry there. Wealthy geriatrics can travel to Pluto, spend their last years enjoying themselves in VR, and then have their body frozen at the point of death, in the hope of a future cure being found.

When Aidan Samuels' wife is diagnosed with a terminal illness, the two of them head to Pluto to spend their last months together. But once his wife dies, Samuels refuses to come out of the VR environment, where he is consumed by grief. When his employers demand that he's pulled out, as he's needed to resolve a boardroom dispute, the sentient AI 1-of-Antonia, nicknamed Suri, is sent into his VR simulation to talk him around. But when a man just wants to be left alone to mourn the love of his life, how on Earth does an AI, no matter how sentient, persuade him that the cares of the real world are more important?



A distinctly pessimistic view of cryonics, Dennis Potter's *Cold Lazarus* 1996 TV play released two years after Potter's death from pancreatic and liver cancer.
Source: IMDB

Despite this story initially appearing to have no connection to interstellar exploration or the Ross 248 star system, I found it fascinating and enjoyable. The central idea, of a sentient AI having to find a way to engage with a human who is entirely driven by his emotional state, is intriguing, and well handled. And there's a dry sense of humour running throughout the entire tale, ensuring it never becomes maudlin. Later in the piece, a connection to Ross 248 is made, and it works very well, without seeming to be shoehorned in.

JL Curtis' story, 'MTBF (Mean Time Between Failures)', takes place on Nordheim, the 5th planet in the Ross 248 system, some 23 years later, in the year 106 AA. Nordheim has almost Earth-normal gravity, so has been prioritised for human settlement, given the overcrowding elsewhere.

Sergeant Niklas Berndt of the Space Patrol is promoted to Lieutenant and sent, with his AI buddy 60-of-Sigrid, nicknamed Bear, to set up a new branch of the central bank that is run by the Patrol in New Hope City, the latest human settlement to be constructed on the planet. Nik and Bear have spent their last few years investigating criminal activity, and it quickly becomes apparent that their posting to Nordheim has little to do with bank management. Someone, or *something*, is sabotaging the construction of the new city, and it's their job to find out who and how, and then put a stop to it. But the deeper they dig, the larger seems to be the potential conspiracy. Will they be able to stop it?

This is a well-written, highly enjoyable story which has some extremely interesting points to make. In a universe where almost all communications are overheard by one or more sentient AIs, all of whom are in constant contact with each other via SAIN, the Sentient AI Network, how do you run a criminal investigation if one of your suspects is an AI? Equally, given that it's almost impossible for an AI to 'go off the rails', why would someone (presumably human) try to frame an AI for the crime? And finally, and most seriously, what should the appropriate penalty be for a crime that threatens the future of the colonisation project?

The penultimate story, 'A Field of Play', by K S Daniels, takes us back in both time and space to Pluto in the year 2440 AD, some 143 years prior to the first ships arriving at Ross 248. The sentient AI 6-of-Chandra, nicknamed Yato, is a designer of virtual reality games for humans. To fulfill his role better, he spends his time trying to get inside the mind of his human customers, trying to 'be' as human as he can be. This makes him rather idiosyncratic, and is a constant source of irritation to his much more logical 'older brother' 5-of-Chandra, nicknamed Noburu.

When both brothers are summoned by their AI 'mother' Chandra, Yato is initially annoyed to be asked to stop work on his current project. However, when Chandra tells him that his intuition for how humans think is needed on an urgent new project, he's flattered.

Chandra wants the two of them to work together on producing a long-term extrapolation of the future of humanity, for a client called Torajiro Ito, a rich Japanese engineer with a terminal illness. The problem is, their early predictions are almost uniformly negative. Are they doing something wrong, or are humans and Cerites genuinely doomed?

◀ It's interesting to note that the author's biography says she grew up reading the works of Isaac Asimov, amongst others. It shows, because the kind of long-term predictions which Yato and Noburu work on in this story are somewhat reminiscent of Hari Seldon's science of psychohistory, as seen in Asimov's 'Foundation' series. A nice tip of the cap to golden-age SF.

This story works well as a means of explaining why the Ross 248 Project came about. I enjoyed it a great deal.

The final story in the anthology, prior to the various appendices, is called 'Not Too Tired', and it was co-written by the editors, Les Johnson and Ken Roy. It takes place in the year 3291 AD, or 708 AA, a considerable period into the future of the Ross 248 system. Things are going well for the humans, the Cerites and the sentient AIs. However, not everyone is happy with that, as the now-Director of the entire Ross 248 Project, 5-of-Chandra (or Noburu, as he was nicknamed 850 years earlier, as seen in the previous story) finds out one day.

A brave young Cerite called C'Maria, who volunteered to infiltrate the violent anti-colonisation movement a year earlier, sends him an encrypted message. In it, she tells him that she has been identified as a government agent and taken prisoner, and will be killed unless 5-of-Chandra agrees to meet with Anticol's leader. It's obviously a trap, but he agrees to go anyway, after taking the precaution of moving himself into a heavily shielded, armoured and armed humanoid shell.

But when 5-of-Chandra does finally meet the leader of Anticol, the man's arrogance, and the extent of his plans to destabilise everything that's been achieved over the previous seven centuries, makes the AI start to wonder just how deeply embedded the conspirators are within the forces running the Ross 248 system. More importantly, is it too late to stop them?

'Not Too Tired' turns out to be an excellent way to end a wonderful anthology. It includes references to several of the previous stories, all the way back to the second one, 'And a Child Shall Lead Them', which was set one year after the ships arrived at Ross 248, just over 700 years earlier. It also tackles some really big issues, including terrorism, genetic enhancement, slavery, free will, and the human desire for money and power. It turns out that Les Johnson and Ken Roy aren't just a good pair of editors. They are talented co-authors too.

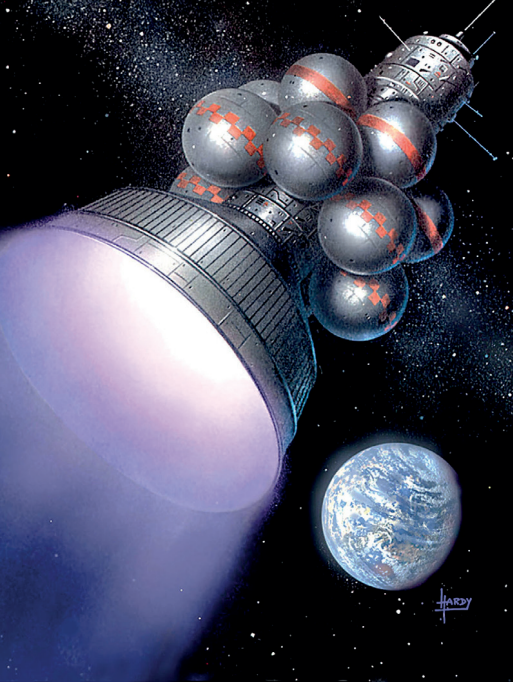
Taken as a whole, *The Ross 248 Project* is an impressive achievement. The inclusion of three different 'races' (humans, Cerites and sentient AIs) is a major strength, providing several different lenses through which to view the colonisation experience.

Characterisation is almost uniformly strong, with varied casts of complex characters who enable the reader to feel genuine empathy when things aren't going well. The stories include a wide range of settings which are vividly described, helping to bring this varied stellar system to life and forcing the characters to confront very different challenges. And the plots explore a wide range of the issues that might arise if such an ambitious mission were to be attempted.

If I were forced to voice a criticism of the anthology, it would be the overwhelming focus on the Ross 248 system purely as a location for human colonisation, rather than as a stellar system of inherent scientific value and interest. In most of the stories, the aim is to change whichever planet or moon it's set on, so that it's more suitable for the colonists. Seen from an entirely practical engineering mindset, this makes total sense. But having spent over a century travelling over ten light years to get there, virtually no-one seems remotely interested in the star system itself, as a place to study, to explore, or to engage with on its own terms. And least of all to do biological or ecological research on Eden, the habitable planet featured in the first story, 'Garden of Serpents'. Indeed, in that story, as I mentioned earlier, the response to finding advanced alien lifeforms is not to study them, but to 'kill hundreds of the monsters' until they learn to stay away.

It would have been nice to read just one story that was focused less on colonisation, and more on scientific exploration of the first extrasolar star system to be visited by humanity. However, that's not the focus of this anthology.

Putting that criticism to one side, *The Ross 248 Project* is a wonderfully rich anthology of pieces which provides much food for thought to those of us who are interested in considering what it might be like to explore a new star system many light years from home. I thoroughly enjoyed reading it, and I'd recommend it to anyone who is interested in interstellar exploration.



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)

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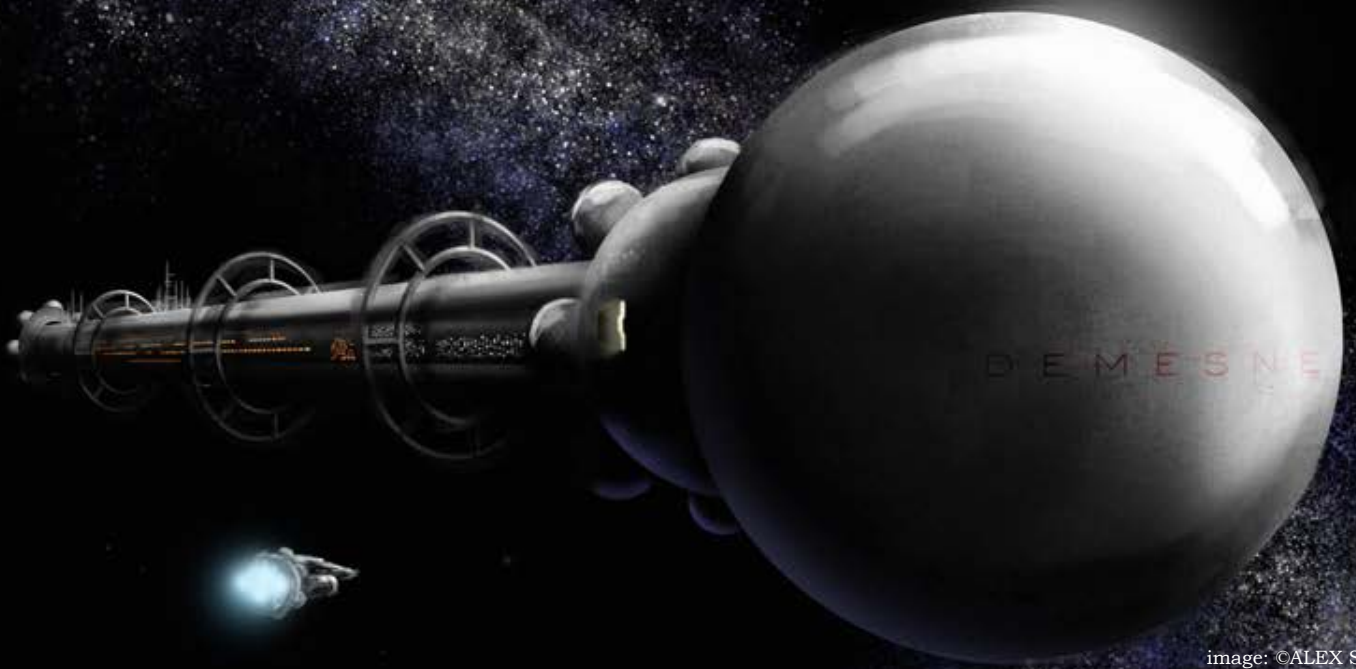


image: ©ALEX STORER

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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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John I Davies reports on recent developments in interstellar studies

A 3rd Interstellar Object (ISO)

The third known interstellar object, 3I/ATLAS, was discovered on July 1 2025 by the Asteroid Terrestrial-impact Last Alert System (ATLAS) - fallingstar.com/ - and subsequently imaged by the veteran Palomar 200-inch telescope. In *Interstellar comet 3I/ATLAS: discovery and physical description*, Bolin et al (arxiv.org/abs/2507.05252) provide details. The new ISO appears to be a comet, like the second, 2I/Borisov, and unlike the enigmatic 1I/Oumuamua, the first discovered of these visitors from beyond our Solar System. It seems to be the largest ISO yet seen according to a paper by Colin Orion Chandler et al, NSF-DOE Vera C Rubin Observatory Observations of Interstellar Comet 3I/ATLAS (C/2025 N1) - arxiv.org/abs/2507.13409. Chandler et al report an equivalent effective nucleus radius of around (5.6 +/- 0.7) km. They use early images gathered "Serendipitously, the Rubin Observatory collected imaging in the area of the sky inhabited by the object during regular commissioning activities". It also has a fairly low inclination to the ecliptic (the plane where most of the mass of the Solar System orbits) at 5 degrees (though retrograde) while 1I is inclined at 122 degrees and 2I is at 44 degrees.

Our i4is lead astrodynamacist, Adam Hibberd, has been considering this object and he comes to an initial pessimistic conclusion about the possibility of a mission to take a closer look *Missions to 3I/ATLAS* [i4is.org/missions-to-3i-atlas/](https://arxiv.org/abs/2507.12213). He concludes that it would be much harder to reach than 1I/Oumuamua which, in any case, looks much more intriguing than either 2I or 3I, though with a low probability chance that 3I is non-natural, see below.

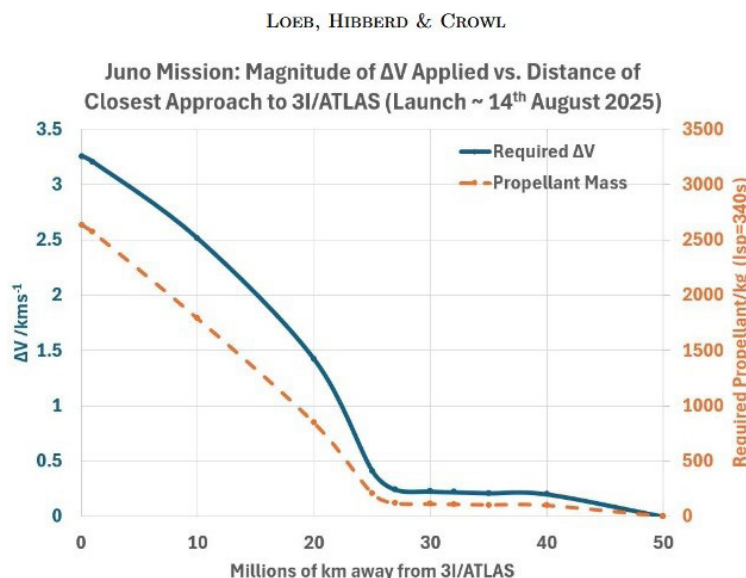
1I appears to exhibit no outgassing unlike a comet yet has experienced some kind of accelerating force. More about 1I and missions to it in many previous issues of Principium beginning with *Project Lyra*:

Sending a Spacecraft to the Interstellar Asteroid, in Principium 19 November 2017 and in - en.wikipedia.org/wiki/1I/%CA%BBOumuamua#Discussion.

Adam has also done some speculative investigation of the trajectory of 3I with an i4is colleague Adam Crawl and Professor Avi Loeb (Harvard) - *Is the Interstellar Object 3I/ATLAS Alien Technology?*, Adam Hibberd, Adam Crawl and Abraham Loeb arxiv.org/abs/2507.12213. They present a testable thesis of a non-natural origin. They describe their investigation very cautiously as a "pedagogical exercise" but point out that if 3I is non-natural then its trajectory might imply a threat.

The consensus within i4is is that all three ISOs are almost certainly natural but that 1I and 3I both deserve further investigation,

A later paper *Intercepting 3I/ATLAS at Closest Approach to Jupiter with the Juno spacecraft* arxiv.org/abs/2507.21402 by the same three authors shows how the Juno spacecraft, near its long extended end of mission (science.nasa.gov/mission/juno/#end-of-mission) could use its remaining fuel to encounter 3I next year (2026) with a closest distance about 53 million km (about one third of an astronomical unit) and relative velocity about 66 km/s. This was reported widely including in the well respected New Scientist magazine, *Can we send a spacecraft to intercept interstellar object 3I/ATLAS?* (www.newscientist.com/article/2490618-can-we-send-a-spacecraft-to-intercept-interstellar-object-3i-atlas/) with a rather pessimistic conclusion.



Thrust impulse ΔV (left vertical axis) and propellant mass (right vertical axis) needed for Juno to come within a range of distances from 3I/ATLAS (horizontal axis). The launch date is assumed to be August, 14 2025. Credit: *Intercepting 3I/ATLAS at Closest Approach to Jupiter with the Juno spacecraft*. Figure 3.

More recently Joan-Pau Sánchez and Colin Snodgrass have considered whether the planned ESA Comet Interceptor (CI) - (www.cometinterceptor.space/) could intercept another object with a trajectory like that of 3I. Prof Snodgrass, University of Edinburgh, is chair of the CI Target Identification Working Group. Joan-Pau Sánchez, Institut Supérieur de l'Aéronautique et de l'Espace, is a member of the Working Group. The current CI Δv capability would have meant that 3I would have had to be detected at 28 AU from the Sun and even the mighty new Vera C Rubin observatory's LSST would not have been capable of this. They conclude "A future CI-like mission dedicated to intercepting an ISO needs to have significant, but not unrealistic, Δv capability, and will still need a more co-operative ISO than 3I, that at least has a close approach somewhere near Earth."

Flying to a Potentially Hazardous Object

Adam Hibberd (i4is astrodynamist) and T Marshall Eubanks (Space Initiatives Inc) will be presenting *Flying to a Potentially Hazardous Object - A Mission of Gravity* at the very active West Midlands branch of the British Interplanetary Society (BIS) on 20 September 2025 at 14.00. They will present their recent research into a mission to the Potentially Hazardous Object (PHO) 2024 YR4. This asteroid is now known to be unlikely to hit the Earth at its next close approach in December 2032 but currently has about a 4% chance of hitting the Moon. This would result in an explosion equivalent to moderately large nuclear weapon and a large meteor cloud in the space between Earth and the Moon. The effects on satellites and, to a lesser extent, the Earth can be imagined. We will know more when it passes at some distance in 2028. Register for the talk, in person or online, at - docs.google.com/forms/d/e/1FAIpQLSd-FNFORRjwGpvn4Fv1b1UGI6bWJ6fLabDSQkpAHvhYPnittQ/viewform.

Voyager 1 - One light-day from home

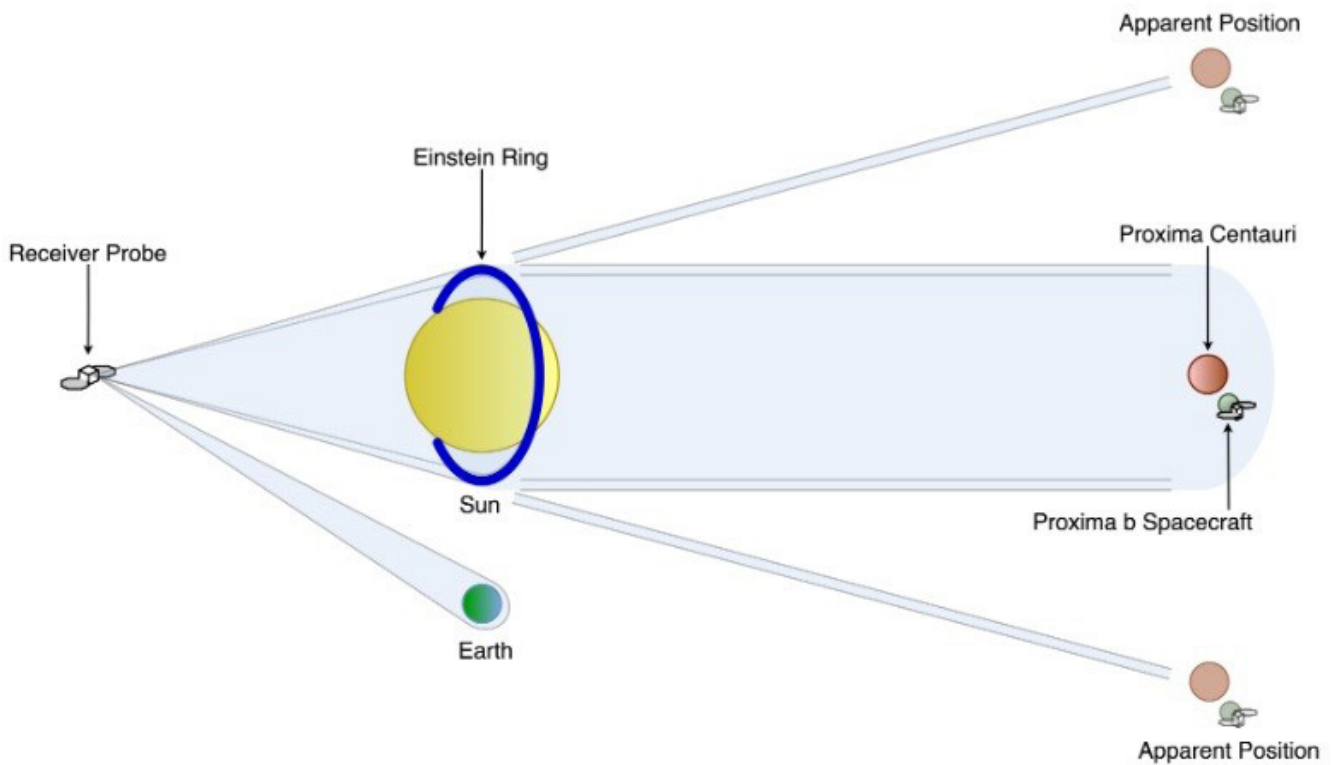
The two Voyager probes are still operating, 47 years from their launch and later this year Voyager 1 will reach one light-day from its home planet. NASA updates its distance on science.nasa.gov/mission/voyager/where-are-voyager-1-and-voyager-2-now/. Recalling that our nearest neighbour star is more than one light-year from reminds us of the magnitude of the challenge we face in reaching it. So it has taken 47 years for the Voyagers to achieve one 365th of the distance to that neighbour. But we are now confident we will have the technology to reach that distance in a time comparable to the Voyagers journey so far. This is a prime objective of i4is and we will continue to advocate for it, educate for it and prepare for it.

By Fusion to Proxima b

In her thesis *Interstellar Mission Design of a Fusion-Powered Spacecraft to Proxima b*, Amelie M Lutz, Virginia Tech, presents results of her Masters research in Aerospace Engineering [1]. The thesis examines three propulsion systems: the Fusion Driven Rocket (FDR), an Inertial-Electrostatic Confinement (IEC) fusion system, and an Antimatter Initiated Microfusion (AIM) system each tailored specifically for a Proxima b mission using four possible fuels: D-D, D-He³, D-T, and p-B¹¹. System performance was examined for a fast and slow flyby of Proxima b, and bounded orbit. It concludes that a slow flyby or bounded orbit, ideal for data collection, and can only be supported by FDR using D-He³ with a mission time of 57 years. The thesis also examines instruments for the mission including Magnetometer, Magnetic Sounding, Thermal Emission, Imaging, Ultraviolet Imaging, Gravity and Radio Science, Mass Spectrometer, Compositional Mapping, Radar Sounding, Dust Sampling, Imaging System and Communications [2].

[1] [vtechworks.lib.vt.edu/items/90b3f3e1-bb96-4006-8701-7f2e593fb009](https://techworks.lib.vt.edu/items/90b3f3e1-bb96-4006-8701-7f2e593fb009)

[2] A minor error, the thesis refers to designs for a mission to Alpha Centauri, such as Breakthrough Starshot, using solar sails. This work and its predecessors suggest laser sail propulsion



The Lutz paper considers the use of solar gravitational lensing for the downlink from Proxima b. Credit: Lutz, Figure 2.1: 2D representation of the solar gravitational lens communication system.

Do we need to understand Dolphin to understand an ETI?

Leonard David in *Space Insider* draws our attention to the first award of the Coller Dolittle Challenge \$100,000 annual prize to accelerate progress toward interspecies two-way communication (www.space.com/space-exploration/search-for-life/could-deciphering-dolphin-language-help-us-communicate-with-et). Led by Laela Sayigh from the Woods Hole Oceanographic Institution, the winning research team - including Peter Tyack from Woods Hole Oceanographic Institution, Vincent Janik from the University of St Andrews, Frants Jensen from Aarhus University, Katie McHugh and Randall Wells from Brookfield Zoo Chicago's Sarasota Dolphin Research Program - has been studying a resident bottlenose dolphin community in Sarasota, Florida.

Their report *Dolphins' use of Complex Whistle for Communication* does not yet appear to have been published. We'll be watching for it.

i4is has long been interested in ETI communication. For example Principium reviewed *Extraterrestrial Languages*, by Daniel Oberhaus in issue 31, November 2020 (i4is.org/principium-31).

Are extraterrestrials like us?

Human xenophobia inclines our species to believe that ETIs will differ greatly from ourselves but researchers may more productively look at similarities or at parallels with ourselves. In *Projections of Earth's technosphere: Scenario modeling, worldbuilding, and overview of remotely detectable technosignatures* (arxiv.org/abs/2409.00067), Jacob Haqq-Misra, George Profitiliotis and Ravi Kopparapu (of Blue Marble Space, Seattle, and NASA Goddard Space Flight Center) devise scenarios for our technological future and suggest the resultant techno-signature we would emit. Several of them would appear pre-agricultural. They suggest that such scenarios provide a vital background to our expectations of alien technosignatures.

They analyse using -

Table 1. Global factors multidimensional matrix. This matrix specifies the possible values for the economic, political, and social system factors across our scenario space (Credit: Haqq-Misra et al.

X	Economy	Y	Politics	C	Society
X1	Scarcity	Y1	Rule by one	Z1	Hierarchical
X2	Non-scarcity	Y2	Rule by few	Z2	Distributed
		Y3	Rule by all		
		Y4	Rule by none		

- and Anthropic's "Claude", a large language model (LLM) using the "Constitutional AI" process (www.anthropic.com/claude).

They construct a theoretical worldbuilding pipeline including a set of basic assumptions that are common to all scenarios:

- (1) humans have not gone extinct;
- (2) humans have not speciated;
- (3) humans are the only terrestrial animal capable of producing technology;
- (4) no extraterrestrial technology has interfered with human technological development; and
- (5) the scenario takes place 1,000 years in the future.

They assert that this work pioneers the use of such Earth-extrapolation methods to envisage possible alien technosignatures.

Are Dark Comets just old rockets?

In *Study of Venera Spacecraft Trajectories and Wider Implications* (arxiv.org/abs/2506.09478), Adam Hibberd, i4is lead astrodynamist, investigates trajectories of objects currently referred to as "dark comets" (eg www.jpl.nasa.gov/news/nasa-researchers-discover-more-dark-comets/). He notes that the Soviet Venera programme, an interplanetary campaign, centred around missions to the planet Venus, was beset with difficulties. Many are now in heliocentric orbits and Adam has found previous research speculating that these have been incorrectly identified as dark comets. He has found that several of these show invariance of their Earth Tisserand parameter (en.wikipedia.org/wiki/Tisserand%27s_parameter) suggesting they could be Venera probes.

Historically, there is no doubt that the early years of the USSR space programme put them way ahead of the competition (the USA). Nonetheless, although this was not what the Russians wished to present to the world, the interplanetary campaign, centred around missions to the planet Venus (the Venera programme) was also beset with difficulties. Many of the early Venera probes failed, despite making it to a heliocentric orbit, but naturally the success rate improved with time. The result is that there are now many Venera probes in heliocentric orbits, either completely intact, or the main bus after a successful deployment of the lander; together with the associated Blok-L upper stages. This paper is a response to some previous quite contentious research proposing that a certain member of a new class of objects, designated, may in fact be the Venera-2 probe. In this paper Adam looks into the invariance of the Earth Tisserand parameter in an attempt to establish if there are indeed any members of this class which could be Venera probes. It is found, with extremely small probability, that compared to a sample of randomly chosen NEOs, members of the class of Dark Comet have an Earth Tisserand unusually close to 3, a property shared by the Venera missions. Furthermore there are particular associations of three Dark Comets with three of these probes, the most significant being with the Venera-12 mission.

Skylon reborn?

Again, not strictly interstellar but economic access to low earth orbit is a natural precursor to human expansion into the Solar System. Followers of launcher technology including Principium readers will have been aware of efforts to develop spaceplanes as an alternative to vertical takeoff - vertical landing (such as SpaceX in the USA). The most mature of these was the air-breathing rocket using an atmosphere pre-cooler under development by Reaction Engines Limited (REL). Sadly REL fell into administration in October 2024. However consultancy Frazer Nash have now announced (www.fnc.co.uk/discover-frazer-nash/news/pioneering-new-programme-to-realise-lift-off-for-horizontal-space-launch/) that it has "welcomed a team of experts from Reaction Engines Ltd (REL) into their company who have been developing and demonstrating pre-cooler technology for more than a decade". The new vehicle concept is called *Invictus* and it looks remarkably similar to the REL *Skylon* concept - Perhaps an aerodynamicist could comment on the move of the wing and engines to the rear?



LEFT: The *Invictus* vehicle.

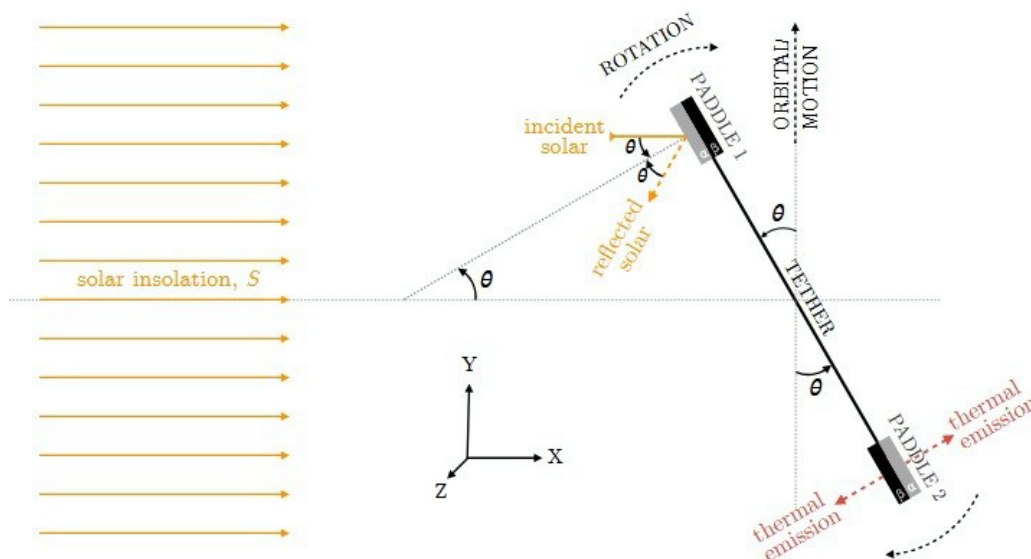
Credit: Frazer Nash video vimeo.com/1101204441/719f1e7261

RIGHT: The *Skylon* vehicle.

Credit: Reaction Engines Limited (REL) video *Reaction Engines Ltd Skylon*

Spinning to the stars

In *Torqued Accelerator using Radiation from the Sun (TARS) for Interstellar Payloads*, David Kipping and Kathryn Lampo of Columbia University propose to convert solar radiation pressure into rotational kinetic energy using a device which operates like a windmill to store energy as rotational momentum. Balanced in a quasi-satellite position at constant radius from the Sun the system can store energy indefinitely, limited only by material issues. The setup looks like the Crookes Radiometer of ancient memory. Though the usual terrestrial device does on rely on photon pressure. The propose quasi-satellite would rely on differential pressure from sails with a reflecting side and an absorbing side.



A simplified version of the TARS system. Here, the system comprises of one tether and two paddles, which together are orbiting around the Sun, with an instantaneous velocity vector along the Y-axis. Incident solar radiation is largely reflected by the α -surface (the reflective surface) of the paddles, but largely absorbed by the β -surface. This leads to a radiation pressure torque that gradually spins up TARS. Note that both paddles experience both reflection and emission; we only show one of each for the sake of visual clarity in the above. Credit (image and caption): Kipping and Lampo Figure 1.

The parallel with the Spinlaunch idea (www.spinlaunch.com/) is fairly clear.

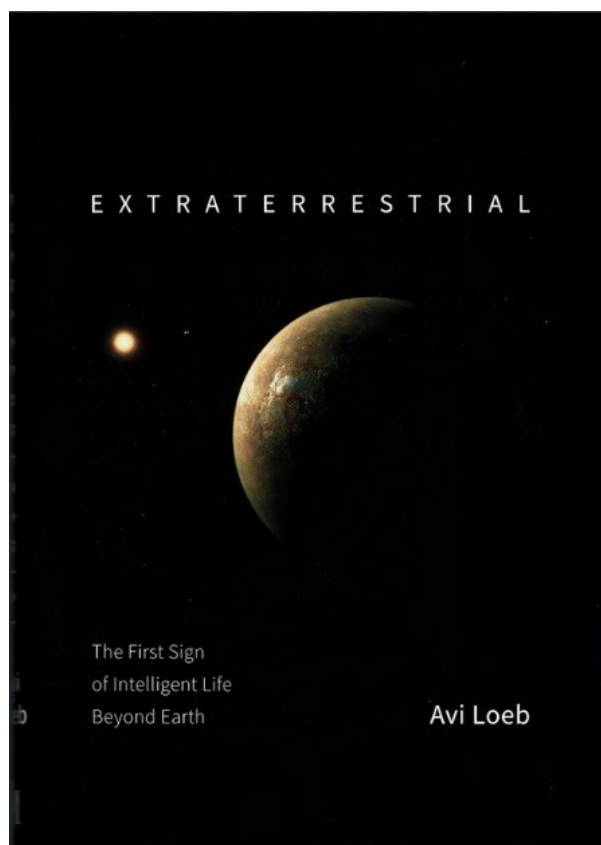
There will be a net outward force on the spinning TARS system and the paper proposes to balance this by orbiting the Sun at a slightly lower orbit than required for a true satellite at that radius from the Sun so that the outward force is balanced by an inward gravitational force - hence the quasi-satellite. The velocities achieved at the ends of the rotating assembly are limited by the strength of the tether between them and the paper mentions graphene as a possible material but prefers carbon nanotube (CNT) sheets which have only one sixth of the strength but are already proven for the role.

The paper concludes that "Although TARS can achieve escape velocity from our solar system using the Sun's radiation pressure alone, the ejection speeds are comparatively slow and thus it is worth discussing methods by which greater speeds could be attained." and discusses improving this by use of-

- the Oberth effect (perihelion thrust to maximise velocity increase)
- gravitational slingshot - as used by all deep space missions notably Voyagers 1 and 2
- additional acceleration with laser pressure as proposed by Breakthrough Starshot, a number of i4is studies and Philip Lubin, the University of California, Santa Barbara, and colleagues
- reducing the tensile stress on the tether using electrostatic forces - discussed in detail in the paper

Who's afraid of Alien Intelligence?

In *From Extraterrestrial Microbes to Alien Intelligence: Rebalancing Astronomical Research Priorities* arxiv.org/abs/2507.17790 Omer Eldadi, Gershon Tenenbaum and Abraham(Avi) Loeb, two psychologists and an astronomer, suggest that the search for habitable exoplanets receives disproportionate public funding in comparison with SETI. They point to the public interest in the three interstellar objects (ISOs) and the absence of any funding for missions to them. Prof Loeb is, of course, a long term advocate of the possibility of artificial origin of ISOs - see *Book Review: Extraterrestrial: The First Sign of Intelligent Life Beyond Earth, Avi Loeb* by Patrick Mahon in Principium 33 May 2021 i4is.org/wp-content/uploads/2021/05/Book-Review-Extraterrestrial-Loeb-Principium33-print-2105280923opt.pdf and *A 3rd Interstellar Object* (ISO) elsewhere in this Interstellar News.



Credit: UK Publisher: John Murray Press, 2021

Near Earth SETI by looking into Earth's shadow

In *A Cost-Effective Search for Extraterrestrial Probes in the Solar System* (academic.oup.com/mnras/advance-article/doi/10.1093/mnras/staf1158/8221885) published in the Monthly Notices of the Royal Astronomical Society (MNRAS) Beatriz Villarroel, Wesley A Watters, Alina Streblyanska, Enrique Solano, Stefan Geier and Lars Mattsson describe four methods for detecting extraterrestrial artefacts and probes within the Solar System -

- use of pre-Sputnik images to search for flashes from glinting objects
- use of space-borne telescopes to search for artificial objects
- examining the reflectance spectra of objects in Earth orbit, in search of the characteristic reddening that may imply long-term exposure of metallic surfaces to space weathering.
- using Earth's shadow as a filter when searching for optically luminous objects in near-Earth space

They focus on demonstrating the latter by conducting two searches for transients in images acquired by the Zwicky Transient Facility (ZTF), which has generated many repeated 30-second exposures of the same fields. Having identified previously uncatalogued events at short angular separations from the centre of the shadow, motivating more extensive searches using this technique, they conclude that the Earth's shadow "presents a new and exciting search domain for near-Earth SETI" and thus "a new and exciting search domain for near-Earth SETI".

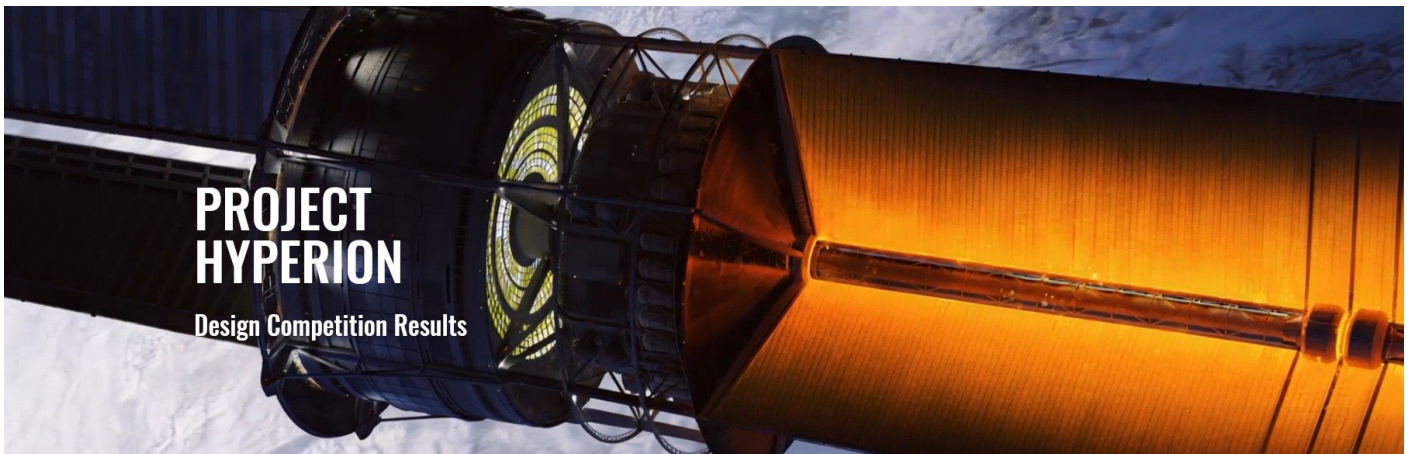
Project Hyperion Competition Results

Global teams reimagined sustainable generation ship habitats for humanity's interstellar future

John I Davies

The results of the i4is Project Hyperion Competition were announced in a Press Release (see **Press Kit** on www.projecthyperion.org/) on 23 July 2025. This News Feature is adapted from that release with additional material from the winning participants and a final section about some of the public attention the Project has attracted.

For more about all participants, the i4is Project Hyperion team and the jury which selected the winners see the Project Hyperion website www.projecthyperion.org/.



Introduction

The Project Hyperion Design Competition challenged interdisciplinary teams to envision a generation ship – a crewed interstellar spacecraft designed for a 250-year journey to a habitable planet. The teams designed habitats of such a spacecraft that would allow a society to sustain itself and flourish in a highly resource-constrained environment. The focus was on the ship and its inhabitants rather than on propulsion and external factors and in most extant worldship studies.

The Competition called on architectural designers, engineers, and social scientists to collaborate and address critical mission aspects that enable a spacecraft to function as a closed society over centuries. The teams were challenged to provide habitability for 500-15,000 people over centuries, artificial gravity via rotation, a society that ensures good living conditions, including essential provisions such as shelter, clothing, and other basic needs, robust life support systems for food, water, waste, and the atmosphere and of course knowledge transfer mechanisms to retain culture and technologies [1].

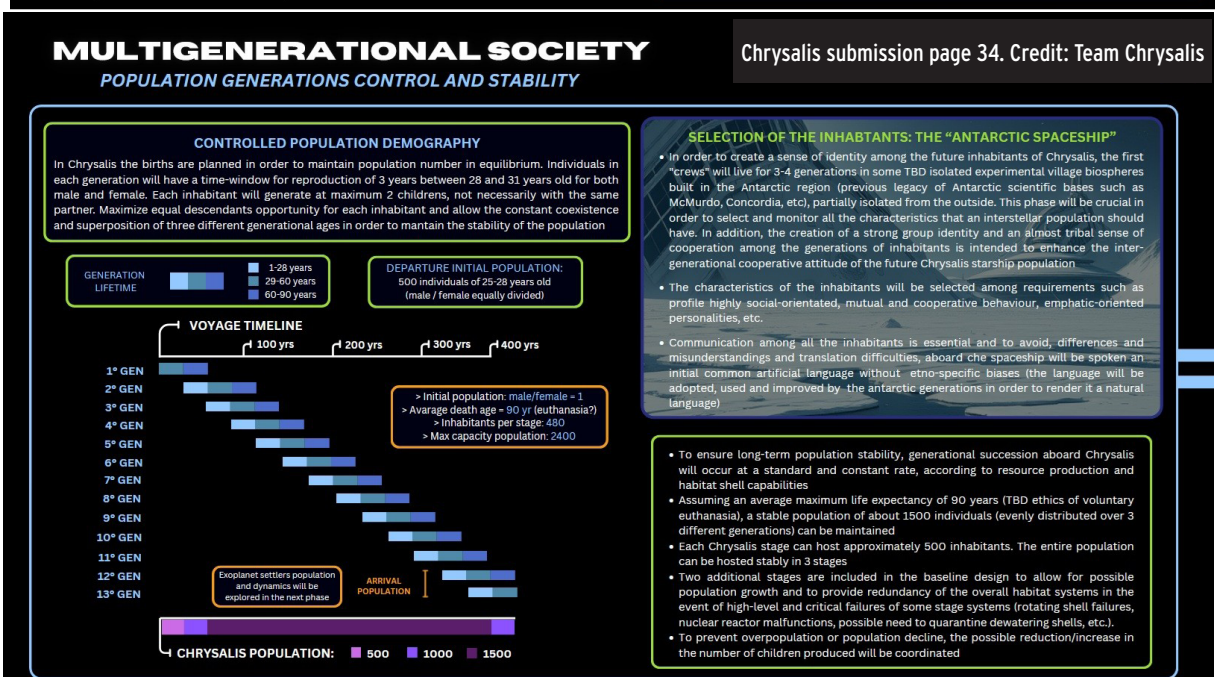
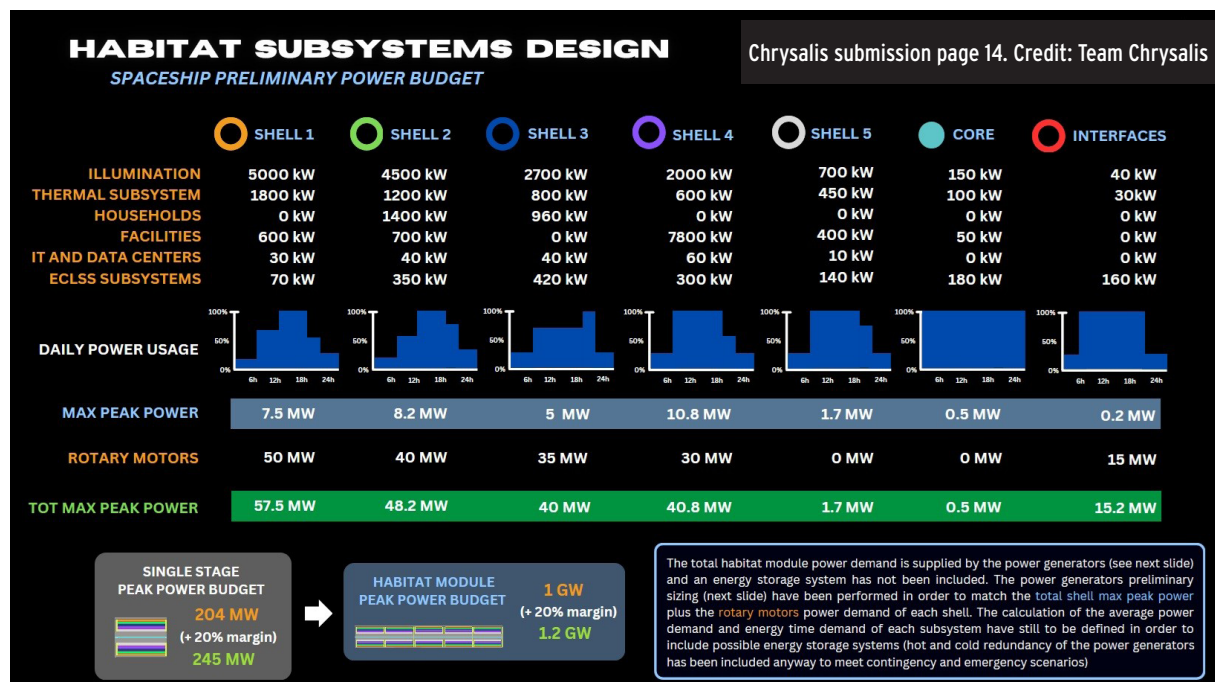
The winners were selected if they were able to integrate the various design aspects (architecture, engineering, social sciences) coherently and their general depth of detail, among other criteria.

[1] Detailed competition requirements www.projecthyperion.org/_files/ugd/91ab16_c3f7196fe5a348cdb0cd56904d02ae81.pdf

First Place: Chrysalis

Chrysalis impressed the jury with its system-level coherence and innovative design of the modular habitat structure but also overall depth of detail, which included, for example, in-space manufacturing and the value of pre-mission crew preparation in Antarctica. Its modular shell design promotes flexibility and connectivity, supporting both functionality and scalability. The large Dome structure adds a dramatic, cinematic quality that evokes science fiction classics, while the overall system-level planning – covering not just architecture but also how to build the vessel – is notably strong. The radiation protection strategy is solid, and the practical structural approach is well-suited. While cultural systems could be further developed, the concept offers a compelling starting point. The presentation is rich and visually engaging, drawing comparisons to iconic works like Rama, and showcasing a clear passion for both design and storytelling. Its overall spacecraft design seems to take inspiration from the gigantic world ship concepts of the 1980s.

Team: Giacomo Infelise, Veronica Magli, Guido Sbrogio', Nevenka Martinello, Federica Chiara Serpe
The project website contains the whole team submission [1] of 41 pages. Here are two examples showing the proposed habitat subsystem design and the envisaged multigenerational society.



[1] www.canva.com/design/DAGmr3ubC8E/LHHAeeAIGGQe_TkZVs-PXA/view?utm_content=DAGmr3ubC8E&utm_campaign=designshare&utm_medium=link2&utm_source=uniquelinks&utm_id=hcfa85973cc

Second Place: WFP Extreme

Commended for overall excellence, WFP Extreme has a particularly strong focus on cultural and societal dimensions, including concepts like clothing and spiritual spaces. It excels in its cultural and societal considerations, offering some of the most thoughtfully developed ideas in this area. The architectural design introduces advanced technologies such as radiation protection and demonstrates creative touches like the “taxi capsule” and personalized crew clothing. Though system-level coherence and interior design in artificial gravity could be further developed, the structural approach is well-suited to orbital applications. Overall, the project balances technical ambition with a unique and sensitive vision of future space living. This concept is clearly presented through a well-crafted booklet and poster, with strong attention to detail and a distinctive, human-centred aesthetic.

Team: Julia Biernacik, Jakub Kot, Aleksandra Wróbel, Jacek Janas, Michał Kucharski, Wiktoria Kuchta, Natalia Łakoma, Katarzyna Śliwa

The project website contains the whole team submission [1] of 40 pages. Here are two examples showing the wide scope of the thinking, a magnetic field to protect the inheritance between generations and attention to the moral and spiritual needs of the travellers.



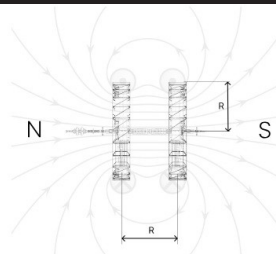
MAGNETIC FIELD

**LIFE IS UNSUSTAINABLE
WITHOUT A MAGNETIC FIELD,
BECAUSE SAFE PREGNANCIES
BECOME IMPOSSIBLE**

The chance of a successful pregnancy in deep space without a geomagnetic field is essentially zero. During mitosis and meiosis, microtubules depend on a stable magnetic field to orient the mitotic spindle and ensure accurate chromosome segregation — processes critical for embryonic growth. A spacecraft lacking any magnetic field would halt human reproduction, dooming both the mission and the survival of the colony.

To prevent this, our vessel was engineered with twin toroidal habitat rings whose radius R equals their separation distance — precisely matching the ideal Helmholtz-coil geometry. By wrapping each ring with N turns of conductor and driving a current I through them, we generate a uniform $\sim 50 \mu\text{T}$ field — equivalent to Earth's geomagnetism — throughout the living modules.

WFP Extreme page 8. Credit: WFP Extreme team



Helmholtz-coil formula used to calculate the required turns and current:

$$B = \frac{\mu_0 N I}{R} \left(\frac{4}{5} \right)^{3/2}$$

Where:

- B - the magnetic field at the midpoint = $50 \mu\text{T}$
- μ_0 - the vacuum permeability = $4\pi \times 10^{-7} \text{ H/m}$
- N - number of turns per coil = 700
- I - current through each turn = 20 A
- R - coil radius = 250 m

more info in *Biology*

8

MORALITY, ETHICS, RELIGION, MYTHOS



Religion

People will follow different religions in a **Common Chapel** will be established for spiritual growth.

Our priority is developing a sense of purpose and mission success. Moral and ethical principles will build from this foundation, under administrative oversight.

During the mission Earth knowledge about religions will be stored in databases, with options for spiritual growth available.

After the journey, some religions may survive, entirely new ones might emerge, or a religion based on mission success may develop.

Death & funeral

The human body provides valuable resources that can be recovered through freezing or lyophilization, carried out in a respectful, ceremonial manner. This process will take place with full dignity, honoring the deceased, and commemorated on a Memorial Wall aboard the ship.

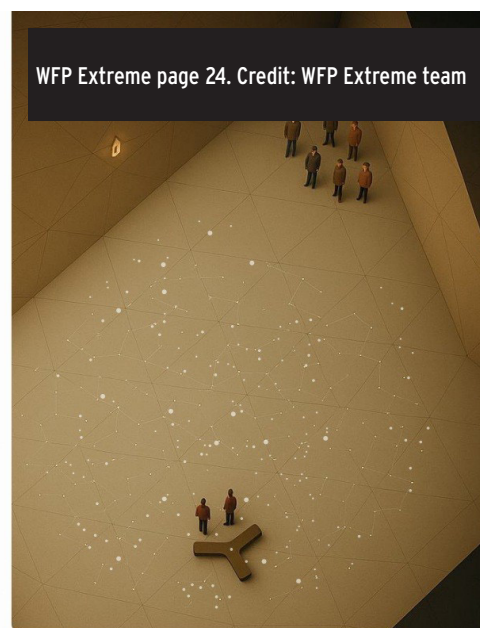
Tiles

The decorative floors of the ship's temple served not only as ornamentation but were also meant to encourage reflection and prayer. The tiles on the floor form a minimalist galaxy map — inviting contemplation of the passengers' journey as **cosmic pilgrims / wanderers** toward a new home.



Sacred Tree, in the Chapel's other part.
3d model → render

WFP Extreme page 24. Credit: WFP Extreme team



Common chapel; simplified illustration, tiled floor with galaxy map
3D model → chat GPT → postproduction

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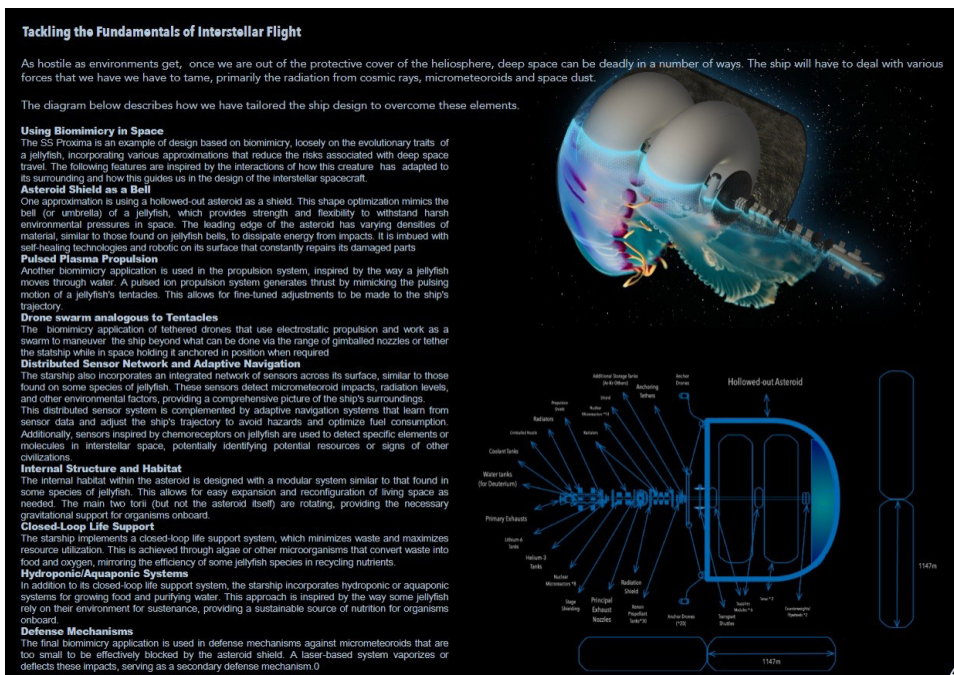
[1] www.projecthyperion.org/files/ugd/1dff9e_6d90df6fdfe14faab644745571b7f63f.pdf

Third Place: Systema Stellare Proximum

Systema Stellare Proximum distinguishes itself by its immersive storytelling, seamlessly tying together technical, social, and cultural aspects. This concept delivers a rich and imaginative narrative that thoughtfully weaves together social, technical, and cultural aspects of long-term space habitation. Its storytelling is engaging, with creative scenarios that explore community dynamics and even spirituality—emphasizing the role of shared values in building resilient, intergenerational societies. The use of an asteroid as a radiation shield is a bold and compelling strategy, paired with a visually striking structure inspired by the form of a jellyfish. While the physical feasibility of the thin-shelled asteroid could be further refined, the concept shows a solid understanding of cosmic radiation challenges. System-level planning is well-considered, and the presentation is detailed and visually dynamic, enhanced by artistic illustrations. This entry leaves a strong impression through its holistic vision and poetic approach to deep space living.

Team: Philip Koshy, Jan Johan Ipe, Amaris Ishana Mathen

The project website contains the whole team submission [1] of 40 pages. . Here are two examples showing the ship concept - rotating torus inside a hollowed asteroid and profound ideological fragmentation at end of mission.



Systema Stellare Proximum page 4.
Credit: Systema Stellare Proximum team



Systema Stellare Proximum page 38
Credit: Systema Stellare Proximum team

[1] www.projecthyperion.org/files/uqgd/1df9e_07324118b6d9407ab51d4aef3817bfd3.pdf

◀ Honourable Mentions

Ten teams received honourable Mentions for excelling in specific, thought-provoking aspects of their submissions that will advance the state of the art - in alphabetical order:

Arkkana - Excellence in considering the temporal dimension and evolving roles of the population over time.

EBS: Endless Beyond the Stars - Innovative "negotiopolis" concept that bridges architecture and social organization.

FAOC first asteroid O'Neill colony - Original architectural vision of integrating the habitat into an asteroid.

HELIOS ARK - A holistic approach and strong system-level coherence.

Orion - A thoughtful, low-tech design emphasizing knowledge and technology transfer.

Principium Hereditatis - A compelling narrative structure and a symbolically rich modular habitat.

STASS Associazione Professionale - Standout in knowledge transfer, immersive storytelling, and humanistic depth.

The Belgian Space Hikers - A highly creative take on the social dimension of space living.

undagila - A deeply poetic, culturally immersive vision with emphasis on intergenerational continuity, ritual, and symbolic heritage.

WeSpace - A cleanly presented, holistic design that balanced aesthetics with conceptual depth, including bio-inspiration and human-centric design.

Purpose, background and conclusion

Project Hyperion, founded in 2011, has built a track record of generation ship research. Notable work includes generation ship designs, population size, and knowledge transfer. Results were presented at ESA's Interstellar Workshop and in peer-reviewed scientific journals such as *Acta Astronautica* and *Acta Futura*. The i4is core team boasts multidisciplinary expertise – architecture, aerospace, anthropology, urban planning – and includes Andreas Hein, Yazgi Demirbaş Pech, Dan Fries, Cameron Smith, Michel Lamontagne, and Claas Olthoff, who have experience working at institutions such as NASA, ESA, and MIT, reinforcing its credibility and global vision.

A jury of internationally renowned experts, covering architecture, engineering, and social sciences was invited to evaluate the submissions, including A Scott Howe (NASA-JPL), Olga Bannova (University of Houston), Madhu Thangavelu (University of Southern California), Elena Rochi (Arizona State University). In conclusion the organizers issued a statement -

“Project Hyperion wasn’t just a design contest – it is part of a larger exercise to explore if humanity can travel to the stars one day. It envisions how a civilization might live, learn, and evolve in a highly resource-constrained environment, and may also provide valuable insights into our future on Earth.” said Dr Andreas Hein, i4is Executive Director.

“We asked participants to integrate architecture, technology, and social systems to conceptualize a functional society spanning centuries – and the outcome was beyond expectations.”

Winning entries will be published and showcased at future i4is and academic events. A closing ceremony is planned in 2025/2026 whereby winners will present their work. In parallel, we will draw inspiration from the various designs and start working on a detailed design of a generation ship to make further progress towards demonstrating the feasibility of the concept.

Principium will invite competition participants to write for the magazine reflecting on their work, discussing their future plans or commenting on this important potential direction for our species.

Press and web interest

Project Hyperion has gathered much interest since the announcement of the results. Here are just a few of the items we have noticed. Please let us know if you spot anything else of interest - email john.davies@i4is.org.

Universe Today

"The Winners of the Project Hyperion Generation Ship Competition have been Announced!" by Matthew Williams in Universe Today - August 2, 2025 www.universetoday.com/articles/the-winners-of-the-project-hyperion-generation-ship-competition-have-been-announced.

This 2,300 word essay is the most extensive report we have seen so far. Our thanks to Matthew and to Universe Today.

Universe Today

The Economist

"How to build a ship for interstellar travel - Winners of a design competition include conjoined Ferris wheels and a 58km-long cylinder" in The Economist - 31 July, 2025 www.economist.com/science-and-technology/2025/07/31/how-to-build-a-ship-for-interstellar-travel. This 830 word piece has an audio readout available in a voice which sounds remarkably like the Voice of the Book, played by Peter Jones, in the original Hitchhikers Guide to the Galaxy.

The Economist is, of course, a very serious newspaper and this article is mostly serious though it cannot resist a little mild jocularly describing the Project as "...what may be the world's first serious (or, at least, semi-serious) competition to design a ship to boldly go where no one has gone before, and settle a planet circling another star."

The Economist

nextBIGfuture

"Winners of Interstellar Generation Ship Design Contest" www.nextbigfuture.com/2025/08/winners-of-interstellar-generation-ship-design-contest.html on nextBIGfuture August 3, 2025 by Brian Wang. A brief account of the competition results focusing on the first place winner.

nextBIG FUTURE

Interesting Engineering

"36-mile-long cigar-shaped starship could take humans on first interstellar trip" interestingengineering.com/space/engineers-propose-multi-generational-spacecraft

-reporting that - The ultimate goal would be to reach and settle on the potentially habitable exoplanet Proxima Centauri b. This is the Chrysalis Project, an award-winning design for a hypothetical starship that could carry up to 2,400 people to Alpha Centauri – our closest stellar neighbor.

INTERESTING ENGINEERING

The Guardian

"Beam me up, jellyfish: experts unveil spaceships to take us to the stars" www.theguardian.com/science/2025/aug/06/spaceships-design-stars-craft-interstellar-travel-project-hyperion

The Guardian continues the rather tongue-in-cheek theme with subtitle "Winner of Project Hyperion design contest envisions polyamorous people thriving onboard cigar-shaped craft". Sadly reporter David Batty betrays his scientific illiteracy writing

"Hyperion, a spacecraft which resembles the space station from 2001: A Space Odyssey. The twin rings of this design are engineered to generate an Earth-like magnetic field, which would be essential for a successful pregnancy in deep space, without which the mission would be doomed." Michael Faraday might have put him straight or perhaps any random science sixth-former.

The Guardian UK ✓

◀ However, the blunder is not repeated in the 7th August print edition, see below.

The paper interviewed Dr Andreas Hein, as follows -

Dr Andreas Hein, the executive director of the Initiative for Interstellar Studies, which ran the competition, said it was "part of a larger exercise to explore if humanity can travel to the stars" and how "a civilisation might live, learn and evolve in a highly resource-constrained environment". He added: "We asked participants to integrate architecture, technology and social systems to conceptualise a functional society spanning centuries - and the outcome was beyond expectations."

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National

The Guardian. 7th August page 12

Out of this world: the winners of interstellar spaceship competition

David Batty

Spaceships modelled on jellyfish, 3D-printed homes, polyamorous relationships and vegetarian diets are among the ways in which experts have envisaged making interstellar travel feasible.

Scientists, engineers, architects and social theorists responded to a global competition to develop plans for "generation ships", self-sustaining crafts capable of supporting up to a total of 1,500 people over a 250-year journey to a habitable planet.

Entrants to the Project Hyperion design competition, launched last year, could only incorporate current technologies or those expected to emerge in the near future, such as nuclear fusion, into their proposals.

An expert panel, including Nasa scientists, judged the viability of almost 100 submissions, assessing how their habitats, architecture and

social structures would allow the crew to flourish as a society across multiple generations of space flight.

The winner was Chrysalis, a 36-mile long cigar-shaped craft, designed around concentric cylinders, each dedicated to a different function: 3-D-printed living quarters; communal spaces, including parks, libraries and galleries; and farms and biomes of different environments, such as tropical forests.

Animals would be onboard only to maintain biodiversity, so a vegetarian diet would be necessary.

The design won praise for how the psychological resilience of the crew would be vetted by living in isolated Antarctic bases. The proposal also explained how family structures would change, with sense of belonging based on being part of the starship community. Inhabitants would be allowed to have children but not necessarily with the same partners.

The design that came in second place was WFP Extreme, a spacecraft



► Chrysalis, a cigar-shaped series of cylinders, won first prize. Above, WFP Extreme, which came second, resembles something from 2001: A Space Odyssey



ILLUSTRATIONS: WFP EXTREME; CHRYSALIS

that resembles the space station from 2001: A Space Odyssey. Judges praised the design's particularly strong focus on cultural and societal dimensions, including concepts like clothing and spiritual spaces.

The proposal includes three pairs of turtles, chosen for their longevity, the fact they are relatively inactive and their resistance to disease.

The third place design, Systema Stellare Proximum, is modelled after the shape of a jellyfish and uses a hollowed-out asteroid as a shield against impacts. It envisages a society guided by a non-human collective intelligence and human council. Judges liked its designers' "poetic approach to deep space living".

Other notable entries included Endless Beyond the Stars, which included light created from biogas, generated from dead bodies.

Dr Andreas Hein, the executive director of the Initiative for Interstellar Studies, which ran the competition, said it was "part of a larger exercise to explore if humanity can travel to the stars" and how "a civilisation might live, learn and evolve in a highly resource-constrained environment".

He added: "We asked participants to integrate architecture, technology and social systems to conceptualise a functional society spanning centuries - and the outcome was beyond expectations."

Popular Mechanics

"If Another Home For Humanity Is Out There, This Spaceship Could Get Us There"
www.popularmechanics.com/space/rockets/a65601801/hyperion-contest-spaceship/
 with a brief and well informed story, noting for example that a even a 400 year journey is "ridiculously fast" - which it is by currently achieved standards.



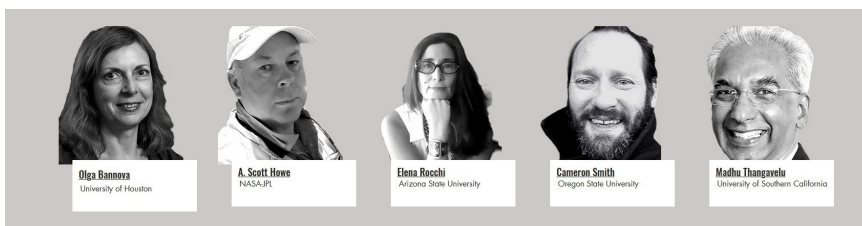
Daily Mail

The Mail publishes images from the Project Hyperion report on its TikTok account with a brief but fairly accurate account and an interesting comment from TikToker Bra Kondo D'Sai TV "So many people here saying it's cruel to the Unborn children just don't get it. It's like saying having a child in a poor country is cruel because the child will grow up poor and probably without a father. But then you find that people in villages are just happy in their own rights. Children born on the spacecraft will adapt to their environment and they might even be the envy of many young people back on earth."



Times Radio

Andreas did a brief interview with the Jane and Fi show of the Times Radio: www.thetimes.com/podcasts/off-air-with-jane-and-fi



The Project Hyperion team thank the jury -

"The submissions were evaluated by our esteemed jury, comprising distinguished professionals with extensive experience in architecture, engineering, and social sciences."

News Feature: Breakthrough Discuss 2025

More reports and a wider perspective

Gurbir Singh

Our last issue P49 included David Gahan's report on proceedings. Here Gurbir Singh (astrotalkuk.org/) delivers two specific reports on topics which caught his eye, *Soaring over the surface of Titan* and *Tiny Cubesat with interstellar Ambitions: The Toliman Space Telescope*.

But we begin with his wider personal perspective on Breakthrough, the conference and its long established chair Dr Pete Worden.

The conference was recorded and is available at -

www.youtube.com/playlist?list=PLyF3OMOIy3nEM6rWMGZ9oTbFX2Kt5W_I3

Breakthrough Initiative - A Decade On

On 14 October 1959, a spacecraft Luna 2, impacted the Lunar surface close to Mare Ibrum. It was launched by the USSR and arrived on the Moon two days after launch. It is the first object made on Earth to travel to the surface of another world. A decade later, spacecraft from Earth arrived on Venus and Mars. In the 21st century, spacecraft have arrived on the surface of Titan, asteroids, and even a comet. Five spacecraft have left or are on a trajectory to leave the solar system. In one lifetime, Interplanetary exploration has become almost routine. But where are we on our quest for interstellar exploration? So far, exploration of the Solar system has been in the purview of national governments, predominantly the USA and the Russian Federation (formerly the USSR) and, in the case of Cassini-Huygens and Hyabusa, the European Space Agency and Japanese Space Agency. Interstellar exploration is many orders of magnitude a more challenging ambition. The immense challenges of interstellar exploration include vast distances, technological innovations, enormous timescales, and a novel funding source. Could the Starshot Initiative from the Breakthrough Foundation be the solution?

The Breakthrough Initiatives are the brainchild of a physicist, entrepreneur and investor - Yuri Milner. Breakthrough Starshot is a \$100 million research and engineering program aiming to demonstrate proof of concept for new technology, enabling ultra-light uncrewed space flight at 20% of the speed of light and laying the foundations for a flyby mission to Alpha Centauri within a generation. The Starshot initiative is a proof-of-concept launched by Yuri Milner and Stephen Hawking in 2016 and is funded by the foundation established by Yuri and Julia Milner.

Milner identified the discrepancy between the outstanding scientific question of our time, Life in the Universe. But he says, "On the bright side, that means it could offer considerable scientific return on investment".

Initiated in 2012, the Breakthrough Prizes are a set of annual international awards in the fields of Mathematics, Life Sciences, and Fundamental Physics. The awards are part of the "Breakthrough initiatives" founded by Yuri Milner and his wife, Julia Milner. Laureates receive \$3 million each in prize money (funded by Yuri and Julia Milner and others, including Sergey Brin and Mark Zuckerberg) during a televised award ceremony designed to celebrate their achievements and inspire the next generation of scientists. Breakthrough Prize was the first and is now joined by Breakthrough Listen, Breakthrough Watch, Breakthrough Message and Breakthrough Starshot.

- » Breakthrough Listen is targeting the 1,000,000 closest stars to the Earth, is the largest-ever scientific research program looking for evidence of civilisations beyond Earth. The radio and optical surveys will cover more of the sky, deploy more instruments in more locations, have higher sensitivity and take advantage of state-of-the-art digital signal processing and artificial analysis tools.
- » Breakthrough Watch is a program to look for Earth-like planets within 20 light years, starting with the nearest Alpha Centauri system. If life exists on these planets with Earthlike characteristics (of temperature, pressure, rocky surface, and potentially water), then the tell-tale signs of biosignatures and techno signatures could make that breakthrough and detect the very first unambiguous signs of extraterrestrial life.
- » Breakthrough Message is an initiative designed to address the question, if the existence and the whereabouts of the first extraterrestrial intelligent civilisation is finally confirmed, what do we say to them? The content of the message is the primary focus, but so are the questions of who decides what form (language) the message will take, how it is constructed and who will send it. As the Apollo 8 astronauts recalled following their 1968 trip to the Moon, "We set out to explore the moon and instead discovered the Earth". This is perhaps the most profound of all the initiatives, as it will allow us to learn about ourselves - even if no message is ever sent.

These Breakthrough Initiatives can inform and direct each other. Results from Watch and/or Listen may direct Starshot and message.

Dr Pete Worden

Pete Worden chairs the Breakthrough Discuss conferences and actively discusses the themes of all the Breakthrough initiatives, emphasising their interdisciplinary nature and focus on fundamental questions about life and intelligence. His interest in space and astronomy started as a boy when he asked his mother, "Okay, what do people do that study stars?" And she called astronomers."

Pete Worden had a long distinguished career with a background in the military, specifically mentioning work with the Air Force, Space Command, missile defence, and being instrumental in the responsive space program during his active duty. He worked on arms reduction with the USSR during the Cold War. In around 1982, long after the Apollo program, Pete Worden applied unsuccessfully to NASA's astronaut program. During his time as the director of Ames Research Centre, he met Apollo 15 Command Module Pilot Al Worden. Both came from Michigan and were able to determine that Al Worden's family was part of the extended Worden family in Michigan that had adopted Pete Worden's grandfather. In 2015, he left as head of NASA AMES Research Centre to become the chairman of the Breakthrough Foundation. In this role, he provides strategic leadership and oversight of the Breakthrough Initiatives suite. Reflecting on his 2015 meeting with Yuri Milner, he recalls, "he asked me to be the chairman of the overall foundation, not just the executive director of the initiatives, and so we've been at it about 10 years, and I think we've made major accomplishments".



Dr Worden at Breakthrough Discuss 2025, Oxford UK

In his 2021 publication "Eureka Manifest", Yuri Milner asserts that "unlike organisations, businesses, companies or even nations, human civilisation can be seen as an entity that lacks a common mission. In the absence of that vision, humanity hinders its collective progress and, thus, in the end, its potential for long-term survival." But he does not simply assert his views as words on a page; by funding a series of apolitical, multidisciplinary, international initiatives, he hopes to make progress in the most challenging questions of our times.

Reflecting on the big question at the root of all the initiatives, Worden says, "I think we're going to find pretty strong evidence of life within a decade. Probably with our own solar system... so I think we'll find life within a decade.... but I'm virtually certain we're going to find life everywhere within a decade". On the question of intelligent life, he said "whether we find evidence of intelligent life that's .. who knows. You know and again it depends on what we mean by intelligence."

Links

breakthroughinitiatives.org/
breakthroughinitiatives.org/yuri-milner
breakthroughinitiatives.org/manifesto
en.wikipedia.org/wiki/Pete_Worden

Soaring over the surface of Titan

In December 2034, a spacecraft will enter the atmosphere of Titan. Two hours later, it will softly land at the equatorial region and begin a 3-year-long exploration of Titan's atmosphere, surface and subsurface. It does not have wheels but rotors. In dozens of hops over the duration of the mission, it will investigate different regions of Titan using various instruments to investigate the nature of the prebiotic chemical process still active on Titan. It is probably similar to the chemical processes that prevailed on the early Earth before life and biology transformed the land, oceans and atmosphere that we experience today. This NASA spacecraft, Dragonfly, will be launched in July 2028.

Sometime in the very distant future, an uncrewed interstellar probe made by humans will arrive for the first time on the surface of another planet orbiting another star. How that future spacecraft will explore the alien world will be modelled by what Dragonfly will do on arrival at Titan in December 2034.

In an interview during the Breakthrough Discuss conference on April 24, 2025, Dr Elizabeth Turtle, principal investigator on the Dragonfly mission, provided an overview and update on the Mission. She characterised the mission by saying, "Dragonfly really is fundamentally a chemistry mission". Titan has a "very complex carbon chemistry with large carbon-rich molecules forming in the atmosphere and falling onto the surface, where the bedrock is water ice, and there might be places where it has melted". A key objective is to "understand how chemistry has progressed in this world in the outer solar system and what that can teach us about the kinds of complex chemistry that occur before chemistry takes the leap to biology".

Dragonfly was selected in 2019. It is the second mission to Titan following the Cassini-Huygens mission, which was launched in 1997 and arrived at Saturn in 2004. It was a joint mission—NASA provided the Saturn Orbiter Cassini, and the European Space Agency developed the Titan lander Huygens. Saturn orbits the sun every thirty years. Dragonfly is targeting this next launch window of July 2028. The Dragonfly spacecraft has recently successfully completed the Preliminary and critical design review, so the project team based at the Johns Hopkins Applied Physical Laboratory is engaged in building and testing the spacecraft and its subsystems.

Dragonfly will not have wheels but skids and will not rove on the surface of Titan but fly through its atmosphere. As Ingenuity has demonstrated on Mars, exploring a new world by flying from one spot to another offers opportunities to sample multiple locations and a wider aerial view of a new landscape. With its five instruments, Dragonfly is primarily a portable, flying chemistry lab that will investigate the chemistry of Titan's atmosphere, surface and even subsurface over a nominal three-year lifetime. The five instruments include a Mass Spectrometer that will analyse Titan's chemistry and look for amino acids, fatty acids and sugars. A drill (actually two - one on each skid) will dig a few centimetres into Titan's surface and pass the contents to the mass spectrometer for analysis.

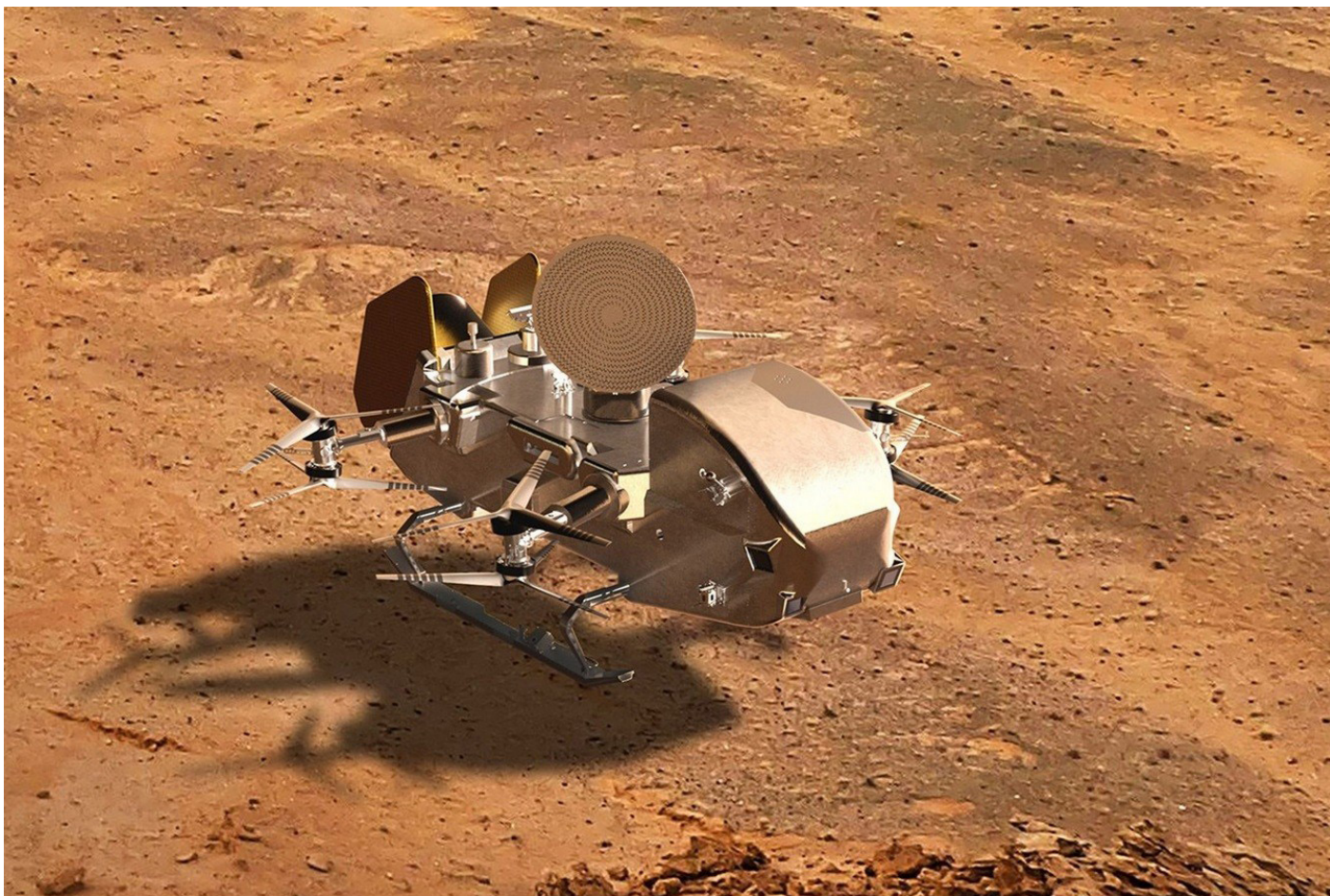
The Gamma-ray and neutron spectrometer is a two-part instrument. An onboard pulsed neutron source generates and fires a stream of neutrons at the surface. The interaction between this beam and the constituents of Titan's surface generates gamma rays. These gamma rays are detected and analysed to identify the presence and relative quantities of elements such as hydrogen, nitrogen, oxygen and minor inorganic elements like sodium and sulphur. Interesting results may be followed up by collecting samples from the identified interesting locations for further analysis by the mass spectrometer.

A collection of sensors make up the Geophysics and Meteorology instrument. Between them, they will measure atmospheric conditions, including temperature, wind speed and direction, and humidity (of methane) that will help understand Titan's methane cycle. The Earth has a water cycle; Titan has a Methane cycle. It is possible that Dragonfly may detect and measure methane rain and snow. One of the sensors will be capable of detecting seismic activity. If such activity is detected, it will allow scientists to understand the internal structure and activities deep below the surface.



Dr Elizabeth Turtle, principal investigator on the Dragonfly mission

◀ Dragonfly will carry a suite of cameras. Downward-facing cameras will capture images during initial descent, landing, and subsequent flights. A series of forward-looking cameras will capture the ambient landscape and closely examine the surface immediately below Dragonfly. Multi-spectral LED illumination will mitigate the weaker illumination on Titan's surface and be capable of detecting certain organics (especially polycyclic aromatic hydrocarbons) via fluorescence. On Earth, some life forms make use of fluorescence. The Dragonfly is not expecting such sources, but if they are present - well, who knows! Dragonfly's instruments and subsystems, including the motors that allow it to fly, will be powered by a Multi-Mission Radioisotope Thermoelectric Generator. It will provide power for everything, including communications, using the 1 m high-gain antenna. There is no relay satellite. Cassini served that role in the case of Huygens in 2005. Dragonfly will communicate directly with Earth from the surface of Titan. Dr Turtle indicated that Dragonfly will collect the "same amount of data that we got from the Huygens probe every Titan day". Given the Earth-Titan distance of around ten astronomical units, where a round trip (Titan-Earth-Titan) will take around 90 minutes. The data rate is expected to be low due to the very low temperature and thick atmosphere.



Artist's concept of NASA's Dragonfly on the surface of Saturn's moon Titan. The car-sized rotorcraft will be equipped to characterize the habitability of Titan's environment, investigate the progression of prebiotic chemistry in an environment where carbon-rich material and liquid water may have mixed for an extended period, and even search for chemical indications of whether water-based or hydrocarbon-based life once existed on Titan.

Credit (image and caption) NASA/Johns Hopkins APL/Steve Gribben

The end of life for Cassini was disintegration during a high-speed encounter into the atmosphere of Saturn in September 2017. Huygens had transmitted for around 2.5 hours during its descent to the surface and another 2.5 hours from the surface. Huygens's mission ended when Cassini, its communication relay to Earth, lost line of sight of Titan. Huygens remains frozen where it landed. That will ultimately be the fate of Dragonfly. The limiting factor is the heat output from the MMRTG. Eventually, this heat will not be sufficient to keep the interior of the lander warm. Despite that point being in the far future, Dr Turtle, with a voice broken by emotions, says, "It's a little heartbreaking to say, but the final state of the mission will be frozen on the surface of Titan".

◀ The Dragonfly Mass Spectrometer (DraMS) is a central instrument for analysing Titan's chemistry. Derived from previous successful Mars missions, its primary objective is to identify the inventory of prebiotically relevant organic and inorganic molecules on Titan's surface. It can analyse samples from different geologic settings, measuring molecular masses up to approximately 2,000 Daltons. DraMS helps determine if complex organic synthesis has occurred and searches for potential building blocks for life like amino acids and sugars. It operates in multiple modes, including analysing samples collected by DrACO and atmospheric gases.

The Drill for Acquisition of Complex Organics (DrACO) is the system responsible for collecting physical samples from Titan's surface and near-surface for delivery to DraMS. Developed by Honeybee Robotics, it consists of two rotary-percussive drills mounted on the landing skids, providing redundancy. DrACO is designed to obtain samples from the top few centimetres of the surface. Once collected, samples are pneumatically transferred through a hose using a blower mechanism, similar to a vacuum cleaner, into the mass spectrometer for detailed chemical analysis.

The Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS) instrument is used to determine the bulk elemental composition of the ground beneath and around the lander without requiring sample collection. Because Titan's atmosphere blocks cosmic rays, DraGNS uses a pulsed neutron generator to excite gamma-ray signatures from the surface. It measures the abundances of major elements such as carbon, nitrogen, hydrogen, and oxygen and minor inorganic elements like sodium and sulphur. This provides a rapid chemical reconnaissance of landing sites, classifying surface materials and guiding decisions on which locations are most scientifically interesting for sampling with DrACO and DraMS.

The Dragonfly Geophysics and Meteorology package (DraGMet) is a comprehensive suite of sensors dedicated to monitoring Titan's atmosphere and subsurface. It measures atmospheric conditions like temperature, pressure, wind speed and direction, and methane humidity, contributing to understanding Titan's methane cycle. Additionally, sensors on the landing skids assess the properties of the surface material and electric fields, which can probe the depth of Titan's subsurface ocean. DraGMet also includes a seismometer to detect ground motion and Titanquakes, providing insights into the moon's internal structure and seismic activity.

The Dragonfly Camera suite (DragonCam)/NavCams, the DragonCam, including the navigation cameras (NavCams), provides the mission's imaging capabilities for both science and operations. It includes panoramic cameras for detailed site surveys, forward and downward cameras for in-flight imaging and landing, and microscopic imagers to examine high-resolution sampled materials. DragonCam's images characterise geologic features, terrain morphology, and surface materials' size, shape, and colour, providing crucial context for sample analysis and understanding material transport. Cameras are also vital for navigation, scouting potential landing sites, and safe flight operations.

Links to more on Dragonfly

www.nasa.gov/missions/dragonfly/nasas-dragonfly-tunnel-visions/
astrobiology.nasa.gov/news/nasas-dragonfly-mission-will-seek-clues-about-titans-habitability/

Tiny Cubesat with interstellar Ambitions: The Toliman Space Telescope

The very first confirmed detection of an extrasolar planet came in 1992. It is called PSR B1257+12 b and is also named Draugr. It is about the mass of the Earth orbiting a millisecond pulsar in the constellation of Virgo, more than 2,000 light years away. Detecting extrasolar planets is tricky because they are tiny, very far away, and usually so close to the host star that they are lost in its glare. Traditionally, large aperture Earth-based and highly specialised space-based telescopes are required to detect and observe extrasolar planets. A new Cubesat with a single instrument, a 12.5 cm telescope, has the potential to reframe capabilities associated with CubeSats. It's called the Toliman Space Telescope.

Just as the Moon has been our stepping stone for interplanetary exploration, the Alpha Centauri, our nearest star system, will be a stepping stone for interstellar exploration. The TOLIMAN (Telescope for Orbit Locus Interferometric Monitoring of our Astronomical Neighbourhood - should you be interested!) space telescope is a new low-cost mission concept for detecting exoplanets. It has a single instrument, a 12.5 cm telescope and (initially) a single target - the Alpha Centauri System (toliman.space/). The technology around which this mission is centred is the science behind high-resolution astronomy.

◀ One of the pioneers of this technology is Professor Peter Tuthill. He has led the development of the aperture masking interferometry at the heart of the Toliman Space Telescope. He is a professor of physics at the University of Sydney and the principal investigator on the Toliman mission.



Dr Karel Valenta
Toliman Space Telescope project director,

In an interview conducted during Breakthrough Discuss in Oxford in April 2025, the Toliman Space Telescope project director, Dr Karel Valenta, outlined the project's origins, objectives and current status. The origins were directly linked to a call for proposals by the Breakthrough Foundation aimed at exploring the Alpha Centauri system. The fundamental scientific goal of the mission is explicitly stated as searching for Earth-equivalent planets in our stellar neighbourhood, with a particular focus on Alpha Centauri. Regarding the current state of the project, he said, "We are currently at the stage when we are really actively building and integrating the spacecraft .. almost the entire telescope is ready... we are aiming for launch in 2026".



Professor Peter Tuthill,
The University of Sydney
Principal Investigator on the Toliman
mission

What makes the mission possible includes several novel technologies. The 12.5 cm aperture TOLIMAN Space Telescope is designed for the detection of exoplanets using the astrometry method. It involves precisely measuring stellar positions to track the tiny angular displacements of the star imposed on it by the gravity of orbiting exoplanets. The goal is to find potentially habitable rocky planets, particularly Earth-mass objects, in the habitable zone of Alpha Centauri A or B. Subsequent to the primary object, other stars will be targeted.

The Diffractive Pupil Optical Mask is affixed to the front of the telescope. It contains features embedded in the pupil that cause starlight to diffract in the image plane, creating a complex pattern of interference fringes. This provides the micro-arcsecond astrometric precision needed to detect the small wobble induced by Earth-mass planets.

Embedded Spectrometer. The diffractive pupil carries an embedded spectrometer or a second set of diffractive features. These features function as a slitless spectrograph performing real-time spectral monitoring of the star. Dr Valenta emphasised the precision involved with the Toliman mission. Measuring a star's wobble, representing only 100,000th of a pixel on the sensor, is "unbelievable" and "many many folds times harder than finding the needle in the haystack."

An onboard Space Edge Computer running custom-built software from an Australian start-up will process massive amounts of data in real time using AI technology. It will use dLux, an open-source differentiable optical modelling framework for image processing. This onboard assessment, reduction and compression of the data will minimise the quantity of data (expected to be around 6 TB) and the time needed for regular (every other day) downlink. Toliman will only be able to observe for around 25 minutes during each 90-minute orbit. Toliman will use a commercial ground station operator called Leaf, which is based in Italy. Ground stations in Patagonia, Europe, Australia and Alaska may be used to collect the data from orbit. Following initial processing, the data at an online location will then be shared among its partners. Three-axis satellite stabilisation has been around for decades. Toliman will employ a bespoke Tip tilt system and critical thermal control systems to maintain the high-precision pointing and stability required for high-precision scientific observations.

Despite its relatively small size and low cost, it will involve scientists, engineers, commercial companies and organisations from multiple nations, including Australia, Japan, Italy, France, the Netherlands, the UK, the USA and Korea.

Toliman is expected to be launched to a 600 km polar orbit. The launch costs are estimated to be around half a million USD. The launch provider has not yet been finalised, but it could come from the USA, Korea, Japan, or New Zealand. The primary target for Toliman, the Alpha Centauri system, dictates specific orbital characteristics that the launch provider must meet.

Cubesats have traditionally been the starting point for space missions for students, startups, and non-profit organisations. The challenges for the Toliman mission are not unlike those for any space mission. However, with low cost, a small team located around the globe, and an array of innovative technologies, it could be a mission that elevates the capabilities of CubeSats.

Letter to the Editor

Where do you look for ET?

A paper in Acta Astronautica

An overlooked Schelling point candidate for optical SETI: 'MiM'

David F Gahan

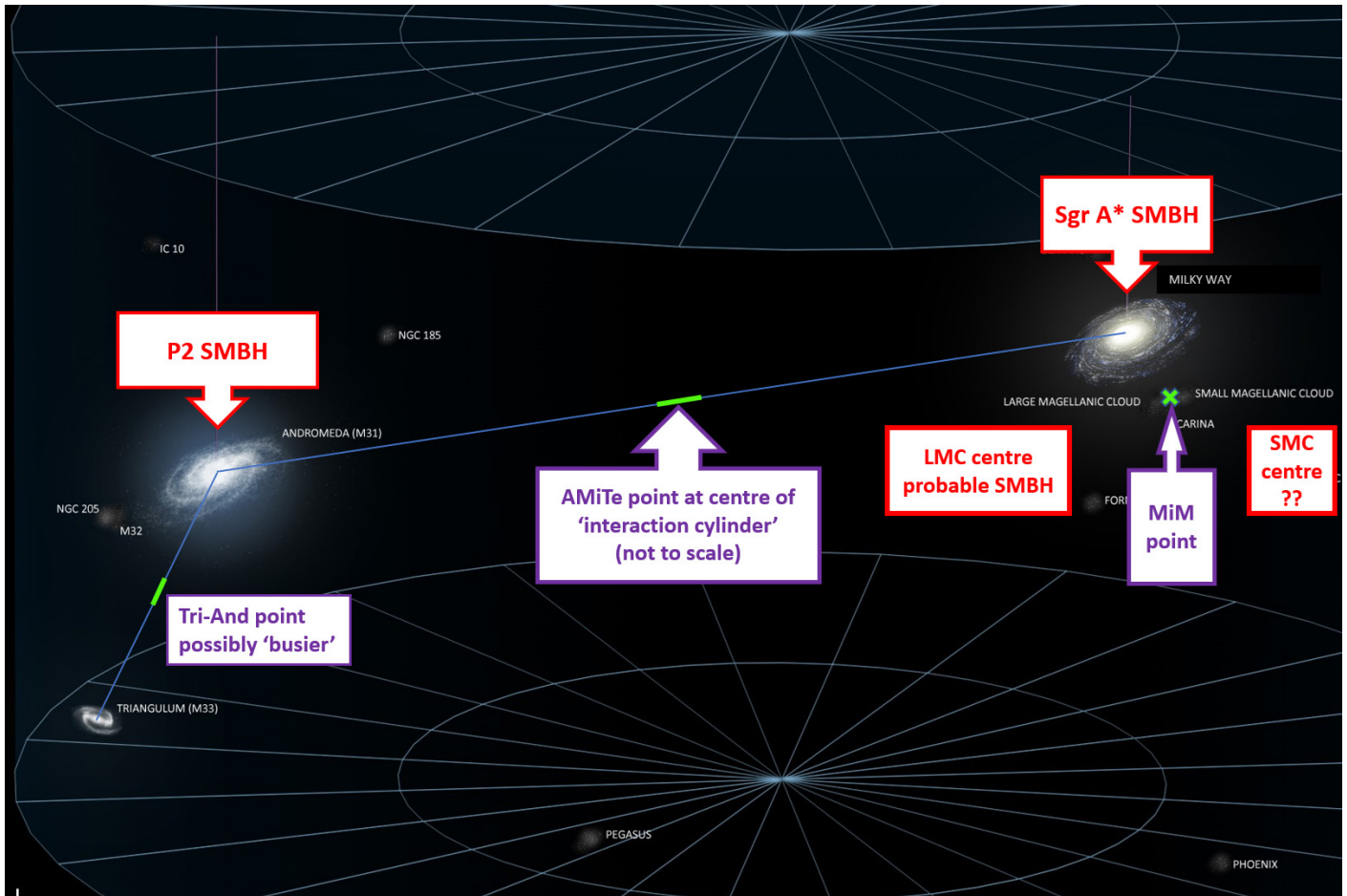
David Gahan is a physicist and entrepreneur who has contributed much to Principium and interstellar studies. In this latest communication he brings us up to date on a subject he has been working on in recent years. In particular in a recent paper for the peer reviewed journal, Acta Astronautica. The author would like to thank John Davies of i4is for help and advice, Michel Lamontagne and Robert Freeland for discussions on Project Icarus and Jason Wright for discussions on Schelling points.

"Where do you look for ET?"

Can there be any answer to that question that makes sense? We've been looking since the 1950s but 'Space is big, really big...'. One answer is to consider from the problem that Schelling posed: "if you have to meet someone in New York City tomorrow but can't communicate, what is your best option on where to go?" That's a Schelling Point, one that both you and the person you hope to meet could mutually guess. ([en.wikipedia.org/wiki/Thomas_Schelling#The_Strategy_of_Conflict_\(1960\)\)](https://en.wikipedia.org/wiki/Thomas_Schelling#The_Strategy_of_Conflict_(1960))).

The most likely answer back in the '50s was the viewing deck of the Empire State building. But in space? Now you have to consider whether you're dealing with Apes, Angels or Men. Don't write off the Apes; they just need time to - bang the rocks together? - and then they'll be as good as us and probably behave like us, so time is the only barrier. But we can write off Angels because they're not here. Something may prevent species like ours ever becoming omnipresent and omnipotent in our own galaxy. So if we limit our search for 'people like us' who are limited to power sources we can pretty much scope out - fusion power and fusion drives - then the BIGNESS OF SPACE becomes the limiting factor, and this includes how far a transmitter can signal and be picked up by the sort of tech we can imagine. It would help, wouldn't it? to have a unique place that everyone knew about to go look for signals. The only location that has been proposed hitherto is the galactic centre. Unfortunately, it's a very nasty place! In addition to the super-monstrous black hole SgrA*, there are (by x-ray observation) probably a million stellar-mass black holes flitting around it. Even a space captain of Luke Skywalker's skill would need all his time and energy dodging problems, let alone set up a beacon. In the very long timescales for a beacon to be of any use, even stars aren't safe as they can be ejected by interactions with the black hole. Need somewhere quieter. In my AMiTe Treffpunkt paper *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations*, Principium 32 February 2021 (i4is.org/wp-content/uploads/2021/06/AMiTe-Treffpunkt-Principium32-print-2102221659-opt.pdf) I proposed the AMiTe point mid-way between the Milky Way and Andromeda galaxies, a great place for chains of starships to thread through and exchange information, but way too far for a beacon to signal with any reasonable chance of refuelling.





Meeting places in our galactic neighbourhood.
Credit: David Gahan from AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations, Principium 32 February 2021

However, there was another point in that paper also defined by Local Group geometries, the 'MiM' (mid-Magellanic) point. At the suggestion of Mike Garrett, academic director of Jodrell Bank, I expanded that idea into a paper. I'm pleased to say that it was accepted for publication by the prestigious Acta Astronautica in June. Sadly, as I wasn't funded for the work and 'Open Access' is very expensive (if not backed up by an institution) it's not available for free unless you have academic access. Partial access to give you a flavour can be seen at *An overlooked Schelling point candidate for optical SETI: 'MiM'*, Acta Astronautica Volume 235, October 2025, Pages 251-257 (www.sciencedirect.com/science/article/abs/pii/S0094576525003455).

The intention of going for publication in a peer reviewed journal is a hope that the precise co-ordinates of the MiM point will encourage observers in the southern hemisphere to point telescopes - the new 'Vera Rubin' would be nice! As any realistic search would take a few decades under the specimen calculations in the paper, even with an expensive asset such as Vera Rubin or ELT, there's a low cost method proposed. Maybe if the idea found favour with the 'Breakthrough Listen' project then a search of this unique point in space could, literally, be 'scoped'. Hence the paper. Any developments on this score will of course be reported in Principium.

Edited by John I Davies

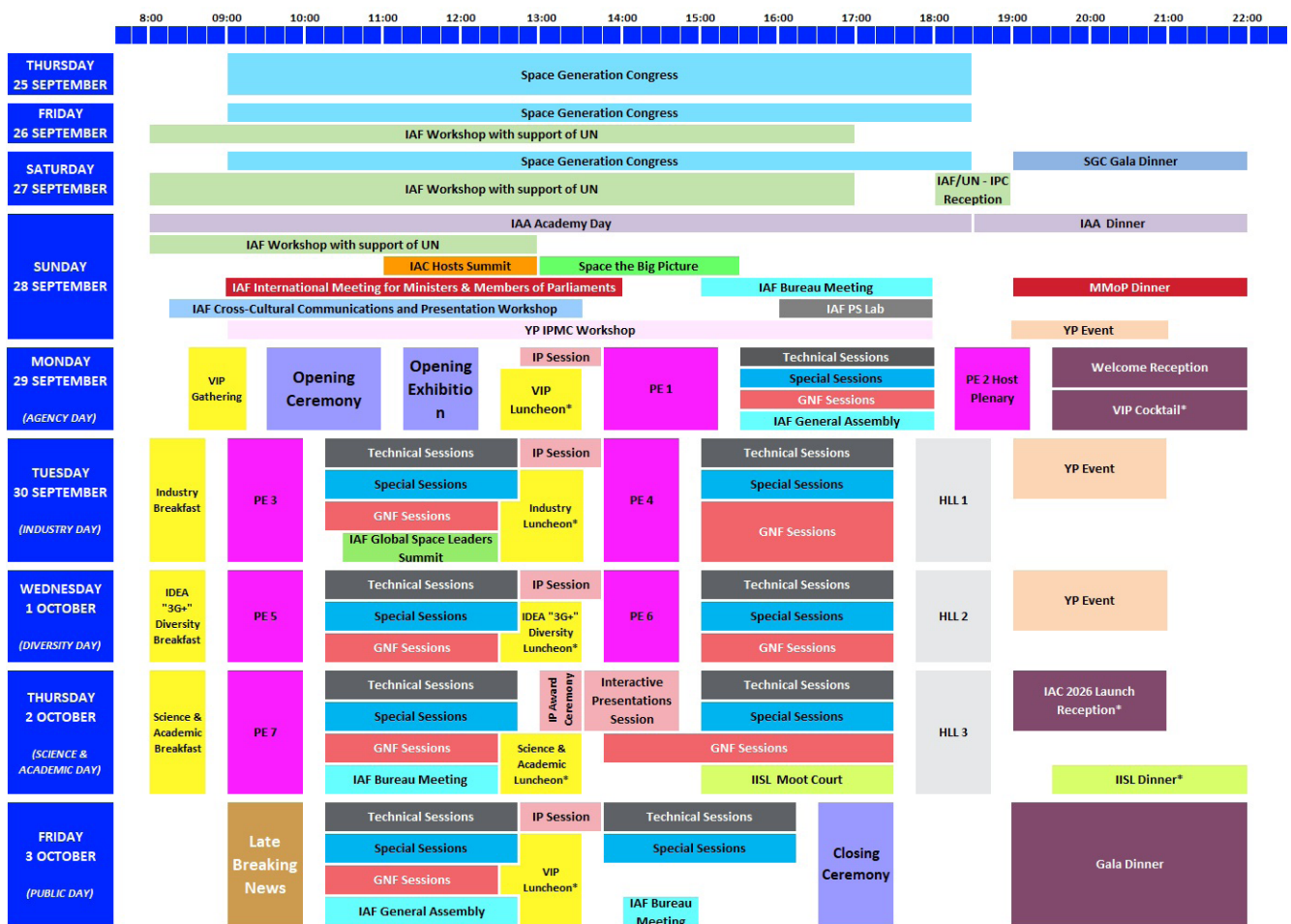


Image Credit: IAF

Each entry is headed -

IAC25 ref	title	author	institution	country
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- and is followed by the abstract.

SETI 1: SETI Science and Technology

A4,1,1,x98468	Enhancing the Breakthrough Listen Technosignature Search with Advances in Anomaly Detection	Dr Steve Croft	University California Berkeley	USA
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Breakthrough Listen, the planet's most comprehensive search for technosignatures, continues to acquire vast amounts of data from telescopes around the world and in space. Classical techniques have been applied to look for candidate technosignatures, but the enormous data volumes make this challenging, and existing approaches may miss certain types of interesting signals. The Listen program has also employed a variety of anomaly detection techniques that are complementary to existing algorithms. Some of these involve machine learning, whereas others employ novel statistical techniques to find signals missed by the standard pipelines. In other cases we can use new algorithms to vet signals found using classical approaches. I will discuss the use of these algorithms on current and future datasets at optical and radio wave-lengths, how they are being used to constrain the occurrence rate of technosignatures, and synergies with anomaly detection techniques being used in other areas of astronomical observations and engineering.

A4,1,2,x98893	Technosignature Searches with Very Long Baseline Interferometry (VLBI)	Dr Dong-Jin Kim	CSIRO Astronomy & Space Science	Australia
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Recent advances in radio telescope technology, combined with a surge in exoplanet discoveries, have significantly refined the search for extraterrestrial intelligence (SETI). Researchers now integrate machine learning techniques, sophisticated data pipelines, and dedicated observing programs to accelerate radio SETI investigations. In particular, future instruments such as the Square Kilometre Array (SKA) and the next-generation Very Large Array (ngVLA) are expected to further enhance detection capabilities and broaden the scope of these studies. However, SETI faces challenges from numerous human-made radio frequency interference (RFI) signals. To tackle this, Very Long Baseline Interferometry (VLBI) is employed, providing a powerful method to distinguish nearby artificial signals from potential extraterrestrial sources. Specifically, VLBI can filter RFI by analyzing signals across multiple baselines, enabling precise localization and trajectory determination of detected signals. This approach was demonstrated using the Long Baseline Array (LBA). Our project includes characterizing planetary satellite signals, conducting wide-band VLBI surveys of exoplanets in habitable zones, and performing follow-up VLBI observations of promising SETI candidates initially identified by Breakthrough Listen surveys. A notable example is the VLBI observation of signals from multiple satellites at X-band. The fluctuating phase and delay rates, driven by the satellites' motion, show how VLBI can effectively rule out RFI sources within a few hundred astronomical units of Earth. To support these efforts, we have developed specialized data reduction and analysis pipelines tailored for VLBI-based SETI observations. These pipelines are expected to play a key role in future high-sensitivity surveys, advancing the search for extraterrestrial intelligence with unprecedented precision and reliability.

A4,1,3,x103208	Breakthrough Listen Search for Intelligent Life Towards the Galactic Center and Plane	Ms Karen Perez	Columbia University	USA
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The discovery of nearly 6,000 exoplanets over the last decade has increased the possibility of life beyond Earth and motivated the continued Search for Extra-Terrestrial Intelligence (SETI). Breakthrough Listen (BL) is a 10-yr initiative conducting the most sensitive and comprehensive search for advanced civilizations to date, with the Galactic Center (GC) and Galactic Plane (GP) as two primary observational targets to search for artificial signals from ETIs. The GC has the highest number density of stars within the Galaxy and its line-of-sight offers the largest integrated Galactic star count of any direction in the sky. Additionally, it is widely cited as a possible location for a beacon built by advanced intelligence, and is the Milky Way's most energetic region. Likewise, the GP is an ideal direction to search for such signals due to the increased likelihood that transmitters would emit toward this region as opposed to random directions. Given the potential for discovery in the GC region, the BLGC survey is covering 700 MHz to 93 GHz using the Parkes Telescope, Green Bank Telescope (GBT), and the Sardinia Radio Telescope (SRT). In total, we will conduct 350 hours with the Parkes, 267 hours with the GBT, and 150 hours with the SRT; to date, 33% of these observations have been completed and 13% analyzed. This is the most extensive SETI survey of the GC to date. In addition to the search for technosignatures, the GC is a rich target for natural astrophysical phenomena, such as pulsars orbiting the central super-massive black hole, Sgr A*, and exotic systems like millisecond pulsars in binaries with black holes. Following Phase I of the BLGC survey (Gajjar et al 2021), I will present updates on our progress, current coverage, projected timelines, and ongoing analysis for various kinds of narrowband and broadband signals, including channel-wide periodic

signals with BLIPPS (Suresh et al 2023) and artificially dispersed broadband bursts using SPANDAK (Gajjar et al 2022). Notably, our 1-hour scans represent the longest continuous integrations ever used for SETI. This GC survey complements and extends the BL GP survey conducted with the Parkes Telescope 21 cm Multibeam receiver, which covered roughly 3,000 square degrees during 1,200 hours, and will also be briefly discussed here (Perez et al. 2025, in prep.)

A4,1,4,x96981	First results of the LOW Frequency pulsar, FRB, and Technosignature Survey	Mr Owen Johnson	Trinity College Dublin	Ireland
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The search for technosignatures – evidence of extraterrestrial life – addresses one of the most profound questions in science: Are we alone in the Universe? Concurrently, the recent flourishing of the field of radio transients has significantly advanced our understanding of various areas of physics. Notably, pulsars and fast radio bursts (FRBs) stand out due to their unique potential to uncover new kinds of physics. These astrophysical phenomena provide valuable insights into gravitational waves, cosmology, and plasma physics, among other fields. All of the above provides the basis for conducting a LOW Frequency pulsar and Technosignature Survey (LOFTS), which aims to search for a range of technosignatures and other transients at 110-190 MHz. Completed through weekly zenith observations using two international LOFAR stations. Here, the first results from the LOFTS survey will be presented, utilizing Breakthrough Listen pipelines to place limits on the prevalence of intelligent life in the Galaxy by searching for narrowband, periodically modulated, and non-naturally dispersed signals.

A4,1,5,x98357	SETI Search with SerendipVI at Medicina (I) radio telescope.	Dr Pierpaolo Pari	INAF - IRA	Italy
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At the Medicina radio telescope, the SerendipVI system collects and elaborates SETI signals in the 32 m dish antenna, together with the Nebula tools to process them. The system is up and running and we will present the results from the data analysis on observations of cluster galaxies we have listened to with the 32 m parabolic dish

A4,1,6,x95796	The VLA and High-Frequency SETI: Expanding the Search for Life	Mr Talon Myburgh	-	South Africa
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COSMIC (Tremblay et al, 2024, AJ) searches for exoplanetary technologies ("technosignatures") using the Very Large Array (VLA), by searching for narrow-band signals that drift in frequency over time due to Doppler motions. The first study for high frequency (25-50 GHz) SETI (Search for Extraterrestrial Intelligence) on the VLA was conducted from October 2023 through February 2024. Within the field of view of the VLA, COSMIC forms beams on exoplanetary sources. Gaia's nearest stars are selected from the DR11 catalogue (Czech et al, 2021, PASP), and the recorded results are examined for technosignatures. Using a Taylor tree de-dispersion (TTDD) algorithm within a real-time pipeline, each recorded beam (coherent and incoherent) is searched for drift-rate magnitudes up to ± 50 Hz/s. All detections are stored as "hits" with the relevant snippet of data stored for posterity. As part of the study conducted on data collected between October 2023 and February 2024, these hits were subjected to several computationally intensive discrimination filters to reject false positives caused by radio frequency interference (RFI), and 12 candidates were identified that required further investigation to determine their origins. The results of this study bound the uncertainty surrounding the prevalence of extraterrestrial life in the Universe and provided insight into the RFI environment at the VLA and the TTDD limitations. This work extends the study from February 2024 to the present and examines the impact of additional filters applied to the hits collection. As a final stage of the pipeline, through beam-forming and imaging, we aim to study these resultant technosignature candidates spatially and in full Stokes. The observable parameter space is therefore significantly expanded beyond that of the conventional SETI.

A4,1,7,x95497	High-frequency targeted SETI with the new MeerKAT band 5 receivers	Dr Andrea Melis	INAF - Istituto Nazionale di AstroFisica	Italy
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MeerKAT is an array composed of 64 13.5 m dishes and represents the main precursor of the SKA-mid radio telescope to which will be incorporated to form the final 197 antennas array envisaged for SKA Mid. MeerKAT is fully involved in the SETI project, specifically it is part of the large Breakthrough Listen telescopes network. So far, SETI searches have been mostly carried out at low/medium frequencies, current SETI trend is to widen the search at higher spectral frequency windows and the available instrumentation at the MeerKAT facility does not allow us to go beyond the S-Band (1.75 - 3.5 GHz). In addition, searches are carried out in commensal/piggyback mode only, ie no specific time is reserved for SETI studies to cover sky regions that might supposedly host life. The band 5 project, with which we will install new high-frequency receivers in the 8.3 - 15.4 GHz band, will overcome this limitation. INAF achieved a large funding in the framework of an European program and decided to devote part of the money to enhance the MeerKAT telescope. In the context of this improvement and the time needed to

◀ commission both technically (digitizers, receivers, compressors, software etc) and scientifically the whole instrument, SETI targeted time will also be allocated to conduct techno-signature studies at nearby stars with exoplanetary systems that could potentially be interesting to host (also) intelligence life. In this work, we will present the current status of the project as well as all of the effort to maximize the scientific return from SETI targeted time at high-frequency with the new band 5 MeerKAT receivers.

A4,1,8,x95702	Research into Unidentified Anomalous Phenomena (UAP) as an official academic research topic at a university	Prof Hakan Kayal	Julius Maximilians Universität Würzburg	Germany
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The Interdisciplinary Research Center for Extraterrestrial Studies (IFEX) represents a unique academic research topic at the Julius-Maximilians-University in Würzburg, combining research fields from the areas of space technology and research, Search for Extra Extraterrestrial Intelligence (SETI) and research into Unidentified Anomalous Phenomena (UAP). The centre has pioneered various space technologies and investigations, including AI applications in space, such as the nanosatellite SONATE-2 (launched in 2024), AI-supported SSA observatory or sensor technologies for Mars exploration. The presentation introduces the specific activities of IFEX in the areas of small satellite missions, space situational awareness (SSA), UAP research and SETI, and discusses the similarities and synergies between these areas, which can open up new perspectives and applications. It also shows how UAP research can be funded and successfully integrated into academic work at a university, giving the example of IFEX in Germany.

A4,1,9,x102728	Quantifying Stellar Activity Effects on Narrowband ETI Signals	Dr Vishal Gajjar	SETI Institute	USA
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Spectral broadening caused by plasma density fluctuations in the interplanetary medium of exoplanetary systems (Exo-IPM) poses a significant but largely unexplored barrier for detecting narrowband extraterrestrial technosignatures. Signals traversing these turbulent media experience frequency broadening, complicating their detection with conventional narrowband search techniques. Particularly at lower frequencies (below 500 MHz), this effect can be pronounced, broadening signals by more than 1,000 Hz, leading to substantial reductions in search sensitivity. With the recently acquired funding support, we have conducted a detailed theoretical study quantifying spectral broadening limits across different turbulence models, orbital inclinations, and stellar spectral types. In this talk, we will present our key findings and their implications for technosignature searches, highlighting how spectral broadening significantly influences detection strategies. We will also discuss how these insights can specifically inform future observational approaches, particularly for next-generation telescopes like the Square Kilometer Array-Low (SKA-Low) being built in Western Australia. Our results emphasize the importance of designing appropriate narrowband signal search strategies informed by intrinsic spectral broadening caused by Exo-IPM, ultimately optimizing the sensitivity of future radio technosignature surveys

A4,1,10,x103232	Gravitational Wave Communications: The Future of Interstellar Messaging?	Ms Samiksha Raviraja	Airbus Defence and Space	UK
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Traditional interstellar communication relies on electromagnetic waves, which are limited by interference, signal degradation, and speed-of-light constraints. Gravitational waves are ripples in spacetime caused by massive cosmic events. This could offer a potential breakthrough in a new form of deep-space communication. By potentially enabling information transfer across large cosmic distances with minimal loss of data or information. This paper will look into seeing the feasibility of recreating this phenomenon or utilising detected gravitational waves to see if information can be sent through them. Be it to keep communications going with a very far away space craft, or to look for ET life, the applications are many and will be explored in this paper. The paper will start off with studying theoretical models of encoding information within artificially generated gravitational waves, as well as potential transmission methods, such as controlled mass displacements or high energy laser induced spacetime oscillations. Then the paper will discuss the several technological challenges of detecting and decoding such signals, considering advancements in gravitational wave observatories like LIGO, Virgo, and LISA. Beyond human applications, the paper will investigate whether advanced ET civilizations could already be utilizing gravitational waves for interstellar communication. If so, SETI (Search for Extraterrestrial Intelligence) efforts may need to shift their focus from the electromagnetic spectrum to gravitational wave detections. This could be valuable information for future SETI work. The paper will define the technological, theoretical, and observational challenges, and how they can be addressed. This research hopes to provide a roadmap for developing gravitational wave-based communication and its potential to revolutionize our understanding of deep-space communication.

A4,1,11,x96711	Moon race, farside protection, United Nations.	Prof Claudio Maccone	International Academy of Astronautics (IAA)	Italy
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The Moon Race is in full swing as of 2025. The most important space-faring countries want to set foot on the Moon for a variety of purposes: national prestige, technological superiority and capitalist returns. But the exploitation of the Moon to increase Humanity's Scientific Knowledge has hardly any official place in this Moon Race. Five areas of the Sciences would greatly benefit if pursued on the Moon: 1) COSMOLOGY: only the radio silence still existing on the Moon Farside would enable us to check General Relativity predictions about the early stages of the Universe, like Dark Ages and the like. 2) ASTROBIOLOGY: Prebiotic interstellar molecules detected by their radio emissions could be found much better from the radio-quiet Moon Farside than from the overcrowded Earth Sky. 3) SETI & TECHNOSIGNATURES: since 1959 the largest radio telescopes existing on Earth have been occasionally used to search for "messages" or "hints" that Alien Civilizations exist. None was found, but the part of explored Milky Way is ridiculously small. SETI from Moon Farside is better. 4) PLANETARY DEFENSE: every asteroid and comet in the Solar System must flyby the Sun. Thus, the six orbital parameters of all asteroids and comets could be determined to a higher precision by optical telescopes set on both Nearside & Farside for the Moon. In turn, that would lead to a better estimate of the LEAD TIME, the time Humanity has to prepare for DEFLECTING SPACE MISSIONS. 5) WATER AT THE SOUTH POLE and other Moon venues shielded from the Sun Radiation. 6) LAVA TUBES as shelters from space radiation would be ideal for Human Settlements on the Moon.

A4,1,12,x94251	Machine Learning Applications in the Search for Extraterrestrial Signals	Mr Abbos Madmurotov	-	Uzbekistan
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The Search for Extraterrestrial Intelligence (SETI) has long been a cornerstone of scientific exploration, aiming to detect artificial signals from extraterrestrial civilizations. However, the increasing volume of data from modern radio telescopes poses significant challenges in traditional signal detection and analysis. This study explores the application of machine learning (ML) technologies to enhance SETI's signal identification capabilities. Objective: The primary objective of this research is to leverage machine learning algorithms to improve the detection and classification of potential technosignatures within large datasets. By identifying patterns and anomalies beyond the capabilities of traditional Fourier transform techniques, this approach seeks to maximize the efficiency of SETI data processing. Methodology: Our approach integrates supervised and unsupervised learning models to process spectrogram data obtained from global radio telescope networks. A convolutional neural network (CNN) is utilized to classify narrowband signals while isolating interference and noise. Additionally, we implemented an autoencoder-based anomaly detection system to examine previously unexplored signal types. The training dataset combines simulated extraterrestrial signals and real-world astronomical observations, ensuring a diverse input set. Results: Initial testing demonstrates a significant improvement in the detection of narrowband tecnosignatures, with a reduction in false-positive rates by 25%. The anomaly detection system identifies potential unknown signal types that do not fit conventional classifications, offering new avenues for SETI investigations. Furthermore, the integration of ML models reduces the computational time required for processing large-scale datasets by 40%, paving the way for near-real-time analysis. Conclusion: The results indicate that machine learning provides a transformative approach to SETI research, enabling the detection of weaker, more complex signals that might otherwise be overlooked. By integrating advanced ML techniques into SETI data pipelines, this work contributes to improving both the scalability and reliability of signal detection systems. Future efforts will focus on incorporating additional observational datasets and expanding the anomaly detection framework to enhance the search for extraterrestrial intelligence. This study demonstrates the potential of machine learning technologies to address the increasing complexity and scale of SETI research, offering a promising direction for future advancements in the field.

◀ SETI 2: SETI and Society

A4,2,1,x99676	The case of the EQ Peg hoax 25 years ago: Would a replay in today's media landscape have the same result?	Dr Carol Oliver	University of New South Wales	Australia
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Potential media reactions to a SETI post-detection event remain the subject of debate. The EQ Peg event, which mimicked media reaction to a potential detection a quarter of a century ago, presents an interesting case if seen in the light of media reaction today. While the event proved to be a hoax, the story reverberated around the world for more than a week – a much shorter timescale than it would take for a potential detection to be confirmed. The event resulted in two back-to-back papers by the authors of this paper. One paper looked at the response of the media and SETI scientists to the claim, and the other proposed an immediate reaction plan, highlighting the need for such plans in the face of potential future events. What have we learned from the event over the past 25 years? Today, fake news, polarisation, and alternative realities spread rapidly across social media. Divisions have deepened across whole societies, and conspiracy theories abound. More recently, generative artificial intelligence, with its ability to create and disseminate content, has unleashed new challenges in communicating the SETI endeavour among public audiences and created opportunities to help direct conversations, particularly in a post-detection event. Understanding and utilising these considerable media changes is not just a matter of interest, but a crucial aspect in the event of a putative signal detection that could hold the answer to one of our most profound questions: Are we alone in the universe?

A4,2,2,x99139	The History of the IAA Seti Permanent Committee - 2000 to 2009	Ms Lori Walton	Consultant	Canada
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This paper is the fourth in a series detailing the history of the International Academy of Astronautics (IAA) SETI (search for extraterrestrial intelligence) Permanent Committee. The IAA established the SETI Committee in 1974 in response to growing awareness that humanity might one day detect evidence of intelligent extraterrestrial life. The SETI Committee has a wide-ranging mandate to examine all aspects of the search for intelligent extraterrestrial life, including international issues, astrophysical and astronomical observations, biochemistry, exoplanets, complex life and evolution, planetary space missions, SETI search strategies, and the societal, legal, and political ramifications of a confirmed detection. The IAA SETI Committee, now in its 51st year, is the only international entity that meets annually to organize symposia, select papers for publication, address specialized topics in SETI, and collaborate with other organizations. The founding and early activities of the committee, up to 1999, have been described in three previous papers. This paper focuses on the committee's activities throughout the 2000s, a decade that began with a key presentation by IAA SETI Committee members to the United Nations Committee on the Peaceful Uses of Outer Space. The presentation outlined a position paper on potential transmissions from Earth in response to a confirmed detection of extraterrestrial intelligent life. Throughout the 2000s, the SETI Committee worked on updating the 'Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence' and grappled with the emerging field of "active SETI." Key search efforts during the decade included the wildly popular SETI@home project, the long-running SERENDIP program, and optical laser searches. In 2007 the Allen Telescope Array became operational, and SETI search programs increasingly focused on examining newly discovered exoplanet systems for evidence of extraterrestrial technology. The decade concluded with the launch of the Kepler Space Telescope in 2009, ushering in a new era of exoplanet discovery.

A4,2,3,x101000	Patterns in Perception of a Simulated Message from Space	Ms Daniela De Paulis	SETI Institute	USA
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Between March and June 2024, we conducted a pilot project as a follow up to A Sign in Space. The initial project consisted in receiving a simulated extra-terrestrial message that was transmitted towards Earth, with a community of citizen scientists working on decoding the message. The project generated 6,639 images that represent the chronology of the visual analysis of the message by 137 citizen scientists from 24 May 2023 to 18 June 2024. The overall interpretation process of the message produced 55,006 posts over 120 chats, all collected on one Discord channel. The message image, called the "Star Map" by the citizen scientist community, was widely studied, and there were a total of 285 active interpreters from various cultural and social backgrounds. The rich collection of interpretation data allows us to explore how humans in general and those from various countries responded to the message. What patterns emerged in the responses? What were the salient aspects of the message? We next ask if this is particular to humans or do other species recognize patterns in the message? We wondered how chimpanzees, next of kin to humans, would respond to the message. We conducted a study with five chimpanzees at a

sanctuary (Fauna Foundation) to systematically explore their reaction and potential interpretation of the stimuli. We conducted three separate experiments in a pilot study that established a methodology to collect chimpanzees' interpretations of the message. The chimpanzees directed behaviors toward the stimuli as compared to images with random arrays. The chimpanzees marked on the images with crayons in one experiment. While the study was limited in scope with only five chimpanzees, this methodology can be used for future research. By analyzing pattern recognition around A Sign in Space, our research aims at comparing interpretation results from various animal species, with diverse cognition, perception, anatomy, and ecological adaptations. This could help identify SETI's limits and strengths in interpreting a potential extraterrestrial signal or message. It would also help SETI in making predictions about possible forms of alien communication. By understanding how various species interpret the same message, we might be able to highlight possible pathways to cognition, generalised across various species. This knowledge would in turn help SETI make possible estimates on the cognitive patterns of an extraterrestrial species. The team on this proposal takes an interdisciplinary and humble approach to search for patterns of perception on Earthlings.

A4,2,4,x99704	SETI Post-Detection Protocols: Progress Towards a New Version	Prof Michael Garrett	University of Manchester	UK
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The International Academy of Astronautics (IAA) has long provided guiding principles for the response to a potential SETI signal detection. The foundational Declaration of Principles Concerning Activities Following the Detection of Extraterrestrial Intelligence, first formulated in 1989, has been widely recognised by the international scientific community. A supplemental set of draft protocols addressing the possibility of a reply to an extraterrestrial signal was prepared in 1995, with both documents presented in a position paper to the UN Committee on the Peaceful Uses of Outer Space. In keeping with the evolving landscape of SETI research, the IAA SETI Protocols were streamlined and updated in 2010. Recognising the need for continued adaptation, the IAA SETI Committee established a Task Group in 2022 to re-examine the protocols in light of recent advances in search methodologies, the expansion of international participation in SETI, and the increasing complexity of the global information environment. As SETI operates in a rapidly changing world, the protocols are considered a living document, requiring ongoing refinement to remain relevant and effective. A preliminary report was presented at the International Astronautical Congress (IAC) in Baku in 2023, outlining proposed revisions. This effort continued through the IAC 2024 in Milan, where a Draft Revised Declaration of Principles was presented, and initial feedback was received from the community, including members of the IAA SETI Committee. Since then, we have continued to seek broader community input, refining the proposed updates based on further discussions and consultations. At IAC 2025 in Sydney, we wish to present the outcomes and convergence of this process, including the finalised text of the revised protocols.

A4,2,5,x102557	The International Institute of Space Law SETI Working Group: Introduction, Overview, and Findings So Far	Prof Andrea Harrington	Institute of Air and Space Law, McGill University	Canada
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In 2024, the International Institute of Space Law (IISL) commenced a Working Group to address legal issues relating to SETI. The group substantially re-evaluated its mandate and recommenced its work from January 2025. The purpose of this paper is to provide an overview of the Working Group's efforts to this point. By presenting our findings at IAC, we hope to be able to engage and receive feedback from the wider SETI community, rather than just those linked with the IISL. The IISL has a long history of hosting subject-specific working groups under the umbrella of space law research, including the most recently completed efforts of the AI Working Group. The SETI Working Group is an interdisciplinary effort, not one simply limited to those who study law, policy, and the social sciences. By integrating participants across disciplines, it endeavors to provide insights that are comprehensive and match with the most current understandings in the field. The Working Group is tackling the issues through a sequential evaluation of five subtopics, preceded by establishment of underlying assumptions and definitions to be utilized by the group as a whole. The first subtopic addresses the legal implications of METI or "messaging extra-terrestrials." These efforts can be conducted by state or non-state actors, but can states be held responsible? Are there disclosure requirements for these activities? Are these activities governed by the existing international space law regime? Subtopics 2-5 address potential alterations to obligations of terrestrial states under international law that may occur. Subtopic 2 addresses the confirmation of extraterrestrial technology or discovery of such an artefact. Here, issues include potential responsibility to share information and the legal and ethical questions addressing whether a response could or should be

made. Subtopic 3 addresses first contact that could occur as an ETI response to human METI activities, direct outreach from the ETI, or human outreach after detection/confirmation. Here, the issues surround the potential human response. Who should respond and how? Is it possible to achieve co-ordination rather than fragmentation of contact? Do states bear responsibility for a response? Subtopic 4 addresses ongoing contact, managing the activity and responsibility for it. Finally, subtopic 5 addresses potential conflict that may arise between humanity and ETI. Is there a possibility for unified action, and if so how? What rules of warfare would apply? It's important to the group that issues of conflict with ETI do not dominate the final report.

A4,2,6,x99521	The Societal and Legal Consequences of Detecting Extraterrestrial Intelligence: A Governance Gap	Ms Shrawani Shagun	National Law University, Delhi	India
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The search for extraterrestrial intelligence (SETI) has long been a scientific endeavour, but its legal and societal implications remain largely unexplored in governance frameworks. While scientific protocols such as the SETI Post-Detection Framework provide voluntary guidelines for how an extraterrestrial signal should be discovered, no binding international legal framework addresses the political, ethical, and societal consequences of first contact. The Outer Space Treaty (OST) and other space law instruments are silent on governance mechanisms in the event of extraterrestrial detection, leaving a regulatory vacuum that could lead to geopolitical tensions, misinformation, and ethical dilemmas. The core problem is the lack of a structured, multilateral approach to handling the discovery and communication with extraterrestrial intelligence (ETI). If a signal is detected, who has the authority to respond? How should such information be disclosed to the public? What role do international institutions play in mitigating potential risks, including political instability, cultural disruption, and security threats? This paper explores the research question: Does the absence of a legal and institutional framework for extraterrestrial contact create risks for global security, governance, and social stability, such as the potential for geopolitical tensions, misinformation, and ethical dilemmas? This paper assesses existing protocols and their limitations by employing an interdisciplinary approach that draws upon international law, political science, sociology, and risk analysis. This research identifies patterns in governance failures and successes by examining historical instances of major scientific discoveries with global impact – such as nuclear technology and artificial intelligence. Additionally, it evaluates how different political and cultural systems might react to extraterrestrial discovery, highlighting the risks of disinformation, monopolisation of information, and geopolitical exploitation. This interdisciplinary approach ensures a comprehensive analysis of extraterrestrial intelligence detection's legal and societal implications. The paper argues that the current lack of legal and institutional preparedness could result in fragmented national responses, where individual states or private entities act unilaterally, potentially exacerbating global instability. It proposes establishing an international governance mechanism under the United Nations or through a new multilateral treaty to ensure transparency, ethical considerations, and co-operative decision-making. This mechanism would include a legally binding post-detection protocol, an international ETI response council, and mechanisms for managing public disclosure and media narratives. By framing extraterrestrial contact as a global governance issue rather than merely a scientific or speculative question, this research contributes to the emerging discourse on space law, security, and international co-operation.

A4,2,7,x103067	Refiguring Communication in SETI: Cybernetics, Analogy, and Improvisation in the Search for Extraterrestrial Life	Ms Kate Genevieve	University of Sussex	New Zealand
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The search for extraterrestrial intelligence (SETI) can benefit from a reassessment of how communication is defined and understood. This paper integrates cybernetic, ecological and creative theories of communication, drawing on the ecological cybernetics of Gregory Bateson, to propose a relational and process-oriented approach. Building on this semantic and epistemological emphasis, this paper presents Islands, an interdisciplinary art-science project developed in collaboration with SETI scientists, creative technologists, and performance practitioners. In terms of narrative, the project draws together insights from disaster studies in Oceania to examine how local narratives and adaptive governance models can inform SETI's post-detection frameworks and the challenge of imagining interspecies communication, recognising that any post-detection scenario unfolds within diverse sociopolitical and epistemic contexts. Novel to the SETI discussion, Islands employs digital techniques that leverage projective geometry to create a speculative topological research tool to model complex communication. This mathematical approach responds to and extends models based on projective geometry used to model intersubjectivity and conscious perception in affective Neuroscience and animal communication and explores the value of applying such methods to questions of the more-than-human. The practical implications of mobilising theoretical work on process in a way that brings together projective geometry, complexity science, and

bioacoustics to explore alternative topologies and sensory architectures, is to sketch methods that may support creative and responsive frameworks of communication and search. Proposing interdisciplinary topological methods attempts to leverage emergent possibilities in creative technology for SETI, with potential value for identifying systemic anomalies, adaptive structures, self-organising systems and encoded patterns in astronomical data. This paper argues that SETI can broaden its theoretical foundations with cybernetic methods capable of incorporating research on comparative cognition, non-human communication systems and enactive epistemologies. Aesthetic and technological approaches to communication, and to the context-dependent, metaphoric underpinnings of analogic and abductive thought and meaning-making itself, extend creative computational methods to approach philosophical and semantic questions in ways that suggest fresh approaches to the recognition and detection of non-anthropocentric modes of communication and technology.

A4,2,8,x102108	Space and Interstellar Travel and What We Want to be Remembered For - The Case for Indigenous Knowledges for Communication with Prospective ET's and for Human spaceflight purpose and a Collective Earth Message	Dr Sasha Alexander	Western Sydney University	Australia
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This paper presents a study comprising avenues to enhance engagement of space industries sharing of indigenous cultural perspectives in support of the health and wellbeing for human spaceflight and maximising the opportunities to connect with civilisations yet unknown or identified and how we capture earth-based cultural diversities and richness. The future of space exploration is envisioned and motivated to travel as far as possible in the pursuit of new knowledge and to explore new environments possibly inhabited. The prospect to engage has created wonderment and challenges on what to share and what format visual, auditory or other may engage with extraterrestrials optimistically in a non-combative way. In recent decades approaches to sharing cultural knowledge have included the 'Arecibo message' in 1974, space probes Pioneers 10 and 11 from 1972 with small metal plaques, Voyager 1 and 2 with gold-plated copper disk phonographic record with natural sounds, musical selections from different cultural eras initially in 1977, and an orbiting TESLA Roadster electric car one of the latest forays relaying the status of our world today and values of cultural origins. Voyager contents were assembled in part at Cornell University under planetary scientist Dr Carl Sagan including 115 images and a variety of natural sounds, spoken greetings from earth-people in 55 languages and physical recording disk technology was thought the most robust and ET approachable. Therefore, scope to reconsider what Earth and it's peoples could be remembered for is yet to be fully realised for series of cultural affirming actions in captured representations of a sustainable civilization often defined in continuity by recordings, patterns, motifs, totems, designs, architecture, science and advancing technologies. The 76th Annual International Astronautics Congress Sydney, Australia is being held on the lands of 29 clan groups of the Eora Nation which form part of over 600 indigenous nations and 250 languages in Australia and represent the longest continuous culture in the world at more than 65,000 years pre-dating Europe and the Americas. The contributions of this paper will be a series of reflections on past cultural indigenous engagement and cultural representations of space, astronomy, and contributions and opportunities that the space missions of today and tomorrow offer towards further discovery, to reinforce and promote indigenous cultures in space for the health, wellbeing, physical and cultural sustainability supporting Earth's continued future and the space missions that follow a shared and culturally respectful and enriched engagement model.

A4,2,9,x101040	A first contribution to the history of Italian SETI	Dr Paolo Musso	InCosmiCon Research Center	Italy
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The first seminal paper about SETI, Searching for Interstellar Communications, published in Nature on 19 September 1959, was written by an American author, Philip Morrison, and another Italian, Giuseppe Cocconi. Nonetheless, from then on, for 30 years Italy has not taken part in the research that arose from that article. But in 1990 two Italian guys, Claudio Maccone and Stelio Montebugnoli, met while participating in the Bioastronomy Meeting held in Val Cenis, and the history of Italian SETI began. From then on, the contributions by Italian investigators to search for extraterrestrial civilizations have constantly increased, both in number and quality, but so far nobody had tried to tell their history. In 2024, on the occasion of the IAC Milano 2024, a first contributions appeared, in a book written by myself (Ascoltando l'infinito silenzio. L'Italia e la ricerca delle civiltà extraterrestri), but which could count on several contributions from the main protagonists of Italian SETI. In this paper I present the main topics covered in the book and the possible future developments of this work.

A4,2,10,x99230	New Cosmic Perspectives: Indigenous Knowledge and SETI	Dr Alvin D Harvey	MIT	USA
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"Is there 'life' in the cosmos?" is a fundamental question that drives a multitude of international scientific and engineering endeavours. From SETI to astrobiology, the fundamental framing of this question from a Western scientific lens has already dictated fundamental assumptions. Such assumptions and resulting answers provide a concreteness to the interdisciplinary effort SETI that may limit its ability to respond to the consequences of detecting an extraterrestrial signal. Such an effort with a potentially globally impactful finding could be supported by additional frameworks of knowledge and science. Namely, Indigenous Knowledge Systems, representing perspectives, experiences, and philosophies of Indigenous People who have held relationships with land and stars across millenia may provide a more holistic understanding and response. In this presentation, this broad and exciting partnership area is investigated from philosophy to promising practices in mutually beneficial partnerships between the space community and Indigenous Peoples. Generational socio-ecological knowledge is diverse across the Indigenous Peoples and Nations around the globe. Respecting the contextual nature of Traditional Ecological Knowledge, while still acknowledging shared principles of Indigenous People, forms a flexible network of life practices that challenges and complements fundamental western scientific frameworks. In particular, the question of what "life" is from a shared Indigenous worldview diverges from Western science - a divergence that is representative in the differing treatment of biotic and abiotic elements of our terrestrial environments. Developed approaches based on Indigenous scientific values that favour respectful, inquisitive, and reciprocal relationships to alternate forms of "life" are also informed by lived experiences of colonization by "explorers" seeking resource extraction and "civilization development." These divergences and others are places of conversation, partnership, and co-creation that can grow the SETI community and further expand its cosmic outlook, communication, and purpose. This presentation will provide a grounded overview of ongoing successes and challenges in such partnerships across the space community that provides guidance on building SETI-Indigenous partnerships. Additionally, this presentation will touch upon the potential alignments and contrasts in scientific philosophies between Indigenous communities and SETI that could provide a basis for novel concepts and language on SETI's work and impact.

A4,2,11,x97016	Sustainability Puzzles and the Extraterrestrial Turn	Dr Chelsea Haramia	University of Bonn	Germany
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The goal of sustainability is often used to both critique and justify the accelerated development of humans' technological capabilities, leading to sustainability puzzles and various self-defeating solutions. Sustainability-reasoning also shows up in debates about detection of and contact with extraterrestrial others – for example, the Sustainability Solution to the Fermi Paradox. While it is indeed possible that the technological trajectory of some alien species has run roughly parallel to ours, speculation about the sustainability-practices of extraterrestrial others is at the same time yet another example of the cosmic mirror, wherein our reasoning about the cosmos reflects strongly back onto ourselves. SETI searches and debates regarding extraterrestrial technology can assist us in understanding our own technology and its potential trajectories. Sustainability discourse in technology ethics has taken a decidedly planetary and species-level direction, with theorists positing both a Terrestrial Turn based on Anthropocene concerns and the impact of the human species on geological and ecological systems, as well as a Structural Turn based on AI and digital technologies' embeddedness in humans' socio-technical systems—a turn that speaks to environmental concerns as well as social sustainability. In intersection with these moves, I posit the Extraterrestrial Turn, uncovering notable parallels among the puzzles we encounter in sustainability discussions regarding AI and other technologies on Earth and puzzles regarding outer space use and exploration of the Solar System and beyond. Both the Space Sustainability Paradox and the Sustainability Solution to the Fermi Paradox highlight legitimate fears about social and environmental activities that are not only deeply unsustainable but also deeply unwise. Such fears have led to worthwhile reasoning about the relevance of wisdom and the possibility of an aspirational Sapiezoic Eon in Earth's geologic record. I recognize moral wisdom as an important piece of a Sapiezoic solution to sustainability puzzles. I contend that sustainable technology goals should include contributions from extraterrestrial technology debates, specifically with respect to scope, teleology, and methodological tools. I conclude that both contemporary SETI searches for extraterrestrial technology and the ancient concept of moral wisdom together have an important role to play in sustainability debates regarding humanity's terrestrial and extraterrestrial futures.

A7.2 Science Goals and Drivers for Future Exoplanet, Space Astronomy and Space Physics

A7,2,1,x102212	Interstellar Probe: US Decadal Survey Recommendations and Strategic Next Steps	Dr Pontus Brandt	Johns Hopkins University Applied Physics Laboratory	USA
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In 2022, a four-year, NASA-directed concept study on a pragmatic Interstellar Probe was completed by Johns Hopkins APL and submitted to the US Solar Space Physics Decadal Survey. Released late 2024, the Decadal Survey Report recommended for the first time that the “NASA Science Mission Directorate (SMD) should develop a cross-divisional approach for planning, operation, and management of future projects and programs for interdisciplinary science. Specifically, . . . support development of a mission to interstellar space”. Interstellar Probe is a mission to escape the solar system to understand how the Sun upholds our protective magnetic bubble - the heliosphere. Targeting more than twice the distance of the Voyager mission, Interstellar Probe would explore completely new territory in the Very Local Interstellar Medium (VLISM) carrying a comprehensive suite of in-situ and remote instrumentation. On its escaping trajectory, flyby observations of unexplored dwarf planets and Kuiper Belt Objects would push our understanding of planetary system formation and evolution. Beyond the zodiacal cloud infrared measurements would uncover the extragalactic background light, providing new knowledge in to stellar and galactic formation. An Interstellar Probe is timely as recent findings indicate that the Sun is currently transitioning between two interstellar clouds. Furthermore, recent studies show that a few million years ago the heliosphere may have been wiped out for hundreds of thousands of years as it passed through a very dense interstellar cloud, pointing to a potentially game-changing role of the heliosphere in the evolution of our home in the galaxy. With Voyager going offline in the next few years, Interstellar Probe is also an urgent mission for NASA, for the US, and for the world as a whole. A trajectory through the forward hemisphere of the heliosphere would be accomplished by a launch in 2036-2042 using conventional chemical propulsion and a launch vehicle, such as the Space Launch System, Falcon Heavy, or Starship. A Jupiter Gravity Assist would propel the 860 kg spacecraft to between 5 and 10 au/year with the first dwarf planet flyby as soon as four years after launch, and arriving in the VLISM after only 12-24 years. The spacecraft is designed to a 50-year nominal lifetime using modern-day technology with two next-generation Radioisotope Thermal Generators ensuring 300 We at end of nominal mission. Here, we present an overview of the mission, discuss the decadal recommendations, the need for cross-divisional approaches and the strategic roadmap toward launching Interstellar Probe in the coming decades.

C3.5-C4.10 Joint Session on Nuclear Power and Propulsion Systems, and Propellantless Propulsion Innovative Concepts and Technologies

C3,5-C4.10,4,x103235	Cold Fusion in Space: A Game-Changer for Deep Space Propulsion?	Ms Samiksha Raviraja	Airbus Defence and Space	UK
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Long distance and duration space missions are limited by current propulsion and power generation technologies. Chemical rockets require excessive fuel, nuclear fission poses radiation risks, and solar energy is impractical for deep-space travel beyond the heliopause. This paper discusses a possible alternative called Cold fusion. Cold fusion is a theoretical energy source that could potentially provide almost limitless power with minimal radioactive byproducts. This could revolutionize propulsion and space infrastructure if realistically feasible and successfully developed. Recent research, advancements and breakthroughs in low energy nuclear reactions will be studied in this paper, the challenges in achieving sustained fusion reactions, and potential reactor designs optimized for space environments. Its advantages and risks will also be dived into. The possibilities cold fusion offers makes it a worthwhile innovative technology to look into and study the extent of its applications in space. If cold fusion can be harnessed, it could enable lightweight, high-efficiency propulsion systems, dramatically reducing mission costs. Besides just propulsion, cold fusion could potentially power future space colonies, providing a sustainable long term energy source for lunar bases, Martian settlements, and asteroid mining operations and any other mission that is away from accessible resources. However cold fusion is a very new arena and in early stages, and faces a good level of skepticism. The paper will study the current state of research around cold fusion, regulatory considerations, and potential ways to test cold fusion reactors in microgravity environments to understand more about how it reacts. Finally, the paper shall provide a roadmap to future studies, tests and applications specifically for space missions.

C3,5-C4.10,12,x103188	Experimental analysis of a Centrifugal Fuel Element from a Centrifugal Nuclear Thermal Propulsion Engine	Mr Spencer Christian	The Ohio State University College of Engineering	USA
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Centrifugal Nuclear Thermal Propulsion (CNTP) is an unproven Nuclear Thermal Propulsion (NTP) design with improved specific impulses than traditional NTP designs. While traditional NTP designs, such as those from the Rover and NERVA programs, have past experimental data on which to base design decisions, the CNTP design has been largely theoretical. Only a few models have been made to predict its operability and practicality. This work details the progress and operation of an experimental test environment at The Ohio State University to investigate the CNTP design. The primary focus of the test environment is the centrifugal fuel element, specifically its functionality and thermos-mechanical behaviour. The experimental data gathered from the test stand is vital to validating the models for the CNTP design. Initial experimentation has included a range of propellant flow properties, propellant outlet pore size, and rotation rates. Further advancements to the test environment are still needed to represent the materials and components from the CNTP design more accurately.

C3,5-C4.10,14,x95943	Mission Burn Characterization Using a Centrifugal Nuclear Thermal Rocket	Mr Mitchell Schroll	Propulsion Research Center, University of Alabama in Huntsville	USA
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A Centrifugal Nuclear Thermal Rocket (CNTR) is an advanced propulsion concept that would allow for a near doubling of specific impulse over traditional nuclear propulsion and quadrupling of specific impulse compared to traditional chemical rockets. However, this increased theoretical performance comes at a cost. Studies conducted during the ROVER/NERVA program and models developed for more modern nuclear engines show substantial mass cost to cool down the reactor after each engine firing. Additionally due to the dynamic nature of the liquid core reactor and centrifugal elements a more complex startup process is also required compared to traditional chemical rockets. The purpose of this paper is to investigate the transient operation modes of a CNTR and combine those results with previously conducted studies on steady-state operation to characterize the total system specific impulse. This result is then applied to a mission analysis model to determine the overall benefit of such a system. Using previously developed systems models an expanded transient state systems model was developed in Python utilizing OpenMC, CEA, RefProp and other open-source libraries. The code calculates the optimum operating conditions for the engine geometry provided then performs an analysis of the startup and shutdown conditions for a given burn length. From this data a total propellant mass, fuel burnup, and total impulse can be calculated. These parameters are then fed into a trajectory analysis model to determine the required burn lengths for the prescribed target destination and payload. The mission analysis was performed using a SysML model previously developed and modified to accommodate the CNTR system. The payload configurations were determined using the NASA Mars Reference Design Architecture 5.0 for a manned Mars mission and New Frontiers program requirements for outer planetary scientific missions. The results of the study found for the configurations considered that CNTR is viable for scientific missions to all the outer planets with mission durations closing in 12 years or less. Additionally, it was found that CNTR would be a viable upgrade to a manned Mars mission reducing total mass required by 100 mT and enabling round trip missions to less than 420 days.

◀ D4.4 Strategies for Rapid Implementation of Interstellar Missions: Precursors and Beyond

D4,4,1,x96464	Nuclear Electric Propulsion for Fast Interstellar Precursor Missions: Physical Limits on Performance	Dr Ralph L McNutt, Jr	The Johns Hopkins University Applied Physics Laboratory	USA
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Reaching “nearby” interstellar space is challenging due to the long distances and associated long travel times. Of 20 Interstellar Probe studies and concepts articulated from 1960 through 2022, three have been based upon nuclear electric propulsion (NEP), seen as an enabling technology relying on multiple years of continuous thrusting at large distances from the Sun. Promised large solar system escape speeds of 10 to 20 au/year depend upon decadal time scales for continuous thrusting combined with sufficiently large “specific power” for the combined spacecraft-power-propulsion system. The “figure of merit,” usually denoted by $\alpha\tau$, with α the power per unit mass (usually expressed as kilowatts/kilogram) and τ the thrust time of the system (typically in years). The former is often also expressed as the reciprocal “specific mass” (kilograms/kilowatt). Electric propulsion has become common for station keeping of near-Earth assets, but its use, in the guise of solar electric propulsion (SEP) relying on solar arrays for electrical energy, for primary propulsion in interplanetary space has been limited to date. The notable examples are Deep Space 1 (DS-1) (2.5 kilowatts, electric (kWe), launched 1998), Dawn (10.3 kWe, 2007), the Double Asteroid Redirection Test (DART) mission (6.6 kWe, 2021), and Psyche (19.2 kWe, 2023). No corresponding NEP systems have ever been built, much less flown: SNAPSHOT was a 500 We reactor 1 Paper ID: 96464 oral aimed to provide power to a small test ion engine (1965, failed after 43 days in orbit) and the Nuclear Electric Space Test Program (NEPSTP) was to have flown a mix of ion engines powered by a Soviet Topaz II (aka Enisey) reactor (35 kW, thermal/6 kWe thermionic, Preliminary Design Review (PDR) 1993 and then cancelled). Since NEP continues to be advocated as a primary solution for near-term interstellar exploration, we have examined the Master Equipment Lists (MELs) for various extremely deep-space missions, as a function of time and technological maturity to look for commonalities in what sort of $\alpha\tau$ parameters and other constraints may be implicitly imposed on notional interstellar missions. Examples include, durability, multi-year autonomous operation, decade-long reactor lifetime, and associated reactor and waste-heat rejection masses, as well as communication and science instrument requirements needed for a viable scientific mission toward the stars.

Co-authors

Prof Mike Gruntman, Viterbi School of Engineering, USC, United States;
 Prof Stamatios Krimigis, The Johns Hopkins University Applied Physics Laboratory, United States;
 Dr Pontus Brandt, Johns Hopkins University Applied Physics Laboratory, United States;
 Dr Elena Provornikova, Johns Hopkins University Applied Physics Laboratory, United States;
 Mr Michael Paul, Johns Hopkins University Applied Physics Laboratory, United States;
 Dr Paul Ostdiek, The Johns Hopkins University Applied Physics Laboratory, United States;
 Dr James Mastandrea, Johns Hopkins University Applied Physics Laboratory, United States;
 Ms Meagan Leary, Johns Hopkins University Applied Physics Laboratory, United States;
 Mr Steven Vernon, Johns Hopkins University Applied Physics Laboratory, United States;
 Mr Stuart Hill, Johns Hopkins University Applied Physics Laboratory, United States;

D4,4,4,x103236	META-STARWISP: An Autophagic Interstellar Probe	Haroon B Oqab	Space Canada Corporation	Canada
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As humanity sets its sights beyond the solar system, there is a need for dedicated interstellar precursor missions to explore and characterize the interstellar environment. Before we can send probes – or eventually crewed missions – to other star systems, understanding these conditions is essential for designing future deep-space missions that can withstand the harsh and unknown environment between the stars. In this talk, we introduce a novel concept for an interstellar precursor probe designed to push the boundaries of exploration beyond the heliosphere, into the interstellar medium, and to another star system. Meta-Starwisp, is an autophagic interstellar probe – a self-consuming spacecraft that is accelerated to relativistic speeds by beamed power. This proposed interstellar probe utilizes its own structural components as fuel integrating in-situ resource utilization with advanced propulsion, enabling extended mission lifetimes without reliance on external refueling. By gradually consuming non-essential structural elements, the spacecraft reduces mass while sustaining its journey, optimizing energy efficiency for deep-space exploration. Crucially, this system also allows for a controlled deceleration manoeuvre upon arrival at another star system, and maximize the scientific return of the mission. We will explore the key engineering principles behind this self-consuming design, its implications for long-duration interstellar travel, and its potential to pave the way for the humanity's initial missions to another star. This approach redefines long term space sustainability, offering a transformative pathway toward our interstellar future.

D4,4,5,x95149	Interstellar Travel That Uses Cosmological Entanglement, Topological Propulsion, and Mathematics' Riemann Hypothesis	Mr Rodney Bartlett	-	Australia
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Cosmological entanglement - not limited to laboratories and temperatures near absolute zero - might be achieved by adaptation of cosmology's holographic principle. The principle says the 3rd dimension results from information in a 2nd dimension. If every particle (even the photon and graviton) has many positive and negative electric charges that potentially cancel, the charges would - as electronics shows - produce binary digits making the 2nd and all dimensions programmable. By reprogramming that 2nd dimension, the 3rd dimension (and thus, distance) is feasibly totally removed between the centres of particles or wave functions, physically quantum-entangling them. Wick rotation's x-axis could describe the four known dimensions of space-time while its y-axis could describe the physical quantum entanglement of particles and waveforms achieved with the holographic principle. Being different from ordinary space-time and incorporating Wick Rotation's imaginary numbers, the holographic entanglement's lack of distances in space and time might produce "imaginary space" and "imaginary time". To understand topological propulsion, we start with a parallelogram. When a parallelogram is visualized in three dimensions, this physical cosmological entanglement can be compared to "collapse" of the 3-dimensional analogue of the parallelogram. The bottom and top would occupy an identical one-line space. This would result in a shape having two dimensions and a single surface viz topology's Mobius strip - along which particles like photons, gravitons, and electrons could travel. Electricity, and its associated magnetism, traversing an array of these single surfaces could produce what might be called "topological propulsion" and photon-graviton interaction could, using Einstein's 1919 paper "Do gravitational fields play an essential role in the structure of elementary particles?", produce any and all particles, forming a 100% emissions-free "topological manufacturing" which is applicable to every factory and powered form of transportation. This collapse is a form of warping of space. The Riemann hypothesis is concerned with "nontrivial zeros" on the "critical line", stating that these zeros lie on the vertical axis of the Complex Plane ie on the y-axis in then undiscovered Wick rotation. We saw how Wick rotation describes imaginary space-time. Since the critical line links Wick rotation to the Riemann hypothesis, spacetime may be describable by Riemann. The critical line pertains to zeros - so the distances in space-time that could be described by the Riemann hypothesis might equal zero, making time travel to both the past and future possible as well as making instant intergalactic travel feasible.

D4,4,6,x103127	Design of a Self-Sufficient generation for Interstellar Travel: Project Hyperion	Mr Saeed Vahdani	Space Generation Advisory Council (SGAC)	Iran
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The Hyperion Project's ambition is to design and test the feasibility of a self-sustaining spacecraft for a 250-year journey to a nearby exoplanet. The main focus of the study would be that which concerns interstellar exploration: sociocultural conditions, life support, propulsion, and long-term sustainability. One design challenge involves architectural provisions for artificial gravity within the ship to work against physiological degradation from generation to generation. The habitat is modulated to also contain radiation shielding, micrometeoroid protection, and modular adaptation to improve its resilience capabilities to deep space. A proposed optimal population size of 1,000,500 individuals is to be maintained for genetic diversity, social stability, and continuation of knowledge for maintenance of the ship and eventual settlement of planets. It is a bio-regenerative, closed-loop air, water, and waste recycling system that does not deplete resources. Food production includes hydroponics, cellular agriculture, and microbes. All of these methods maintain a healthy ecology. Industrial subsystems including additive manufacturing and in situ material recycling ensure that production continuities are always there for strategic production of tools, infrastructure, and even medical supplies. A governance model incorporating adaptive decision-making, education, and ethical frameworks would be fundamental for the eldership of societies succeeding each other across generations. A knowledge-preservation strategy would hedge against technological stagnation through the combined use of digital repositories, apprenticeship models,

and education assisted by artificial intelligence. The propulsion basis for this study centres on nuclear-electric propulsion (NEP) and highly efficient energy systems to provide the necessary delta-v for interstellar flight, and all of its needed redundancy and fault tolerance. A communication system with long-distance delayed messaging protocols ensures student research continuity and interaction with Earth. Technical aspects are being incrementally improved by means of computer simulations, integrated socio-cultural models and research from literature reviews, expert consultations, and 3D modeling software). In precision, habitat design maximizes modularity, flexibility in the workplace, and mass minimized. Sociological and psychological models assess the societal impact of multi-generational space travel. The current study details some of the critical trade-offs and engineering constraints, including mass budget, risk mitigation, and redundancy planning. Future work will delve into AI-controlled habitat upkeep, psychological adaptation mechanisms, and new propulsion that reduces travel time.

D4,4,7,x97805	The Cosmic Development Goals	M Tessa Rankin	International Space University (ISU)	France
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We propose a set of Cosmic Development Goals (CDGs) – a forward-looking framework to guide and encourage the international community in the responsible, sustainable, and equitable usage of space in order to maintain space as a domain of opportunity, co-operation, and shared prosperity for all. We are witnessing a transformation of the space sector with the involvement of new players including student and commercial enterprises, increased participation from new nation-states, and the expansion of public-private partnerships. As a result, the space environment is becoming increasingly interconnected and competitive and stands to gain from an outline of guiding goals that aim to align and co-ordinate all actors in transparency and accountability of space activities. The CDGs were drafted from modern-day insights related to space law, governance, sustainability, ethics, and industry trends drawing from literature on government policies, academic research, and perspectives of industry leaders, private stakeholders, and key investors in the space sector. From this literature, we synthesized the broad culmination of concerns of the developing sector and aligned the CDGs to encompass these issues and priorities such as environmental stewardship and the protection of space, equitable access to and sustainable use of space resources, the ethical considerations of human exploration and expansion beyond Earth, and the promotion of international collaboration for ethical governance of space. In this paper, we present the CDGs to help shape a future where space exploration and utilization can contribute to scientific innovation, economic growth, and international relations in line with global sustainability goals and the evolving needs of the space sector. By addressing both current challenges and leveraging emerging opportunities, the CDGs present an encouraging and adaptable method of balancing innovation and ambition while maintaining the peaceful and sustainable use of space.



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

Seven issues of JBIS have appeared online since our last issue, P49. They are - volume 77 issues #7 (July 2024), #8 (August 2024 Interstellar issue), #9 (September 2024), #10 (October 2024 Interstellar issue), #11 (November 2024) and #12 (December 2024 Interstellar issue). Of the 12 2024 issues six were Interstellar issues.

Volume 77 #8 August 2024 Interstellar issue		
A Case Study in Characterising Nuclear Propulsion Emission Signatures from Astrophysical Sources	Kelvin F Long	UK

The detection of propulsion and power emission signatures in deep space is made more difficult by the background of various astrophysical sources of different types. In this paper we consider the example of nuclear pulse propulsion, such as via using nuclear fusion reactions, and examine hypothetical scenarios for the expected emissions. We consider the case study of object XTE J1739-302, an astrophysical object believed to be a supergiant fast x-ray transient with a thermal bremsstrahlung temperature of 21.6 keV. We confirm its likely astrophysical nature, but demonstrate under what conditions its emission properties would match the expectations for an artificially generated propulsion signature as a means for guiding future observations, which would likely require a high Kardashev Type II advanced technological civilisation.

Migration to Gliese 710 Using Large Space Habitats Flying Rectilinear Trajectories	Gregory L Matloff	USA
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Gliese 710 (GL710) is a K7 dwarf star with no currently known planets. Observations using the Gaia space telescope indicate that this star will pass within about 0.2 light years of the Sun in about 1.35 million years. During this close stellar encounter, GL710 might be a tempting target for far-future residents of terrestrial space habitats seeking to expand beyond the solar system. It is demonstrated that a large space habitat departing from a parabolic solar orbit with a 0.45 AU perihelion could reach this star at its closest approach to the Sun in ~1,000 years along a rectilinear trajectory at a constant velocity of 63 km/s. If acceleration of a 3×10^9 kg space habitat is provided by a 30 nm thick pure aluminum disc sail, sail radius is about 800 km. Peak acceleration at perihelion is about 0.003 g. It is also shown that a pure aluminum sail will likely have no thermal issues during the 0.45 AU perihelion pass. Because Gliese 710 is only about 300 million years old, visitors from Earth in the far future may elect to seed habitable planets of this star (if they exist) with terrestrial life.

Three Principles for the Application of Artificial Intelligence as a Future Tool in the Search for Other Intelligences in the Cosmos	Elio Quiroga Rodriguez	Spain
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The author explores the integration of Artificial Intelligence (AI) in the Search for Extraterrestrial Intelligence (SETI) and discusses recent developments in this field. It highlights the detection of eight highly promising signals using historic Green Bank radio telescope in collaboration with Breakthrough Listen. Additionally, the study reveals signals from a dataset of 820 nearby stars, originally obtained from the Hipparcos catalog and analyzed using deep learning techniques, which suggest possible communication from extraterrestrial civilizations. The paper emphasizes the potential of AI in uncovering promising signals, while acknowledging the early stages of this approach. It also proposes three fundamental principles for AI's role in SETI, including the need to desensitize search criteria, explore diverse communication forms, and employ AI to create artificial constructs for analyzing non-human intelligence.

A Review of the Theoretical and Empirical Foundations of SETI	José Antonio Molina	Spain
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The search for extraterrestrial intelligence (SETI) is sometimes perceived as a futile activity carried out by a few dreamers. However, since its beginnings SETI has had the support of eminent scientists and its theoretical and empirical foundations are solid. Indeed, SETI starts with an evidence: intelligence exists in the universe because we exist. Since intelligence is a natural phenomenon, it is more likely that we are a particular sample of it rather than the only sample in the entire universe. On the other hand, we know that intelligence can become a remotely detectable astronomical phenomenon, because we are. Consequently, SETI is searching for natural phenomena that we know are possible, so all criticisms about the lack of scientific validity of SETI are wrong. Also, the attention that a scientific project deserves should not be measured based on its chances of success, but by the importance of its consequences for humankind.

Sub-Scale Demonstration of an Axial Pulsed Magnetic Nozzle for Nuclear Propulsion Systems	Nathan Schilling, Naoji Yamamoto, Taichi Morita, Hideki Nakashima, Kento Koba & Jason Cassibry	Japan/USA
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With current technology, a crewed mission to Mars takes 2-4 years, during which astronauts are subject to the dangers of cosmic rays and microgravity. Pulsed nuclear propulsion systems can reduce trip times by as much as 90%, due to their inherent high specific power (1-10 kW/kg). However, these systems face several technical challenges, namely high heat loads incident on the nozzle. Instead, it has been proposed to use a magnetic nozzle; a magnetic nozzle functions by directing the plasma exhaust with high-strength magnetic fields. Previous work investigated magnetic nozzles with the solenoidal topology, but recent work has suggested an alternate topology, the axial topology, to be more effective. However, this configuration has never been tested. In this work, the researchers conduct the first test of the axial magnetic nozzle. The nozzle is cylindrical, 0.12 m in diameter and 0.12 m in length with 40 struts. A current of 1 kA is run through each strut to produce a 1T field. The plasma is generated using a 1,064 nm Nd:YAG laser with a maximum energy of 0.65 J and a laser spot diameter of 0.5 mm. The researchers compare the experimental impulse bit with simulation results from the Smooth Particle Fluid with MAXwell equation solver (SPFMax) code. Impulse bit is estimated using a series of charge collectors. While the simulation predicts impulse bits between 6.8-7.3 μ Ns for the nozzle currents of 0 A and 1 kA, respectively, the experiment only measures thrust between 1.0-2.2 μ Ns for the same conditions. This difference is most likely due to differences between the computational model setup and experimental setup. Future work includes performing simulations that more accurately model the experimental setup, and devising alternate ways to more accurately estimate thrust from the charge-collector data.

Volume 77 No.10 October 2024 Interstellar Issue

Faster-than-Light Travel using Dark Energy Inflaton in a Compact Region of Spacetime

J A Morgan

USA

Dark energy dominates the mass-energy content of the present-day universe. A similar dominant component drove primordial inflation in the Big Bang. This paper explores how a sufficiently advanced civilization might manipulate a dark energy inflaton [1] for a form of faster-than-light travel. A solution of the Einstein gravitational field equations exhibiting highly anisotropic inflation in a compact region of spacetime illustrates the concept.

Detection of Warp Signatures for SETI

Travis S Taylor

USA

The search for extraterrestrial intelligence (SETI) has traditionally focused on electromagnetic signals. However, advanced civilizations may employ spacetime engineering methods, such as warp fields, that alter the fabric of spacetime itself. This paper explores theoretical approaches to detecting such warp signatures, including metric perturbation detection and experimental designs based on existing gravitational wave observatories.

Mission Architecture Calculations for the Enzmann Interstellar Spacecraft Concept

Kelvin F Long

UK

Strategies for sending human populations to other stars often involve large world ship structures, but must be preceded by lower mass, faster speed vessels carrying a smaller population of people to properly survey the planetary system of interest and any potential resources. Such a concept is presented by performing some modern calculations of the *Enzmann Slow Boat* starship which is a vessel designed to travel over interstellar distances within decades carrying a population of 100s-1,000s of people. Its unique design involves the use of a spherical mass of fusion fuel at the front of the vehicle which is replenished on arrival at the target system by mining from local gas giants. We demonstrate mission profiles using a 24-engine parallel thrust propulsion architecture for such a vehicle. In a modified concept we refer to as the *Long-Enzmann Slow Boat* it is envisaged that it would use gram-scale inertial confinement fusion capsules and may be aided with expellant propellant for thrust augmentation which reduces the quantity of thermonuclear fuel. This work is presented as a part of a larger attempt to construct interstellar roadmap planning and supplements the recently published world ship studies by this author.

The Ultimate Rocket, the Ultimate Energy Source, and Their Use in the Ultimate Future

Frank J Tipler

USA

The ultimate rocket is a rocket that has the highest specific impulse allowed by the laws of physics: $I_{sp} = c/g \approx$ thirty million seconds. I show that new experimental results in cosmology suggest how such a rocket might be constructed. Basically, the observed cosmological matter-antimatter asymmetry shows that baryon number and lepton number are not conserved at high energies, and thus it must be possible to convert matter into pure energy. Standard Model baryogenesis allows the reaction $p+e \rightarrow \nu + \bar{\nu}$, which would mean a rocket exhaust of neutrino-antineutrino pairs created from hydrogen atoms.

Neutrinos have very close to zero mass, so they travel at close to light speed. The reaction $p + e \rightarrow \gamma + \gamma$ is also allowed, which would be the ultimate energy source. I show that the laws of physics require the universe to be spatially closed, end in a singularity, and require our descendants to engulf the entire universe and construct a universal computer.

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

Torqued Accelerator Using Radiation From the Sun (TARS) for Interstellar Payloads

D Kipping & K Lampo

USA

The concept of exploring space using solar power is energetically appealing, but interstellar solar sails typically require extremely low areal densities ($\sim 0.8 \text{ g/m}^2$). This work explores an alternative approach: storing solar energy as rotational kinetic energy, which is later released to propel a microprobe beyond the solar system. The proposed Torqued Accelerator using Radiation from the Sun (TARS) consists of two thin surfaces with contrasting albedos that gradually spins up over weeks to months while in a sub-Keplerian "quasite" orbit around the Sun. Though constrained by material strengths, careful design allows a phone-sized payload to reach interstellar velocities in less than a year, using commercially available materials (eg CNT sheets). The entire system spans tens of metres and has a mass in the order of a kilogram. Whilst there is no theoretical limit to the achievable speeds, practical designs grow exponentially in size as velocity targets increase, making interstellar flight feasible but relativistic speeds implausible. Several strategies, including the use of graphene sheets, gravity assists, the Oberth effect, and electrostatic confinement, could further maximise velocity. TARS is an attractive light sail technology when high-powered directed energy systems are impractical, offering a potentially low-cost solution for deploying small, sub-relativistic interstellar probes.

Genetic evolution of a multi-generational population in the context of interstellar space travels - Part II: Phenotypic effects of gene expression

Frédéric Marin, Camille Beluffi-Marin & Frédéric Fischer

France

In the first paper of this series, we included the effects of population genetics in the agent-based Monte Carlo code HERITAGE under the hypothesis of neutral phenotypic effects. It implied that mutations (genetic changes) had only neutral physical manifestations. We now relax this assumption by including genetic effects of mutation and neo-mutations (from radiations) onto the population's life expectancy, fertility, pregnancy chances and miscarriage rates. When applied to a population aboard a generation ship that travels at sub-light speed towards a distant exoplanet, we demonstrate that natural selection indirectly affects the genetic structure of a population via the contribution of phenotypes, in agreement with past studies in conservation biology. For large starting crews (about 500 individuals), the effect aligns with the neutral hypothesis and the frequency of alleles (for non-sexual chromosomes) is stable over centuries. Results are completely different if the spacecraft shielding, integrated into hull design, fails to efficiently protect the crew from high-energy cosmic rays and showers of secondary particles. We tested different scenarios, in which the level of radiation is either fixed at normal or extreme levels, or changing over time due to, eg shield degradation, on-board nuclear incident or the outburst of a supernova situated 50 light-years away.

Redefining Habitability: Adapting the Drake Equation for Exoplanetary Gas Giant Satellite Systems

Elio Quiroga Rodríguez

Spain

This work proposes a novel adaptation of the Drake Equation tailored to systems comprising gas giant planets and their satellites, with a focus on assessing the potential for life on these moons. We redefine the concept of the "habitable zone" to account for the unique conditions present in gas giant systems, particularly the possibility of liquid water existing beneath thick ice crusts on satellites due to gravitational tidal heating. The study presents mathematical models for tidal heating, thermal equilibrium, to reach finally into a modified Drake Equation which evaluates the likelihood of life in these environments. Additionally, we derive an equation to estimate the theoretical size of the habitable zone around a gas giant. This approach aims to expand our understanding of potential habitable environments beyond traditional terrestrial planets, encompassing moons like Io, Europa, Ganymede, Callisto, Titan, Ariel, Umbriel, Oberon, Titania or Triton, which orbit gas giants such as Jupiter, Saturn, Uranus and Neptune and are thought to home liquid oceans below an ice crust. We have many possible examples in our Solar System to play with and extrapolate to other star systems with gas giants.

◀ Acta Astronautica

Acta Astronautica papers are announced online before print. These relevant papers have appeared since our last issue, Principium P49, which reported announced papers up to Volume 232, July 2025 - and they go up to and including [Volume 235 October 2025](#)

Unexplained starlight pulses found in optical SETI searches	Volume 233 August 2025	Richard H Stanton
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Years spent searching more than 1,300 sun-like stars for optical SETI signals have finally yielded unexpected results. A “signal” of two fast identical pulses, separated by 4.4 s, was discovered in the light of HD89389. No single pulses, even remotely resembling these, have been found in these searches. Close examination of this signal reveals that several unique features of the first pulse are repeated almost exactly in the second. Comparison of this signal with those of airplanes, satellites, meteors, lightning, atmospheric scintillation and system noise, emphasizes their uniqueness. During the re-examination of historical data, another pair of similar pulses was found in an observation of HD217014 made four years earlier. Not fully explained at the time, this signal had been dismissed simply as “birds.” After all pulses were examined in detail, and shown that they could not have been made by birds, several theories are proposed that might explain their origin. A theory based on edge diffraction is discussed in some detail. If correct, this theory should enable future observations to measure the distance to the occulting object, and using arrays of telescopes, determine its size, shape and velocity.

An overlooked Schelling point candidate for optical SETI: ‘MiM’	Volume 235 October 2025	David F Gahan [1]
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Recent SETI strategies have been attempting to confront the multipoint to multipoint nature of the signalling challenge, ie lack of prior knowledge of where to look, with broad sky surveys. ‘Schelling point’ is a concept from game theory suggesting that parties wishing to communicate can converge on the same solution if they make plausible guesses as to similarities in the other's analysis. This concept has been invoked in SETI to propose several candidate listening frequencies but with fewer proposals for points in space capable of unambiguous definition. Such a physical Schelling point could offer an opportunity for a simple and scalable SETI initiative. The only unambiguous location within the Milky Way proposed as a candidate SP is the galactic centre; however, this is also the location of the supermassive black hole Sgr A* which implies complex considerations.

This paper extends earlier work in considering locations defined by Local Group geometries. Key elements in the reasoning (and foundational to the game theory approach) are a series of conservative ‘hunches’ for the number, spread and population-dynamics of civilisations, and conservative hunches on technical capabilities (propulsion systems and probe technology), limited to those currently being studied by engineers. These hunches (while not intending to suggest any actual limits) are available to any intelligent species, and lead to the proposal of a new physical Schelling point, possibly optimum in the immediate environs of the Milky Way. This mid-point between the barycentres of the Magellanic Clouds (‘MiM’) can be reasonably defined in space and time and is in an observationally ‘quiet neighbourhood’ for examination by SETI. While no home world is considered at the MiM point, it might be favoured by a civilisation or civilisations unconcerned by time constraints as a suitable location for a beacon to send unambiguously artificial signals. It could be continually resupplied with the energy needed to maintain signalling for an arbitrarily long time (eg 100 MY), but on a restricted energy budget necessitating low-divergence signalling (hence ‘optical’). The paper considers power, range, and potential signalling and detection strategies in order to propose an observational effort, and compares with a benchmark paper for optical SETI detection levels. NB Direct data transfer is not considered in this paper, only signal detection.

[1] David Gahan is a regular contributor to Principium. His article *Where do you look for ET?* based on this paper is in this issue. Find his first article on this subject *AMiTe Treffpunkt - A proposal for communication between Kardashev Type IIb civilisations* in Principium 32, February 2021 i4is.org/principium-32

“It is not easy to see how the more extreme forms of nationalism can long survive when men have seen the Earth in its true perspective as a single small globe against the stars...”

Arthur C. Clarke, The Exploration of Space (1951)

BECOME AN i4is MEMBER

John I Davies

If you're fascinated by what you read in Principium, and want to help us turn science fiction into science fact, it's time to become an i4is member!

i4is is a growing community of enthusiasts who are passionate about taking the first steps on the path toward travel beyond our solar system. Our ambitions are high, but to achieve them we need your support.

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 endeavour – reaching other star systems. i4is is not only advancing research but also igniting the passion for interstellar exploration in schools and universities worldwide.

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

THE i4is MEMBERS' PAGE

John I Davies

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

Recent member newsletters

There have been two member newsletters since P49, our last issue. All member newsletters are emailed to members and also available from the members-only area on the website - i4is.org/members. They include access to preprints of Principium articles as well as interstellar news and announcements from i4is.

The most recent, July 2025, included preprints from this issue of Principium #50 -

- The Journals - reporting more and more peer-reviewed work related to interstellar studies, including SETI
- International Astronautical Congress - IAC25 - Sydney 29 September - 3 October - Announced Interstellar Presentations

We'll be reporting on IAC25 in our next two issues, #51 November this year and #52 February 2026.

Working for i4is

All our team are unpaid. Some are professionals in fields like astronomy and space technology but many are enthusiasts inspired by that Outward Urge which has carried sailing canoes across the Pacific and Asian peoples to populate the Americas. There is lots to do from gathering news for Principium to maintaining our website and membership scheme - and of course contributing to our technical R&D for those with suitable skills and qualifications.

Writing for Principium

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

"I am left with the desire to communicate two aspects of this work more completely. On the one hand. I would like to display for review more of the details of calculations and references than is possible here.

And on the other hand, I am acutely aware of the need for discussion outside our own group of physics-oriented people.

This work should be discussed and debated as widely as possible, by people with a range of technical and artistic talents, and by people who claim no special talent beyond the ability to work hard for a worthwhile goal."

Closing remarks in *The colonization of space*, Gerard K O'Neill in Physics Today / September 1974

The O'Neill cylinder (en.wikipedia.org/wiki/O%27Neill_cylinder) inspires recent designs for interstellar worldships including the recent i4is Project Hyperion competition reported in this issue.



i4is Deputy Executive Director Rob Swinney (right) at our *Skateboards to Starships* workshop in August. John Davies (left), Principium editor listens to Rob's ideas about nuclear fission for space propulsion.

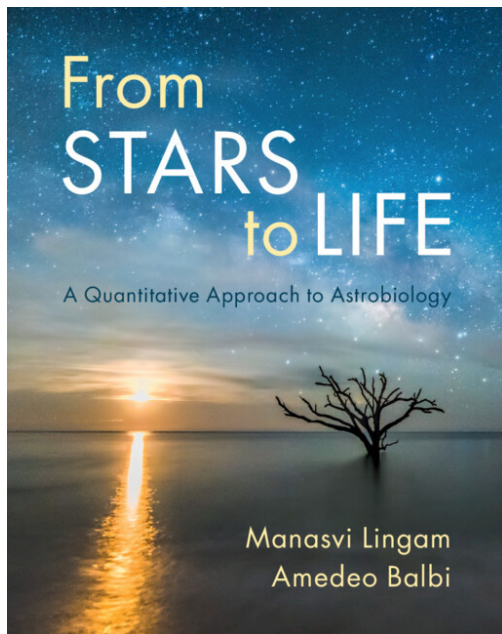
The Royal Institution invited us back for another session in August. The school students looking on are, we hope, up-and-coming space scientists and engineers!

Picture Credit: Hanchao (Sophia) Li of KCL Space. One of three people from the student space organisation of Kings College London who helped us deliver the workshops

NEXT ISSUE

Next time, in P51 - November 2025

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



**From Stars to Life
A Quantitative Approach to Astrobiology**

A review by Andreas Hein of the new book by Manasvi Lingam, Florida Institute of Technology and Amedeo Balbi, Università degli Studi di Roma 'Tor Vergata'.



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**International Astronautical Congress IAC25:
The Interstellar Presentations Part 1**
First reports of interstellar papers and presentations
at the 2025 International Astronautical Congress.

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

Our 51st Issue!

COVER IMAGES

Cover images for this issue 50

Our cover images for this issue reference the far future, as envisaged by participants in the i4is Project Hyperion worldship competition, and the possibility of reaching an interstellar object in the Solar System in the near future.

FRONT COVER

Chrysalis Worldship



"Generation Spaceship Chrysalis" first place in i4is Project Hyperion competition. More from the Chrysalis team at tinyurl.com/Chrysalis-team-submission [1]. Image credit: Chrysalis team

BACK COVER

Project Lyra spacecraft approaches 1I/'Oumuamua



Now far from the Sun in the outer solar system, the strange interstellar object known as 'Oumuamua is depicted here as it's approached by a questing spacecraft. Project Lyra is still aiming to launch such a craft to explore our first known visitor from another solar system and provide the detailed study scientists desperately seek. Our astrodynamacist, Adam Hibberd, calculates this will remain possible well into the 2030s. Image credit: Maciej Rebisz

[1] www.canva.com/design/DAGmr3ubC8E/LHHAeeAIGGQe_TkZVs-PXA/view?utm_content=DAGmr3ubC8E&utm_campaign=designshare&utm_medium=link2&utm_source=uniquelinks&utlId=hcfa85973cc

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

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

Mission

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

Vision

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

Values

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

Front cover: Hyperion winner Chrysalis.

Credit: Chrysalis team

Back cover: Project Lyra spacecraft approaches 1I/'Oumuamua

Credit: Maciej Rebisz



SCIENTIA AD SIDERA
KNOWLEDGE TO THE STARS

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

